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Sesame improvement by induced mutations

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FOREWORD

Sesame *(Sesamum indicum* L.) is an ancient oil crop considered to be still at an early stage in breeding. The fact that sesame is a crop of mainly developing countries with limited available research funds for long term breeding programmes, resulted in very few breeding efforts in research stations. Furthermore, sesame is not a mandate crop of any of the international agriculture research centers.

Until recently most of the released sesame varieties in countries such as China, India and the Republic of Korea were the product of selection and pedigree breeding. A major constraint in this approach was the lack of sufficient genetic variation within the existing germplasm collections, especially for traits such as resistance to various diseases and seed retention. This is where mutation techniques could offer a possible solution. The United Nations Food and Agriculture Organization (FAO) organized some expert consultations on sesame breeding between 1981 and 1987, which all recommended the use of mutation induction for the enhancement of genetic variability with a focus on the following traits: modified plant architecture, seed retention, and resistance to diseases and pests. As a result, most of these recommendations have been included in this five year co-ordinated research project (CRP) that started in 1993, organized by the Plant Breeding and Genetics Section of the Joint FAO/IAEA Division.

This CRP focused on the induction of the above mentioned characters in different sesame improvement programmes, and on the enhancement of co-operation between sesame breeders in developed and developing countries. Each participant covered a number of traits important for their specific breeding needs. During regular meetings under this project the participants had the opportunity to jointly appraise and evaluate sesame mutants and varieties in demonstration fields, thus strengthening the mutual effort for the genetic improvement of sesame through mutation techniques.

The success of this CRP is documented by the official release of 12 sesame varieties in Egypt, India, Republic of Korea, Sri Lanka, and the more than 140 agronomically useful sesame mutants developed by the participants. More mutant varieties will be released in other countries in the near future as a direct spin-off from this project. Besides, the established collaborative links between sesame breeders of the participating countries and the exchange of germplasm has been and will be invaluable for the further advancement of sesame breeding and improvement of production.

The present publication gives a detailed description of the various research activities and summarizes the achievements of this CRP obtained as the result of a joint effort from all the participants to push forward the breeding of sesame with the use of mutation techniques. The officer responsible for this publication is L. van Zanten of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. Special thanks are due to A. Ashri for his assistance in the development of this report and his tremendous support to the advancement of sesame breeding. For those interested in obtaining a copy of this publication and for more information on activities, achievement, and contacts of this Division, we kindly refer to the following Internet site: *http://www.iaea.org/programmes/nafa*.

EDITORIAL NOTE

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SESAME IMPROVEMENT BY INDUCED MUTATIONS: RESULTS OF THE CO-ORDINATED RESEARCH PROJECT AND RECOMMENDATION FOR FUTURE STUDIES

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Abstract

The FAO/IAEA Co-ordinated Research Project has brought together sesame breeders from 11 countries. They, together with pathologists, agronomists and physiologists, have made considerable effort to advance the genetic improvement in sesame. The results and conclusions from this project cover the mutation techniques used for the genetic improvement of various aspects of sesame. These recommendations do not only deal with the application of mutation induction, but also with the wider plant breeding related objectives and methods to be considered for this semi-domesticated crop. It is clear that more advanced techniques can and should be incorporated in the process which would enhance the genetic improvement. Although five years is a relatively limited time in a plant breeding programme, the participants have been able to produce and make available a considerable pool of agronomically interesting mutant sesame germplasm. The participants in the CRP considered that, together with other specialists, plant breeders can gain fuller benefit from the mutations induced by radiation or chemicals. Work on these mutants must continue in co-operation/consultation with plant physiologists and pathologists, and with biotechnologists who may in the future be able to provide in the future methods for introducing beneficial traits from other crops into sesame. The sesame programme should include scientists from the Member States where sesame grows and scientists from developed countries who may have greater access to physiological and molecular research facilitites.

1. SESAME MUTANTS DEVELOPED THROUGH THE PROJECT

During this Co-ordinated Research Project a total of 142 mutants with agronomically useful characters were registered through different national sesame improvement programmes.

These mutants were developed through the use of chemical and physical mutagens as well as crosses with mutants. Doses and concentrations were all within the range of the recommendations given in this chapter. These were the following:

TABLE I. DEVELOPED CONFIRMED MUTANTS WITH AGRONOMICALLY USEFUL CHARACTERS ORGANIZED PER COUNTRY

Country	Mutant line name
Bangladesh	SM-5
	SM-7
China	95 ms-2
	95 ms-3
	95 ms-4
	95 ms-5
	95 ms-6
	95 ms-7
	CC-1
	DC-1
	MC-1
	MC-2
	MC-3
	WC-1
	YC-1
Egypt	EFM 92
	EXM 90
	Mutant 12
	Mutant 14
	Mutant 15
	Mutant 48
	Mutant 5
	Mutant 6
	Mutant 7
	Mutant 8
	Mutant 9
India	AUS 1138
	AUS 1198
	AUS 1207
	AUS 993

Country	Mutant line name
India (cont.)	AUS MS 1034
	DTF
	N-105 (Virescent)
	N-112
	N-113
	N-115
	N-147
	N-157
	N-169
	N-171
	N-238
	N-29
	N-57
	N-93
	NM-26
	NM-28
	NM-31 (Chlorina)
	NM-54 (Chlorina)
	NM-58
	NM-65
	NM-67
	NM-71 (Chlorina)
	NM-74
	NM-77
	NM-80
	NM-85
	NM-87 (Mosaic)
	NY-21
	NY-9
	PTM-1
	T-Leaf
	TMST-10
	TMST-11
	TMST-15
	TTL-3
	Y-55
Kenya	SIK MU 291/2
	SIK MU 296/1
	SIK MU 303/2/2
	SIK MU 353/6/1
	SIK MU 36/1
	SIK MU 55/1/1
	SIK MU 96/3
Pakistan	Pr.14-2 D-1
	Pr.14-2 EF-1
	Pr.14-2 EF-2
	Pr.14-2 HB-1
	Pr.14-2 HB-2
	Pr.14-2 MS-1
	Pr.14-2 MS-2
	Pr.14-2 MS-3
	Pr.14-2 PB-1
	Pr.14-2 PB-2
	Pr.14-2 PB-3
	Pr.14-2 PB-4
	Pr.14-2 T-1
	Pr.14-2 T-2

Country	Mutant line name
Pakistan (cont.)	Pr.19-9 D-1
	Pr.19-9 D-2
	Pr.19-9 EF-1
	Pr.19-9 HB-1
	Pr.19-9 MS-1
	Pr.19-9 MS-2
	Pr.19-9 PB-1
	Pr.19-9 T-1
	S-17 D-1
	S-17 EF-1
	S-17 EF-2
	S-17 MS-1
	S-17 MS-2
	S-17 S-1
	S-17 St-1
Rep. of Korea	SI84075-2B-23-1-1 (Suwon 144)
	SIM86029-2B-5-1-1-3-1(Suwon 158)
	SIM88H30-2B-68-1-1 (Suwon 155)
	SIM88H30-68-3-1
	SIM89101-2B-20-1-1
	SIM89JBE-2B-10-1-1-1(Suwon 157)
	SIM89JBE-2B3-1-2-1
	SIM89JE-2B-3-1-1-1
	SIM90HS2/3-2B-1-1-1
	SIM90HS2/3-2B-15-1-2
	SIM90HS2/3-2B-6-3-1
	SIM90JBS2/2-2B-1-1-1
	SIM90JBS2/2-2B-7-1-1
	SIM90JBS2/2-2B-7-3-1
	SIM91129-2B-6-1-1
Thailand	GMUB-1 (NS-1)
	GMUB-7 (NS-7)
	KU M 6005
	KU M 6011
	KU M 6015
	KU M 6021
	KU M 6026
	KU M 6040
	KU M 6041
	KU M 6045
	KU M 6051
	KU M 6054
	PMUB 19
	PMUB-1
Turkey	cc-?-1 (9430001)
	cc-?-2 (9413047)
	cc-?-3 (9422059)
	cc-?-4 (9413806)
	cc-?-5 (9415000)
	cc-?-6 (9511609)
	cc-?-7 (9531092)
	cc-?-8 (9542305)
	dt-?-1 (9411144)
	dt-?-2 (9412178)
	dt-?-3 (9512368)

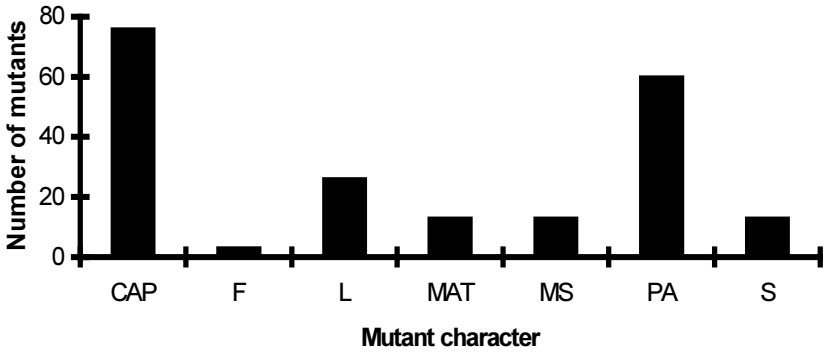


FIG. 1. Mutation induced characters in the developed, confirmed mutant sesame lines.

Various characters were induced mostly affecting the capsules (CAP), flowers (F), leaves (L), maturation (MAT), male sterility (MS), plant architecture (PA), and seeds (S) (Figure 1). Most mutations (76) were found for capsule related characters such as, 3-capsules-per-leaf-axil, shape, size, non/semi shattering, and capsule density on the stem. Also plant architecture was a frequently selected (60) character in mutant sesame lines, including short internode length, profuse branching, uniculms, and semi-dwarfs.

Sesame is a neglected crop from the plant breeding point of view, being in the second stage of plant domestication. This is part of the reason that the majority of the above mentioned characters are related to plant morphology. Also these traits are relatively easy to select for and this project from the start focused on these traits. A few mutants were reported with induced resistance to diseases, such as powdery mildew and some with improved seed oil content. Overall, more than 100 different traits were observed to have been the result of induced mutations in this project. There is still a long way to go before sesame will reach the desired production levels, but clearly the use of mutation techniques has shown to be a very useful tool in the genetic improvement of locally well adapted germplasm.

2. METHODS FOR MUTAGEN TREATMENT

The parent materials chosen for sesame breeding programmes using induced mutations should preferably be the best well adapted available varieties requiring improvement in one or two characters, which lend themselves to screening large number of plants. The treated varieties or lines should be homozygous and uniform, and if necessary selfed first for one or two generations to attain the above.

At the conclusion of this CRP the various mutagen treatments employed were reviewed and recommendations given, as follows:

— For **gamma rays,** doses ranging from 150–800 Gy proved successful in inducing useful mutations. Doses in the lower range were recommended for inducing desirable mutations with minimal simultaneous induction of additional, often undesirable mutations.
— With **fast neutrons'** irradiation of dry sesame seeds, preliminary results in Thailand showed that doses of 30 and 80 Gy were effective for the induction of useful mutations.

Treatments with **EMS** have also proved successful. The following protocol is recommended: Pre-soak the seeds for 24 hours in water (preferably at a low temperature, 4°C); soak the seeds in EMS solutions of 0.4–1.0% v/v with a phosphate buffer (pH = 7) for 2 to 4 hours, with occasional shaking; post-wash in running tap water for at least 4 hours.

For **sodium azide (**NaN_3), the seeds should be pre-soaked in cold tap water (4°C) for 24 hours, then soaked in a 4–6 mM NaN_3 solution with Sörenson phosphate buffer (pH = 3) for 4–6 hours at 18–24°C, then post-washed in running tap water for at least 4 hours.

Since sesame seeds are small and fragile, they should be placed in nylon net bags (mosquito net size) for easy handling during pre-soaking, mutagen soaking and post-washing; labels indicating variety and mutagenic treatment details should be tied to the bags. Excess moisture should be removed using filter paper or paper towels, and the seeds should be planted in the field as soon as possible after the post-washing. Optimal conditions for germination of the treated seeds should be ascertained in all the various mutagenic treatments; this is especially critical when wet seeds are sown following post-washing.

3. MANAGEMENT OF M_1 AND SUBSEQUENT GENERATIONS

The handling of mutant populations in the different generations is important for efficient use of resources and enhanced probability of positive results.

3.1. M_1 generation

A maximum number of targets should be exposed to the mutagenic treatments in order to maximize the number of useful mutations. A large number of M_1 plants should be grown, and 2–5 capsules per plant harvested from the circumference of the main stem, so the required plot area and labour would be small. Whenever possible, precautions should be taken to minimize the risk of cross pollination (by insects) in the M_1. The M_1 plants can be harvested individually, if the M_2 will be grown in progeny rows, or in bulk (see below).

3.2. M_2 generation

The M_2 generation can be grown in progeny rows or in bulks, by varieties and treatments, depending on objectives, available financial resources and facilities. About 30–50 plants should be grown in the M_2 from each M_1 plant. The remaining seeds can be held in reserve for sowing in subsequent seasons. Previous experience has shown that desirable sesame mutants were identified when grown in progeny rows as well as in bulks. Progeny rows will furnish more genetic information. The M_2 plants should be amply spaced (between and within rows) to facilitate testing and screening during the season.

When putative recessive mutants are selected in the M_2 progeny, it is advisable to obtain seeds also from selfed normal sib plants where possible. Some of these plants may be heterozygous for the given mutations and will give in M_3 genetic segregations, thus furnishing information on their genetic control sooner then F_2 populations from crosses of the mutants with the source varieties.

3.3. M_3 generation

The M_3 generation should include progeny from individually selected M_2 plants to confirm the mutations' nature, and to study their breeding behaviour and agronomic value. M_3 plant progeny (bulks) should be planted to facilitate selection for various quantitative traits especially those affecting yield. In subsequent generations, the usual pedigree selection and evaluation procedures should be followed.

4. USE OF MUTATIONS IN CROSS BREEDING PROGRAMMES

The use of mutation techniques has proved very successful in inducing in sesame desirable mutations such as increased seed yield, earliness, modified plant architecture, disease resistance, seed retention, and high oil content. It is recommended to use wherever possible also the cross-breeding approach, involving 'local varieties x mutants', 'mutants x mutants', and 'mutants x introduced lines', in order to get new genotypes having more than one of the desired characters mentioned above. This is particularly valuable for building up promising ideotypes and for exploiting heterosis by developing hybrids between suitable parents (mutants) with good combining ability. It is recommended that while for qualitative characters selection could start with single plants in the F_2, for quantitative characters it should be initiated in the F_3 generation.

5. BREEDING OBJECTIVES IN SESAME IMPROVEMENT PROGRAMMES

Key potential mutant traits of importance for sesame improvement are: good seed retention, shorter plants, higher harvest index, shorter growing period, determinate habit, uniform maturity, and reduced biomass. Some important characters which are highly desired are described below.

5.1. Disease resistance

Disease problems tend to be country/region specific. Therefore, varieties that are resistant to the locally prevalent diseases (and at times pathogenic races) should be developed. Diseases that are known to be important in most countries/regions are *Fusarium oxysporum* f.sp. *sesami*, *Phytophthora parasitica* var. *sesami*, *Macrophomina phaseolina* ssp. *sesamica*, *Cercospora sesami*, *Alternaria sesami, Pseudomonas syringae* pv. *sesami, Xanthomonas campestris* pv. *sesami*, phyllody (Mycoplasma Like Organism = MLO), powdery mildew (*Oidium sp.* and others) and Sesame Mosaic Virus. In the Republic of Korea mutant varieties have been developed with resistance to Phytophthora; mutants resistant to it were induced also in Sri Lanka. However, the yield potential should be improved in these resistant or tolerant lines. The programme in Bangladesh has successfully induced tolerance for Sesame Mosaic Virus.

In general, it isrecommended that if possible, screening under disease pressure should not take place before the M_3 generation. It would be helpful to have the assistance of plant pathologists and to prepare visual aids for the purpose of better identification of the different diseases. Exchange of seeds for screening for resistance should be encouraged. If possible, the presence of different pathogenic races should be checked and thus obtain more critical information. It was also suggested to collect from host plants spores of certain fungal diseases every season, in order to maintain the locally prevalent mixture of races.

5.2. Pest resistance

Until now no efforts have been made to induce mutations for pest resistance, but identifying lines with tolerance or resistance to devastating pests in sesame such as *Antigastra catalaunalis* (webworm, leaf webber, capsule borer), sphingid moth (*Acherontia styx*), aphids and gall-midge would be very helpful.

5.3. Shatter resistance

Seed shattering before and during the harvest causes considerable losses in sesame. Mutations for seed retention (often monogenic) were critical in the domestication of most seed crops. A spontaneous indehiscent mutant (*id*) was discovered in 1942 in Venezuela by Langham (1946). However, due to its low yields and other undesirable side effects it has not been possible to use it in commercial varieties. Non-shattering mutants have been reported also in other crops.

Seed retention in sesame would be aided by determinate habit, i.e. that the plants would stop flowering, shed their leaves, and reach physiological maturity before their first capsules dry. Subsequently, the plants should dry as quickly as possible and release the seeds from the capsules in a way commensurate with the harvest and threshing methods.

Flowering and shattering are affected by branching, capsule length, capsule width, number of capsules per leaf axil and other characters. The preferred trait contributing to seed retention should be chosen according to the projected harvest method. Thus, if the crop is to be machine harvested good placenta attachment is necessary, but if the plants are shocked, this is not necessary. In fact, for manual harvest farmers would prefer no placenta attachment, in order to ease the threshing work.

The *gs* allele for seamless capsules and the *id* allele can be used only for the oil or food ingredients market and then only if the seeds can be processed in a timely manner to minimize the effects of seed damage from threshing. Much breeding work has been devoted to the development of productive *gs/gs* and *id/id* cultivars, adapted to combine-technology and with undamaged, good quality, whole seeds. These efforts have been unsuccessful so far, but still they should not be abandoned. It should be realized that the probability of success is low unless a breakthrough is found, e.g. a modifying gene or a change in the combine technology.

In the present CRP eight gamma ray (300–750 Gy)-induced mutants with indehiscent (closed) capsules were recovered in four different Turkish cultivars. Allelism tests are planned to determine if these mutants are in the same locus, the known *id* locus, or if there are different loci. In Thailand, irradiation with gamma rays (500 Gy) of two local varieties resulted in three shatter resistant mutant lines, all outyielding their respective parent varieties. Furthermore, in Thailand seven delayed shattering and shatter-resistant mutant lines were obtained following treatments with EMS (0.5–1.0%, 4 h).

Agreed terminology is proposed for determinate growth habit, maturity, and shatter-resistance in order to have a uniform frame of reference. Criteria need to be defined with time and additional experience.

5.4. Seed quality and contents

5.4.1. Oil yield

— To improve the oil yield two parameters have to be improved, that is seed yield of the crop and oil content in the seed.
— Oil content of the seed should be higher than 50%.
— There seems to be a correlation between oil content and seed colour; dark seeded varieties have lower oil content than the light seeded varieties, perhaps because the dark ones have thicker seed coats. However, breeders should aim at raising the oil contents of the dark seeded accessions, possibly by selecting for a thinner seed coat. It is suggested to attempt to increase oil production per unit area also through testing of promising lines under higher plant density.
— When screening for oil content, the seed samples (capsules) should be taken about 2.5 cm below the middle of the capsule bearing zone of the main stem of the plant. The seeds should be fully mature.

5.4.2. Oil quality

Mutations were used to induce changes in the fatty acid composition in sesame seeds in the Republic of Korea and could be attempted elsewhere, e.g. in lines with high oil content (>50%).

5.4.3. Antioxidants

Induction of mutations could be attempted for increased contents of lignans in the seeds and for their composition, e.g. relative amounts of sesamin and sesamolin and similar products. These substances have a wide variety of applications in the production of pharmaceutics, pesticides and other industrial end products.

5.4.4. Confectionery quality

The lines to be developed for confectionery uses should be screened for seed colour, size and shape, for flavour, and for seed coat thickness and texture, using specific descriptors developed together with the processors.

5.5. Harvest index

This is an important character that may be improved by modifying plant architecture. According to the various farming systems this would mean to develop cultivars that:

— are optimal in height (0.5–1.5 m),
— are uniculm for dense stands under high input conditions,
or
— are medium branching with appressed branches for low input conditions,
— have high capsule density,
— form the first capsules at the height of 15–20 cm above ground for hand harvested crops,
or
— form the first capsules at the height of 15–40 cm above the ground for mechanical harvesting, depending on the machinery and topography.

In several programmes within this CRP mutants were induced with distinct plant architecture modifications, e.g. reduced height, three capsules per leaf axil, uniculm, high capsule density and determinate growth habit.

5.6. Yield potential

To improve yield the important components to be considered are:

— Number of capsules per unit area. This should be given priority rather than number of capsules per plant.
— 1000 seed weight.
— Number of seeds per capsule. A representative sample of capsules from the top, middle and bottom part of the plant should be used to obtain a mean value for this parameter. However, the use of this parameter is debatable since eight-loculed plants have more seeds per capsule but they are not necessarily the highest yielding cultivars. Thus, the breeder should decide whether this is an appropriate parameter for his lines and conditions.

5.7. Adaptability

Cultivars to be developed should be adapted to the production systems of their prospective area(s) of cultivation.

— Short duration, early maturing cultivars that can be planted as a second crop (e.g. after rice in India, Pakistan, Bangladesh or after wheat or hay in Turkey, Israel) or as a single crop to exploit the short duration of the rainy season.
— Cultivars should be developed that are resistant or tolerant to the prevalent biotic and abiotic stresses.

5.8. Leaf morphology

This character depends very much on the population size and planting density. To increase photosynthetic efficiency, probably plants with appressed (at 45° angle to the stem) and lanceolate leaves should be preferred. Studies on stomatal anatomy would further enrich the knowledge on 'net accumulation rate' (NAR), and help select plants on the basis of leaf morphology and structure.

6. HYBRID VARIETIES AND HETEROSIS BREEDING

Sesame continues to be a high risk crop in many of the major producing areas. Through the classical breeding methods of selection, pedigree breeding, backcross and induced mutations, a major yield breakthrough was not achieved so far despite many efforts. Thus, sesame continues to be a poor competitor with other crops and is often relegated to the poorer fields.

Certain F_1 hybrid combinations in sesame resulted in marked yield increases. This was the case in studies conducted in China, India, USA and Venezuela. It appears that breeding hybrid varieties may give a yield breakthrough in sesame as seen in other self pollinated crops such as rice, barley, wheat and tomato. This can make sesame more remunerative and competitive. It may lead to its wider cultivation and to greater returns which in turn may lead to applications of higher inputs.

Hybrid varieties must be produced by crossing suitable inbred parents, with high general and specific combing ability. Once such inbreds are found, hybrid seeds can be produced in several ways:

1. By hand emasculation and pollination.
2. By spraying gametocides.
3. By using genic male sterility mechanisms in combination with hand pollination or honey bees as pollinators.
4. By using a genic-cytoplasmic male sterility system, with pollination as above.

In the case of sesame, the additional advantage is that for every successful pollination, a capsule containing 50–60 seeds can be obtained (a good stand is 250,000–300,000 plants/ha). Hand emasculation and pollination are useful in research but they are not feasible for commercial production. In India, the cost of emasculation and hand pollination was estimated to be US $ 10–12/kg for hybrid seed. For the farmers hybrid seeds must be produced on a large scale with lower cost which necessitates the use of male sterility. So far, only genic male sterility (GMS) has been found in sesame. A naturally occurring *ms* allele was found in Venezuela about 30 years ago. This is the one which is being used in China now. Mutations for male sterility were successfully induced in some of the cultivated varieties by four participants in this CRP following treatments with gamma rays (300–500 Gy) and EMS (1%, 2h).

The GMS can be used to produce hybrids but uniformly male sterile rows/plots (*ms/ms*) on which seeds will be produced cannot be obtained. Since, GMS is maintained by hybridizing male steriles (*ms/ms*) with isogenic but heterozygous plants (*Ms/ms*), the offspring segregates 1 male fertile: 1 male sterile. This would require early rouging of the fertile *Ms/ms* progenies. This operation could be feasible economically where labour is inexpensive and/or farmers can produce their own hybrids in an isolated plot or in a net house, rouging the *Ms/ms* plants, growing both the male sterile (*ms/ms*) plants of the A line and an appropriate pollinator, male fertile (*Ms/Ms*) C line, with good combining ability.

For large scale production of hybrid seeds by seed companies the above approach is not feasible, due to the high labour cost. Hybrid varieties could become economically feasible only through genic-cytoplasmic male sterility (GCMS). The search for GCMS should be continued. It should also be realized that searching for spontaneous or induced cytoplasmic mutants is difficult since it requires test crosses; self pollination of the M_1 and M_2 plants and screening their offspring are not sufficient in this case.

The following is recommended for future work:

I. The stability and seed set of the male sterile mutant lines induced in China, India and Turkey should be improved.
II. The induced male sterile mutants should be tested for allelism, to find out if more then one locus is involved.
III. Attempts should be made to obtain GCMS lines for which the following line of action is proposed:
    — Cross cultivated species reciprocally with wild species of *Sesamum* (possibly *S. malabaricum*); cross male sterile F_1 interspecific hybrids with various germplasm lines representing different regions (pollen mixture); grow F_1 plants and search for male fertiles — presumably due to presence of a nuclear, genic restorer; self newly derived fertile hybrids; check offspring for Mendelian segregation of male fertiles vs. male

steriles. In such a way, it would be possible to find a restorer gene for the cytoplasmic male sterility generated by interspecific hybridization (see Figure 2).

— Existing *Ms/ms* lines be crossed with wild species.

"Split corolla" mutants were induced by the participants of this CRP from China, India, Sri Lanka, and Turkey and found naturally also in Venezuela. These mutants reduce self pollination drastically and can sometimes be used as female lines effectively. Their use as female parents in producing F_1 hybrids should be evaluated.

Crosses of some of the mutants induced in this CRP with the source parents and with other cultivars, gave F_1 hybrids showing very high heterosis for yield. The nature of this observed heterosis-like behaviour, which was noted also earlier in sesame and in other crops should be investigated further.

7. RECOMMENDATION FOR FUTURE RESEARCH IN SESAME IN COMBINATION WITH MUTATION TECHNIQUES

It was generally agreed that the induced mutants developed by the participants in this CRP have and will contribute further to improve productivity. However, it was realized that more sophisticated selection methods are required to take full advantage of the variation provided by the mutants. Involvement of three areas of expertise would make a substantial contribution to further sesame breeding research, namely physiology, pathology and biotechnology.

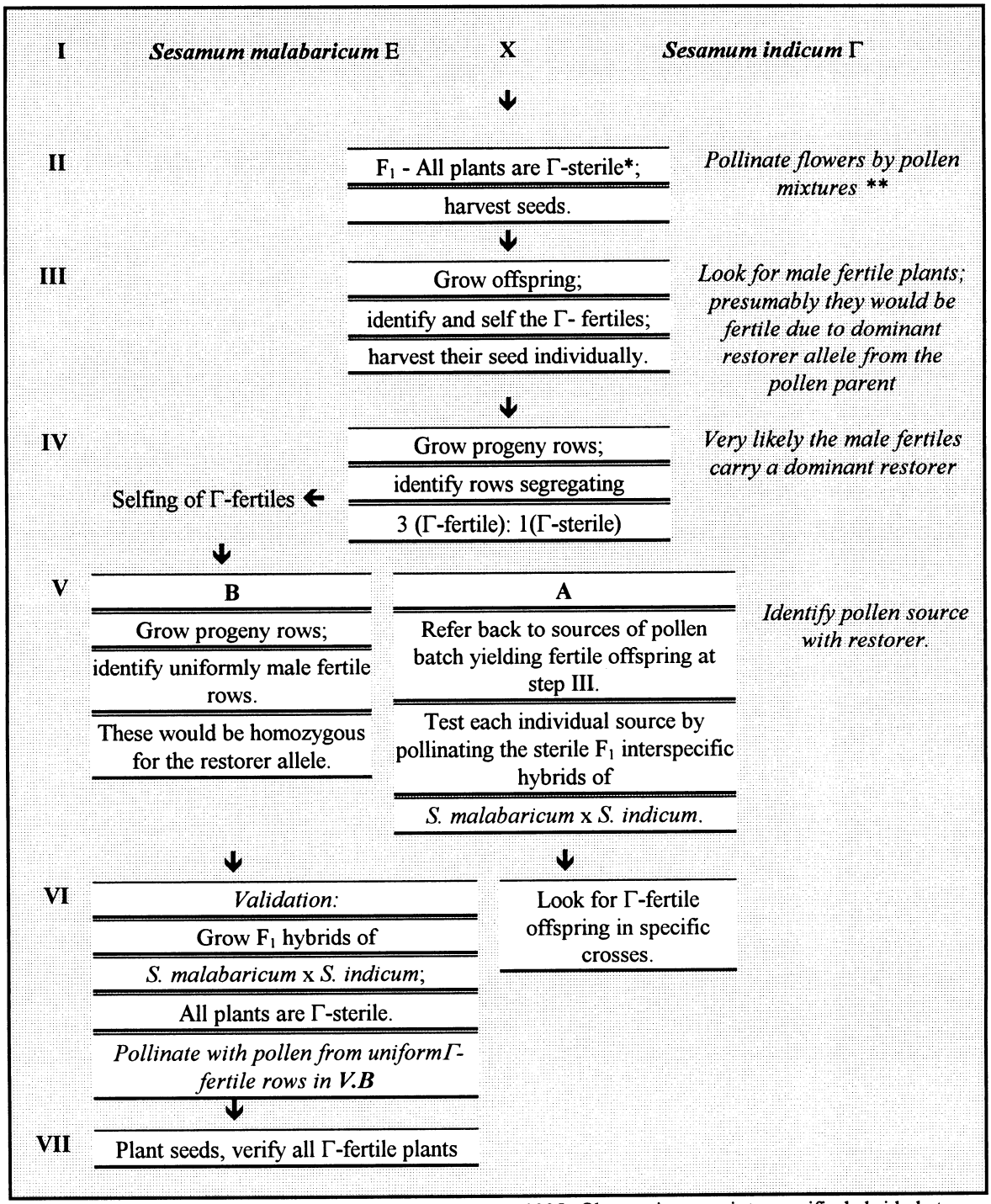
Mutations induced by radiation or chemicals provide variation in plant structure and function from which breeders can select plants having useful traits. Plant physiological and pathological approaches can provide deeper understanding and effective ways to identify characters or plants which can be useful in solving particular problems, thus facilitating more effective selection in breeding programmes. Biotechnology provides methods which enable:

— Screening for desired traits in the seedling or another early stage of plant development (allowing rapid screening for useful mutations of more plants earlier).
— Identification of plants with desired quantitative traits' genotypes, independent of environmental influences masking the traits' phenotypic expressions.
— Utilization of knowledge of gene action in some species for selection of beneficial traits in sesame.

Co-ordination of research in sesame breeding, physiology, pathology and biotechnology will therefore be very beneficial and a model for other crops. Four areas which are important for increasing the productivity and production of sesame in many parts of the world were identified:

A. Higher yields (e.g. increasing the harvest index).
B. Seed retention.
C. Tolerance to abiotic stresses (e.g. drought tolerance, waterlogging).
D. Pest and disease resistance and tolerance.

A. The harvest index of sesame, i.e. the proportion of energy invested in the seeds out of the total above ground biomass is low in relation to other crops. The harvest index may be improved by increasing light reception, photosynthetic efficiency, and by increasing the proportion of photosynthetic products directed towards the seeds. Under field conditions, the lower leaves are shaded by the upper leaves' canopy. Investigations on plant habit and architecture, and on leaf shape, size and angle to the stem could provide an understanding how sesame plants could capture light more efficiently. Mutations provide the necessary genetic variation to study these traits and their effects. Once light has been captured, more of its photosynthetic products must be partitioned towards the seeds, to increase the harvest index. In such studies radioactively labeled carbon from the uptake of CO_2 can be very useful.



* See Prabakaran, A.J. and S.R. Sree Rangasamy, 1995. Observations on interspecific hybrids between *Sesamum indicum* and *S. malabaricum*. I.Qualitative characters. Sesame & Safflower Newsletter 10: 6-10

** Use pollen mixtures drawn from diverse germplasm accessions and mutant lines. Preferably use many pollen batches each from a few identified sources.

FIG. 2. Suggested scheme for identification of restorer allele and GCMS development using interspecific crosses.

B. Reducing seed shattering has the most potential of all traits, to dramatically increase sesame production and to adapt it to mechanized harvesting. Substantial breeding efforts have addressed this problem and recently some anatomical and physiological work has commenced. A number of radiation and chemically induced closed capsule mutants and shatter resistant sesame lines have been selected but sesame varieties used in most areas of the world still shatter. Anatomical and physiological research designed to study the mechanisms leading to seed loss and its prevention, and to identify traits that can be used to select less shattering varieties, will benefit all sesame breeding programmes. More studies are required, particularly to compare the mechanism of non-shattering governed by the spontaneous indehiscent mutant (*id*), and those of other non- or semi-shattering mutants induced in this CRP.

C. Most sesame, whether in developed or developing countries, is grown under rainfed conditions where environmental conditions change drastically. In these conditions, drought is often the most serious yield reducing factor. Therefore, varieties of sesame with drought resistance must be developed. Recent work in other species has shown that methods such as isotope discrimination (the natural ratio of C^{12} to C^{13} in the plant) give a good measure of the water-use efficiency of plants. Certain characters such as leaf shape, leaf pubescence, mucilage glands, and stomatal conductance, control water loss from the plants. In the present CRP it was demonstrated that some of these characters are modified by radiation and supplement natural variation for drought tolerance. There is good evidence that cooperation between plant physiologists and plant breeders, utilizing mutation techniques, could enhance this tolerance further.

D. Breeding experience has shown that tolerance or resistance to pests and diseases can be enhanced in breeding programmes. Some plants with induced mutations have shown promising pest and disease resistance/tolerance, with at least two sesame varieties having induced disease resistance already officially released. Furthermore, the hybridization of different induced mutants with other lines, and between lines from widely different places of origin gave transgressive and unexpected levels of tolerance to diseases.

Molecular technologies

Currently, there is no molecular genetic research or molecular marker work on sesame. Sesame improvement could benefit markedly from the employment of the innovative molecular technologies that offer great potential to increase the efficiency of all breeding approaches. In other crops molecular markers have proved particularly successful when selecting for pest and disease resistance and complex traits, such as yield, quality and tolerance to abiotic stresses.

Since sesame is a neglected crop, grown almost exclusively in developing countries, where molecular approaches are not yet well advanced, the research efforts in this area will benefit primarily the end users in those countries. Co-operation of scientists from developing and developed countries in molecular studies on the nature of mutants such as determinate, closed capsules, disease resistance should be encouraged. The ultimate goal of this undertaking would be to characterize and map induced mutations of sesame using Amplified Fragment Length Polymorphisms (AFLPs) and other PCR based techniques. Mapping the mutant genes would be the first step towards map-based cloning of the genes and molecular marker assisted selection.

***In vitro* techniques**

Combinations of molecular and *in vitro* techniques have been used to incorporate specific traits into cultured protoplasts and tissues of many different plant species, and regenerate them then into whole plants. Induced mutations under *in vitro* conditions have specific advantages such as the option to screen very large cell populations within a limited space and to identify recessive mutations in haploid systems. *In vitro* techniques can also be used to:

i. Generate and identify new genetic variation in breeding lines, often via haploid production, using protoplast-, anther-, microspore-, ovule- or embryo-cultures.
ii. Produce somaclonal and gametoclonal variants with crop improvement potential.
iii. Rescue embryos following interspecific crosses.

Studies on sesame *in vitro* culture have been limited, but some initial success has been reported from China, India, Sri Lanka, Turkey, USA and Venezuela. Some protocols have been developed to produce somatic embryos from hypocotyl derived calli, plants have been regenerated following multiple shoot induction in seed cultures, and callus has been induced from anthers at the uni-nucleate stage of microspores. Attempts have been made to overcome disease problems through interspecific hybridization between the cultivated species and the disease resistant wild relatives *Sesamum alatum* and *S. radiatum* where by using embryo rescue a few progenies were obtained.

A major barrier to successful utilization of *in vitro* techniques for enhancing sesame breeding research is the transfer of sesame plantlets from tissue culture to the field. Only very few varieties of sesame have been examined for their regeneration ability; by testing more varieties some which are less recalcitrant might be identified. The participants feel that support for *in vitro* studies is vital to help overcome this problem.

INDUCED MUTATIONS IN SESAME BREEDING

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Abstract

The scope of induced mutations in sesame (*Sesamum indicum* L.) breeding is reviewed. So far in Egypt, India, Iraq, Rep. of Korea, and Sri Lanka, 14 officially released varieties have been developed through induced mutations: 12 directly and 2 through cross breeding (one using the 'dt45' induced mutant from Israel). For another variety released in China there are no details. The induced mutations approach was adopted primarily in order to obtain genetic variability that was not available in the germplasm collection. The mutagens commonly applied have been gamma rays, EMS and sodium azide. Sesame seeds can withstand high mutagen doses, and there are genotypic differences in sensitivity between varieties. The mutants induced in the above named countries and others include better yield, improved seed retention, determinate habit, modified plant architecture and size, more uniform and shorter maturation period, earliness, resistance to diseases, genic male sterility, seed coat color, higher oil content and modified fatty acids composition. Some of the induced mutants have already given rise to improved varieties, the breeding value of other mutants is now being assessed and still others can serve as useful markers in genetic studies and breeding programmes.

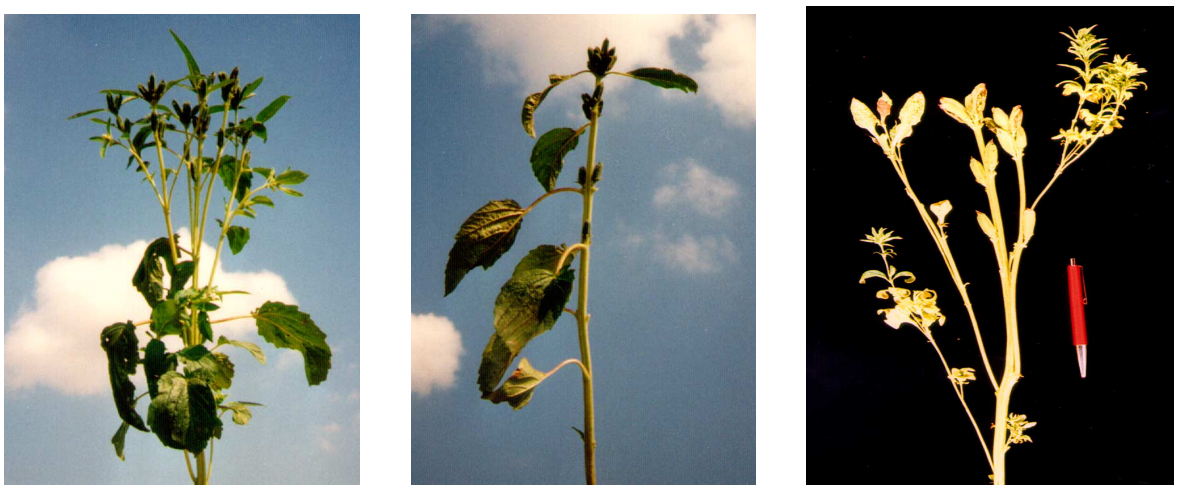
1. INTRODUCTION

Although sesame (*Sesamum indicum* L.) is an ancient oil crop, it is still at an early stage in its breeding history. More focused breeding efforts were undertaken only in recent decades, and even these only in very few research stations. This is mainly because sesame is a crop of developing countries where research funds are scarce and continuous long-term breeding efforts are difficult. In addition, sesame is not mandated to any of the international research institutes of the CGIAR.

The two most commonly used breeding approaches in sesame are selection (mostly from local landraces) and pedigree; introduction, backcross and induced mutations are less common. This is shown for the officially released improved cultivars for China, India, Rep. of Korea and Venezuela in Table I [1].

The induced mutations approach was adopted in the breeding projects because certain much desired traits, such as good seed retention and resistance to certain diseases have not been found in the extensive germplasm collections. Three FAO Expert Consultations [2,3,4] recommended that induced mutations be used to enhance the genetic variability of sesame and to select for characters that can be easily identified in large segregating populations, e.g. seed retention, modified plant architecture and size, modified growing period, and resistance to diseases and pests. Some of these research efforts have been included in the current Co-ordinated Research Project of the Joint FAO/IAEA Division and in previous ones.

Often, but not always, the induced mutations approach was a component of a comprehensive breeding programme. So far, 14 officially released cultivars have been developed through the use of induced mutations in Egypt, India, Iraq, Rep. of Korea and Sri Lanka, as shown in Table II: 12 direct and 2 through hybridization, one involving the 'dt45' mutant induced in Israel (Mutant varieties data base, Plant Breeding and Genetics Section, Joint FAO/IAEA Division, L. van Zanten, pers. commun.). Another mutant variety was released in China (Table I) but no details are available. 'Ahnsan', released in the Rep. of Korea with improved disease resistance in 1985, continues to be a major cultivar there: it was grown in 1996 on 30% of the sesame area (ca. 15,000 ha) and in 1997 on 12,450 ha 26% of the area (C.W. Kang, pers. commun.). 'UMA' and 'USHA' are important in Orissa State in India, while the remaining cultivars cover small areas.



a b c

FIG.1. Homozygous determinate dt45/dt45 segregants from crosses of mutant x different indetreminate varieties (a-more branched; b-uniculm; c-less branched).

2. DIFFERENTIAL M_1 RESPONSES

Sesame seeds have been treated with radiations (mainly gamma-rays) and chemical mutagens [mainly ethyl methane sulfonate (EMS), and recently also with sodium azide, NaN_3]. Sesame seeds proved less sensitive physiologically to the various mutagenic agents, therefore higher doses can be used [5]; but higher doses may also cause simultaneously undesirable mutations which may mask the desired mutants. Several authors reported genotypic differences in sensitivity to the mutagens. Ashri [5] reported that whereas some cultivars gave good M_1 germination after treatments with 0.4% and 0.5% EMS solutions for 24 h, 'Oro' gave only 15% germination and about 65% of the M_1 plants were sterile and stunted. Ashri [5] also demonstrated genotypic sensitivity differences to gamma-rays. Layrisse et al. [6] tested seven Venezuelan cultivars for their gamma-rays LD_{50}. Even for the most sensitive cultivars the LD_{50} was 630 Gy which is quite high, and for the more resistant one it was 800 Gy. Pathirana [7] also reported differences in cultivar tolerance to seed irradiation; 'M13' was much more tolerant to gamma-rays than 'M12', although both were very tolerant. Kamala [8] found widely different sensitivity levels between cultivars. Four Chinese cultivars tested by Li et al. [9] for sensitivity to gamma radiation proved very tolerant to high doses, but there were differences between them depending on seed coat color; the LD_{50} for three white-seeded varieties was 800–900 Gy and for the black-seeded one it was 1000 Gy.

3. SELECTION PROCEDURES

Murty and Oropeza [10] tested three selection procedures following gamma irradiation of seeds of six sesame cultivars. They concluded that single plant selection from M_2 rows was best. The authors recommended that where possible M_2 progeny rows should be used. However, where budgets and/or labor are limited, harvesting the M_1 plants in bulk and growing the M_2 populations in bulks by cultivars and treatments is a good alternative. In this approach it is not possible though to ascertain the number of mutation events that occurred. Thus, if two or more identical mutant plants appear in a given M_2 bulk, it is impossible to determine whether they resulted from one or more mutation events. This was the case when the 'dt45' mutation was discovered; there were four determinate plants in one bulk M_2 population. It is reasonable to assume that they all originated from a single mutation event but it was not possible to verify it at the time. Such resolution could perhaps be achieved by checking the mutants' DNA markers, but this would not be called for usually. For quantitative traits it is generally recommended to make the selections in the M_3 generation (M. Maluszynski, A. Micke, pers. commun.).

TABLE I. NUMBERS OF OFFICIALLY RELEASED IMPROVED SESAME CULTIVARS DEVELOPED BY DIFFERENT BREEDING METHODS BY 1994 IN CHINA AND IN TWO DIFFERENT PERIODS IN INDIA, R. OF KOREA AND VENEZUELA (1980s AND 1990s).

Country	Number of released cultivars								Reference
	Introduction only	Selection from		Hybridization		Induced mutations	Unknown method	Total	
		Introduction	Local materials	Pedigree	Backcross				
China	-	-	17	18	-	1[1]	-	36	[37]
India	-	-	18	6	-	1	-	25	[38]
	-	-	28	25	-	3	18	73	[39]
R. of Korea	1	1	3	6	-	1	-	12	[33]
	1	1	3	8	-	5	-	18	[24,25] C.W. Kang - pers. comm.
Venezuela	-	5	-	5	2	-	-	12	[40]
	-	7	-	6	2	-	3	18	[41]

[1]Laser treatment.

4. INDUCED MUTANT TRAITS

Pioneering investigations on induced mutations in sesame were conducted by Kobayashi [11,12] who found both morphological and developmental mutants. Generally, a wide range of mutants was found [13], as in other crops. Some of the induced mutations have proven their agronomic value and were released as varieties (direct or through cross breeding) as noted above and shown in Table II, some are under advanced breeding tests, others can be useful as markers, and still others can be used in physiological, genetic and molecular studies. Mutations of more relevance to sesame breeding are discussed below.

Good non-shattering plants can be obtained only through an induced or spontaneous mutation or perhaps by transgenic manipulations, since the trait is not available in the germplasm collection, except for *id*. The *id* allele for indehiscence discovered by Langham [14] in Venezuela was a spontaneous mutant. However, because of its many undesirable side effects, including reduced yields due to poor seed set and susceptibility to diseases, it was not incorporated successfully into any commercial variety, despite intensive efforts. It is encouraging that recently Cagirgan [15,16] induced three such mutants whose breeding value and affinity to the *id* allele are now under study in Turkey. In Thailand, Wongyai et al. [17] reported a delayed shattering mutant and Maneekao et al. [18] found semi-shattering mutants. On the other hand, the author was not successful in obtaining mutants with good seed retention in very large M_2 populations of several sesame varieties treated with gamma rays and EMS.

A monogenic recessive determinate growth habit mutant, termed ‘dt45’, with a very unique plant architecture and with clustered capsules was induced by Ashri with gamma-rays (500 Gy) in the Israeli cultivar ‘No. 45’ [19,20]. Typically, 5–7 capsules are arranged at the tips of the main stem and the branches, and the internodes are telescoped, giving smaller plants. Both branched and uniculm lines have been bred with this trait. In this mutant, the apical flowers are often 6-parted instead of the standard 5-parted condition in the corolla lobes and anthers, which is the case in the other flowers on the same plants. Also, the 6-parted apical flowers are bell shaped and symmetrical, while the other, 5-parted flowers on these same plants have a lip and are asymmetrical. Flowers such as these apical ones have not been described before. The resulting apical capsules are often quadricarpellate while the other capsules on the same plants are bicarpellate. Like the source cultivar, the mutant has large seeds [19, 21, 22], which contain the same oil and protein contents as the original cultivar [23, Ashri (unpublished)]. The mutant was bred into diverse genetic backgrounds and distributed by the author to researchers in many countries, including the participants in this and other RCMs. ‘Pungsan’, released in the Rep. of Korea in 1996, resulted from incorporation of the *dt45* allele into a locally adapted cultivar [24, 25]. Wongyai [26] crossed ‘dt45’ with Thai cultivars and derived determinate and indeterminate locally adapted lines; she then compared the development rate, height and flowering time of the materials. The Sesaco Company breeding programme, made crosses involving ‘dt45’ and produced several adapted promising lines, e.g. with desired branching pattern and disease resistance (D.R. Langham, pers. commun.). R.D. Brigham (pers. commun.) made extensive crosses with ‘dt45’ in Texas and selected promising lines varying in height. In view of its multiple, pleiotropic effects, the *dt45* mutant allele is probably a homeotic one. It is planned to initiate molecular studies on the nature of *dt45* soon (I. Çagirgan, C.W. Kang, P. Donini, pers. commun.).

A mutant which is similar to ‘dt45’ was induced recently in Turkey, and is now under study there (I. Çagirgan, pers. commun.). Short flowering period mutations leading to uniform maturation were induced with EMS and gamma-rays in Thailand [26].

It is possible that a breakthrough leading to higher yields in sesame will be achieved with hybrid varieties [1]. Insect pollination can be quite effective [1], but so far only nuclear male sterility mutants were found. A spontaneous, monogenic, recessive, male sterile mutant, found in Venezuela about 30 years ago, is used to some extent in breeding [1]. Using gamma-rays (300–600 Gy) four male

TABLE II. OFFICIALLY RELEASED SESAME VARIETIES DERIVED FROM INDUCED MUTATIONS AND REPORTED TO THE PLANT BREEDING AND GENETICS SECTION, JOINT FAO/IAEA DIVISION, VIENNA[1].

Country	Variety	Year	Mutagen	Main character
Egypt	Cairo white 8	1992	Gamma rays	Non-branching
	Sinai white 48	1992	Gamma rays	Seed color
India	Kalika	1980	EMS	Short stature
	UMA	1990	Chemical mutagen[2]	Uniform maturity
	USHA	1990	Chemical mutagen[2]	Higher yield
Iraq	Babil	1992	Gamma rays	Earliness
	Rafiden	1992	Gamma rays	Earliness
	Eshtar	1992	Gamma rays	Capsule size
R. of Korea	Ahnsan	1985	X rays	Disease resistance
	Suweon	1991	Cross[3]	Lodging and disease resistance
	Yangbaek	1995	Sodium azide	Higher oil content
	Pungsan	1996	Cross[4]	Determinate habit, seed retention
	Seodun	1997	Sodium azide	Somewhat higher oleic acid, Phytophthora blight tolerance
Sri Lanka	ANK-2	1995	Gamma rays	Disease resistance

[1]Source: L. van Zanten, from data base of the Plant Breeding and Genetics Section, Joint FAO/IAEA Division, Vienna.

[2] Mutagen unspecified (possibly an arsenic compound).

[3]From progeny of cross with mutant.

[4]From progeny of cross with the dt45 mutant induced by A. Ashri in Israel.

sterile mutations were induced in India [27] but some were also female sterile. Six male sterile mutations were induced in China [28] and three are under study in Turkey [16]. Male sterile mutations were induced by Rangaswamy and Rathinam [29] and by Ramahathan et al. [30] with lower gamma-ray doses. The allelic nature of all these mutants and their breeding value have not been investigated as yet. A genic-cytoplasmic male sterility system suitable for hybrid seed production still remains to be developed, through induced mutations or interspecific crosses.

A polypetalous recessive spontaneous mutant (known also as "star flower"), in which the split corolla tube reduces markedly the opportunity for self pollination, was discovered by D.G. Langham [31] in Venezuela. It was induced later with gamma rays by Murty and Oropeza [10] in Venezuela, and with fast neutrons by Murty and Bhatia [32] in India. The allelic nature of these mutants has not been studied so far. This trait could be useful in crossing and perhaps in producing seeds of hybrid varieties with high insect pollinators' activity, using just 2 lines with good combining ability: a polypetalous A line and a suitable C line.

Induced disease resistant mutants have been investigated in several countries. Lee and Choi [33] induced a mutation which gave moderate resistance to Fusarium and Rhizoctonia and resistance to Corynespora and Phytophthora. This mutant line was released in Rep. of Korea as 'Ahnsan' (Table II) which continues to be a widespread variety there (see also above). In Sri Lanka, Pathirana [7] induced mutations for resistance to Phytophthora and one of them was released there as the cultivar 'ANK-82'.

Variation for fatty acids content was induced by gamma-rays [32] and by sodium azide [25] in Rep. of Korea. This effort culminated with the release in 1997 of 'Seodun' (Table II), which has somewhat higher oleic acid content and more tolerance to Phytophthora (C.W. Kang, pers. commun.).

Heterosis was noted in F_1 hybrids between true breeding mutants originating from the same cultivar [27]. This finding, which was encountered also in sweet clover, *Melilotus alba* [35] and in barley, *Hordeum vulgare* [36] is intriguing and warrants further studies on the phenomenon and on the nature of the mutations.

5. CONCLUSION

It is concluded that the induced mutation approach has made significant contributions to sesame breeding and to sesame production by the development of new improved cultivars and by generating novel genetic variation. So far though, there have been only a few studies on the genetic control of the mutations and hardly any on their physiological or molecular nature. This is another manifestation of the paucity of genetic and other investigations in sesame. Enhanced genetic, molecular and physiological studies of some of the induced mutants and of diverse genotypes in the germplasm collection will widen our knowledge and will contribute to breeding improved sesame cultivars and to a deeper, more general understanding of some important plant traits.

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THE MECHANISM OF DEHISCENCE IN SESAME — FEATURES THAT MIGHT BE USEFUL IN A BREEDING PROGRAMME

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Australia

Abstract

By understanding the mechanism of seed retention in sesame, the most appropriate parents for a breeding programme can be identified, and superior lines can be selected more effectively. An initial assessment of some capsule traits thought to be related to seed retention, identified varieties with enhanced seed retention under glasshouse conditions. Examination of capsule anatomy and capsule break-strength distinguished two Japanese sesame varieties with particularly good capsule characteristics. These two varieties appeared superior to other lines with a mutation of the *id* gene, suggesting that traits other than indehiscence might significantly contribute to seed retention. Varieties released commercially by the CSIRO fared poorly in the analyses, providing hope that better varieties can be developed by the CSIRO in the future.

1. INTRODUCTION

A component of the 'First Australian Sesame Workshop' held in Darwin Australia in 1995, was development of strategies for a co-ordinated approach to the expansion of the Australian sesame industry [1]. Crop attributes were listed in order of research priority for their potential to substantially contribute to sesame improvement (Table I). By far the greatest priority was placed on improved seed retention. My research is designed to address this priority and proposes to understand the mechanism of seed loss and apply this knowledge to enhance selection of sesame lines with superior seed retention. This paper reports progress towards achieving this goal.

TABLE I. PRIORITY ORDER DEVELOPED BY PARTICIPANTS AT THE 'FIRST AUSTRALIAN SESAME WORKSHOP' FOR POTENTIAL TO CONTRIBUTE TO CROP IMPROVEMENT OF SESAME IN AUSTRALIA. Adapted from Bennett and Wood [1]

Attribute	Score
Seed retention	102
Range of maturity types	35
Resistance to diseases and pests	18
Sensitivity to temperature and photoperiod	17
More even seed colour	12
Synchronous capsule maturation	12
Shorter maturation period	10
More even seed size	9
Better harvest index	8
More rapid seedling growth	7
Germination at lower temperature	4
Shorter growing season	2

Seed retention is a major problem for the Australian sesame industry for two reasons. Firstly, the potential areas for sesame production in Australia [2] generally experience low humidity. Seed loss is thought to be greater in low humidity environments. Secondly, indeterminate growth of plants, non-synchronous maturation of sesame capsules, and Australian farming practice combine to increase seed loss when mechanically harvested at a late stage of maturity [3]. Plants must be dry at harvest to prevent vegetative plant material from blocking the combine and tainting the flavour of the seed during harvesting [2], and because no further drying of the crop is undertaken before threshing [3]. In Australia, up to 60% of seed on the plant can be lost before harvesting [4]. Recent agronomic work has identified practices which can potentially reduce this loss to 10–20% [3].

Seed loss from sesame has been, and continues to be, the focus of many breeding programmes, particularly in the United States of America. The breeding programmes of M.L. Kinman, A.J. Martin, D.M. Yermanos and D.G. Langham and D.R. Langham (Sesaco Corporation) had seed retention as a major goal. Much of the early work involved incorporating the indehiscent (*id*) mutation into high yielding lines. Mutation of the *id* gene increases the strength of the capsule wall thereby preventing capsule opening and seed loss. Unfortunately, threshing the hard capsule without damaging the seed is almost impossible [5]. Work continued with the *id* gene in association with another mutation, papershell capsule [6]. The programmes planned to combine the non-opening capsule resulting from mutation of the *id* gene with the thin wall of the papershell capsule mutation. Varieties resulting from these breeding programmes have met with limited commercial success. Sesaco Corporation has continued to breed sesame with a focus on reducing seed loss under commercial production conditions (Langham, page 95). My approach is to determine the association between seed retention, and the anatomical and physiological characteristics of capsules of many sesame varieties, both to understand the process of seed loss, and to identify traits which may improve seed retention. Selection of lines with these traits could provide a starting point from which a commercially acceptable variety suitable for Australian conditions can be developed.

2. METHODS

2.1. Capsule morphology of glasshouse grown plants

Sesame plants were grown in a glasshouse at the CSIRO Samford Research Station (27º33"S), south-east Queensland, during November to April (summer) with shade cloth reducing light intensity to 50%. The thermostat set point for the evaporative cooler was 25ºC, maintaining air temperature during the experimental period between 20ºC and 35ºC. Plants experienced high relative humidity, commonly between 80% and 90%. Each 3 l pot contained 2 plants growing in a potting mix consisting of 4 parts shredded peat to 6 parts sand, with 10 g/l Osmocote Plus (9 month slow release fertiliser) and 4 g/l each of dolomite and lime to adjust the potting mix to neutral pH and provide trace elements. Plants were maintained by subirrigation.

All 140 sesame lines held in the CSIRO collection were planted, one pot of each line. Once the bottom capsule had turned brown, one plant per line was harvested at soil level and stored upright in a plastic floral tube to dry. Measurements of capsule opening from tip to tip, suture split length from the tip toward the base, capsule length, the total number of seeds per capsule, and the number of seeds retained by the capsule after the plant was inverted were taken from 5 capsules per plant. A visual assessment of seed attachment was made (0 = poor attachment, 1 = moderate attachment, 2 = good attachment).

2.2. Capsule anatomy of glasshouse grown plants

Seed collected from the above plants was used to grow two pots (4 plants) of two commercial sesame culivars (1, 4), 13 lines with mutation of the *id* gene (10, 11, 12, 41, 43, 45, 46, 47, 49, 51, 56, 134, 135), and 12 other lines (8, 17, 26, 37, 70, 71, 86, 88, 97, 101, 109, 117) in the glasshouse as described above, to allow microscopic examination of the capsules (see Table II for origins of lines). Of the 140 sesame lines, these 12 latter lines held most seed in the first experiment. During growth of the plants, flowers were individually tagged. One capsule per plant (4 capsules per line) was collected 12 days after flowering (DAF), and two 1–2 mm transverse sections taken from the mid-point and tip (distal to the most distal seed) of the capsule. Sections were fixed for at least 48 hours in 2% gluteraldehyde and 2% formaldehyde in 50 mM PO_4 buffer, pH 7.0. Sections were dehydrated in an ethanol series and embedded in Spurr's resin [7]. Thin sections (1–2 mm) were cut with a glass knife on a Reichert Jung ultracut microtome, and stained with Toluidine blue (0.5% in 1% boric acid) before microscopic examination and photography with Kodak Tri X-pan 400 film under a dissecting microscope. The minimum endocarp and mesocarp tissue layer widths, the capsule radius via the suture, and the minimum capsule wall width from the epidermis to the locule cavity via the vascular bundle at the suture were measured from photographic prints of the sections.

TABLE II. SESAME LINES USED FOR EXPERIMENTS REPORTED IN THIS PAPER

Line	Identity	Origin
1	Aussie Gold	Selected seeds. Developed by CSIRO.
4	Magwe Brown	Selected seeds. Developed by CSIRO.
8	Kobayashi 393	Prof. Kobayashi, Toyama University, Japan.
10	UCR82-5	Prof. Yermanos, Uni. California, Riverside, USA.
11	UCR82-6	Prof. Yermanos, Uni. California, Riverside, USA.
12	UCR82-9	Prof. Yermanos, Uni. California, Riverside, USA.
17	Kobayashi TK27	Prof. Kobayashi, Toyama University, Japan.
26	Albino Sindos	No. 454, from Sindos, Greece via FAO, Rome.
37	Tashkentskii 122	Cent. Asian Expt. Stn., USSR. Collect D.Bedigan, Univ.of Illinois, USA
41	UCR82-1	Prof. Yermanos, Uni. California, Riverside, USA.
43	UCR82-3	Prof. Yermanos, Uni. California, Riverside, USA.
45	UCR82-7	Prof. Yermanos, Uni. California, Riverside, USA.
46	UCR82-8	Prof. Yermanos, Uni. California, Riverside, USA.
47	UCR82-10	Prof. Yermanos, Uni. California, Riverside, USA.
49	UCR82-12	Prof. Yermanos, Uni. California, Riverside, USA
50	UCR82-13	Prof. Yermanos, Uni. California, Riverside, USA.
51	UCR82-14	Prof. Yermanos, Uni. California, Riverside, USA.
55	UCR82-201	Prof. Yermanos, Uni. California, Riverside, USA.
56	UCR82-202	Prof. Yermanos, Uni. California, Riverside, USA.
57	UCR82-203	Prof. Yermanos, Uni. California, Riverside, USA.
70	Miss White	Myanmar (Burma). Collected Don Beech.
71	Aceitera	Venezuela, via FAO, Rome.
86	Venezuela 51	Venezuela, via FAO, Rome.
88	Line X 30/46	From FAO, Rome.
97	Mbara	Ag. Res. Stn,. Mokwa, Nigeria, via FAO, Rome.
101	Caripucha	Venezuela, from Nampula, Mozambique, via FAO, Rome.
109	Mafaza light	Sudan, via FAO, Rome.
117	Teras 77	SEFERSA, Sinaloa, Mexico, via FAO, Rome.
134	UCR82-206	Prof. Yermanos, Uni. California, Riverside, USA.
135	UCR82-208	Prof. Yermanos, Uni. California, Riverside, USA.

2.3. Capsule break-strength

Two commercial cultivars (1, 4), 14 lines with mutation of the *id* gene (10, 11, 12, 41, 43, 45, 46, 47, 49, 50, 51, 56, 134, 135), and 5 other lines (8, 17, 26, 86, 117) were grown at Gatton, south east Queensland, in alluvial well drained light clay with a neutral pH. Seeds were planted 2 cm deep in 6 m rows with 1 m between the rows, and thinned to an inter-plant distance of 10 cm. Individual flowers were tagged. Twelve days after flowering (12 DAF), 20 capsules were collected from each line and break-strength measured with a Lloyd LRX 2K5 fitted with a 500 N load cell. Capsules were placed on their side with the plane of the suture vertical, on a hard plate so that an 8 mm probe moving at a rate of 30 mm/minute would compress the capsule at the suture line adjacent to the most distal seeds. A dynamic illustration of the change in resistance to movement of the probe during compression of the capsule was produced by the Lloyd R Control (version 3.0) software (Fig. 1). The fracture force (and fracture distance) could be calculated by subtracting the force (distance) at the point of contact between the probe and capsule (zero point), from the force (distance) at the break point. The break point was identified as the first point of inflection in the curve representing the change in resistance to movement of the probe, signalling the change in resistance as the capsule split. Often the change in inflection was abrupt (Fig. 1).

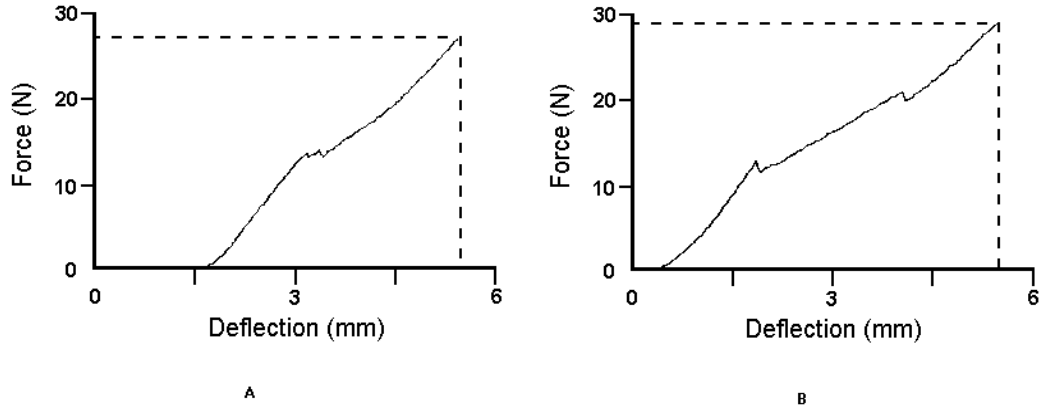

FIG.1. The resistance to compression of a capsule (12 DAF) of sesame lines 10 (A) and 43 (B) as measured by a Lloyd LRX 2K5.

2.4. Statistical analysis

Mean parameter values for each sesame line were analysed using Principal Component Analysis (PCA) (Minitab 8.21, Minitab Inc., Pennsylvania). PCA is a statistical method for distinguishing between lines using information on more than two parameters. Briefly, PCA places each sesame line in a multi-dimensional space based on the parameter means, then draws two or more principal component axes which best separate the sesame lines, and finally provides an estimate of the correlation between the parameters and the principal component axes.

3. RESULTS AND DISCUSSION

3.1. Capsule morphology of glasshouse plants

There was substantial variation in capsule morphology and seed retention between the 140 lines grown in the glasshouse (Fig. 2). There was a strong positive relationship between principal component axis 1 and seed retention and seed attachment, and a negative relationship with ratio of split length to capsule length (Table III). Capsule opening was negatively related to principal component axis 2 (Table III). The relationship was poor between capsule opening and seeds retained, suggesting that the size of the aperture that occurs when a capsule splits is a poor estimate of the seed retention properties of the capsule. Perhaps, once capsules are open enough for the seeds to escape, further capsule opening is likely to have little influence on seed loss.

Seven lines were identified as superior in terms of seed retention, seed attachment, and reduced split length (Fig 2, Table IV). Eight other lines (12, 17, 43, 49, 70, 71, 117, 134) showed good seed retention characteristics. These 15 lines originate from many parts of the world (Table II). Furthermore, only a few of these 15 lines have the *id* mutation in their background (11, 12, 43, 49, 134) suggesting that other genes, in addition to *id*, might have something to contribute to a breeding programme aimed at enhancing seed retention. Two lines released commercially by the CSIRO (1, 4) rated poorly in this analysis. There appears to be substantial room for improvement of seed retention in the CSIRO breeding programme.

We must be wary of reading too much into this analysis because the data was collected from only one glasshouse grown plant. Work is under way to reproduce this analysis under field grown conditions.

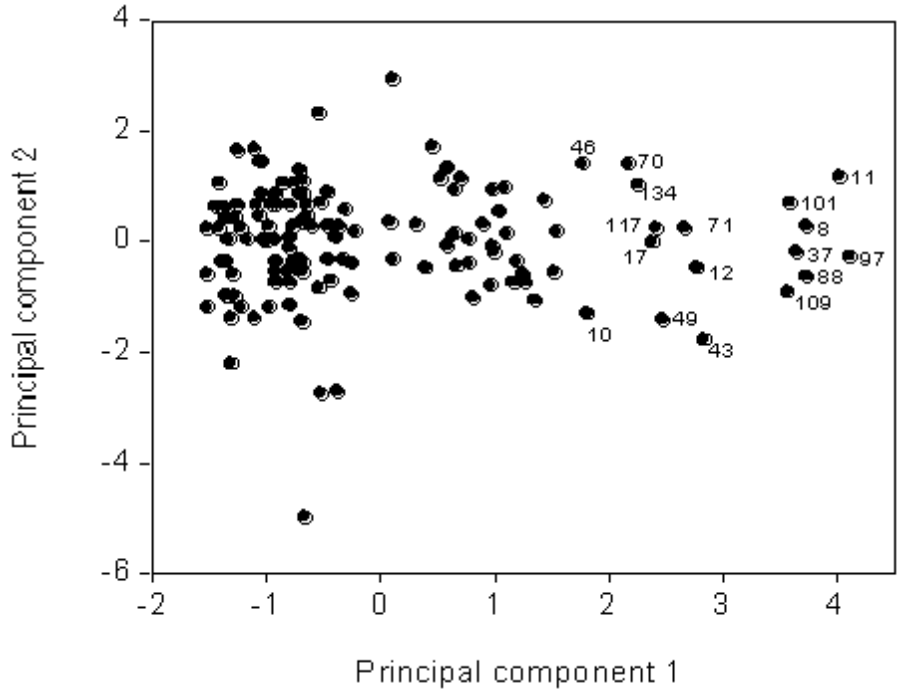

FIG. 2. The relationship, determined by principal component analysis, between the 140 sesame lines in the CSIRO collection based on capsule morphology measurements of glasshouse grown plants. The relationships between principal component axes and the parameters are shown in Table III. The lines with best seed retention are labelled.

TABLE III. RELATIONSHIP BETWEEN PRINCIPAL COMPONENT AXES AND THE CAPSULE MORPHOLOGY VARIABLES MEASURED FROM GLASSHOUSE GROWN SESAME PLANTS

	Principal component 1	Principal component 2
Seeds retained (%)	0.647	0.035
Seed attachment index (0, 1, 2)	0.571	0.162
Suture split length/Capsule length	–0.505	0.216
Capsule opening (mm)	0.007	–0.962

TABLE IV. THE SESAME LINES WHICH PROVED TO BE SUPERIOR IN TERMS OF SEED RETENTION OR PARAMETERS WHICH MIGHT ENHANCE SEED RETENTION, BASED ON THE DIFFERENT ANALYSES

Analyses	Lines
Capsule morphology of glasshouse plants	8, 11, 37, 88, 97, 101, 109
Capsule anatomy of glasshouse plants	10, 11, 17, 43, 47, 49, 70
Capsule wall elasticity	8, 17, 49, 50
Combined PCA	8, 12, 17, 117, 134

3.2. Capsule anatomy of glasshouse plants

In transverse section, the capsule anatomy of all sesame lines was essentially similar (Fig. 3). Seeds are attached to the placenta in the centre of the capsule. The capsule wall consists of an epidermis, and mesocarp and endocarp tissue layers. Mesocarp tissue is comprised of rounded parenchyma cells. The endocarp sclerenchyma cells are heavily lignified. The endocarp layer extends right around the seed from the carpel wall into the partition, but not into the placenta. The partition divides each carpel into two locules. As the capsule dries, the mesocarp cells shrink, causing tension between the mesocarp layer and the unshrunken cells of the endocarp layer. This tension causes the capsule to split back from the tip and from the suture. The suture splits right along the partition, and in some cases between the partition and the placenta. Seeds can then escape either from the tip of the capsule where no partition exists, or from the side of the capsule through the split between the partition and the placenta.

Examination of sesame capsule anatomy suggests three ways in which seed retention might be enhanced.

1. Increase the mesocarp cell layers over the suture region from the suture vascular bundle to the epidermis. This anatomy results from the *id* mutation ([8], Fig. 3B). Presumably these extra cell layers resist the tension set up between the mesocarp and the endocarp as the mesocarp cells shrink, thereby preventing capsule opening.
2. Decrease the difference between the mesocarp and endocarp tissue layers. If the thickness of the endocarp layer or if the amount of lignification of the endocarp cells could be reduced, then the tension built up between the mesocarp and endocarp during capsule drying would decrease. There would be less force pulling the capsule apart.
3. Strengthen seed attachment.

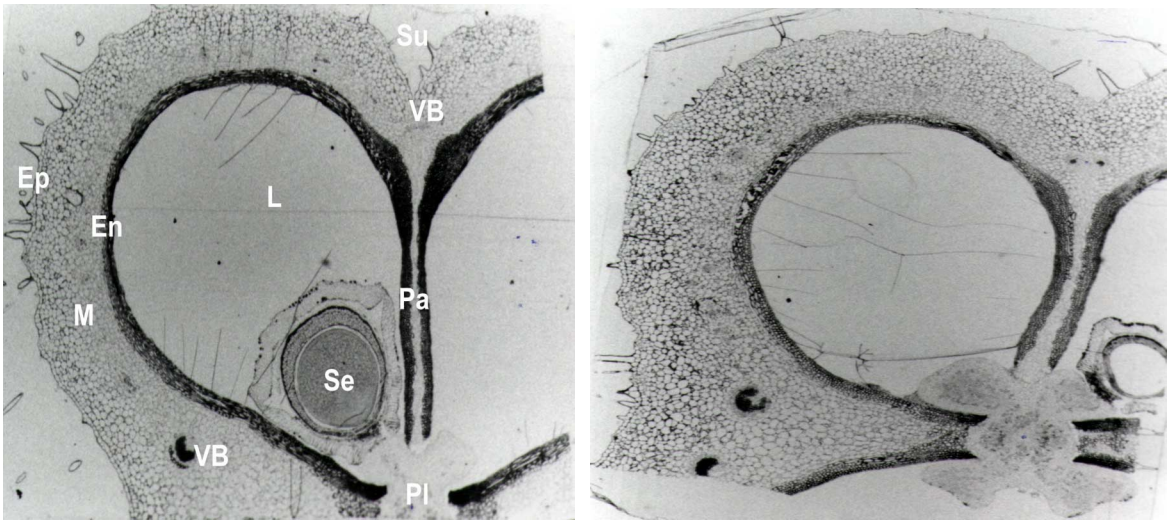

FIG. 3. Transverse sections from the mid-point of a capsule (12 DAF) of sesame line 1 (A) and line 47 (B). En = endocarp, Ep = epidermis, L = locule, M = mesocarp, Pa = partition, Pl = placenta, Se = seed, Su = suture, VB = vascular bundle. Bar = 1 mm.

Two measurements were made which might relate to mechanisms 1 and 2 above (Table V). Capsule wall/capsule radius was calculated by dividing the minimum distance from the epidermis to the locule cavity via the vascular bundle at the suture, by the distance from the placenta to the epidermis via the suture. Endocarp/capsule radius was calculated by dividing the minimum endocarp tissue layer width by the capsule radius via the suture. The lines which might potentially have enhanced seed retention would have a small endocarp width and large carpel wall width (Tables IV and V).

3.3. Capsule break strength

Figure 1 indicates that resistance to downward movement of the probe increased as the probe came in contact with the capsule. At some point, capsule compression reached a break point where the capsule split. Depending on the sesame line, either the break point was discernible only by a change in the slope of the resistance force curve, or (particularly those with the *id* mutation) a sharp drop in resistance occurred following the break point before the resistance force again increased (Fig. 1). For some lines it was possible to discern separate breakpoints where sutures on each side of the capsule split (Fig. 1A). During maturation in the field, capsules of these lines might open more readily on one side of the capsule than the other. Sometimes a third breakpoint occurred where the two capsule tips pulled apart (Fig. 1B).

TABLE V. COMPARISON BETWEEN SESAME LINES OF ANATOMICAL MEASUREMENTS TAKEN FROM TRANSVERSE SECTIONS FROM THE MID-POINT OF CAPSULES. DATA ARE MEANS OF 4 MEASUREMENTS

Line	Endocarp/capsule radius	Capsule wall/capsule radius	Endocarp/capsule wall
1	0.019	0.14	0.14
4	0.016	0.15	0.11
8	0.021	0.18	0.12
10	0.021	0.22	0.09
11	0.027	0.28	0.09
12	0.023	0.21	0.11
17	0.014	0.19	0.07
26	0.020	0.17	0.12
37	0.020	0.16	0.13
41	0.019	0.14	0.14
43	0.026	0.34	0.08
45	0.021	0.21	0.10
46	0.024	0.19	0.13
47	0.022	0.24	0.09
49	0.020	0.22	0.09
51	0.026	0.25	0.10
56	0.020	0.17	0.12
70	0.016	0.17	0.09
71	0.020	0.14	0.14
86	0.022	0.16	0.14
88	0.019	0.16	0.12
97	0.019	0.19	0.10
101	0.017	0.14	0.12
109	0.022	0.17	0.13
117	0.020	0.17	0.12
134	0.020	0.17	0.12
135	0.020	0.15	0.13

The difference between the break point and the zero point provides two measurements, the fracture force and the fracture distance. The fracture force measures the force required for the capsule to split. The fracture distance measures the amount of deformation the capsule endures before the capsule splits and is therefore a function of both the elasticity of the capsule wall and the fracture force. The ratio of fracture distance to fracture force gives a good measure of the elasticity of the capsule wall. There is a negative relationship between fracture force and capsule wall elasticity (Fig. 4). Most of the lines with the *id* mutation (Yermanos lines, Table II) have greater break-strength than other lines. Lines 4 and 117 have the greatest break-strength of those lines without the *id* mutation (Fig. 4). High capsule wall elasticity might enhance seed retention of sesame by allowing greater absorbance of force before the capsules split. Those lines with the greatest capsule wall elasticity are listed in Table IV.

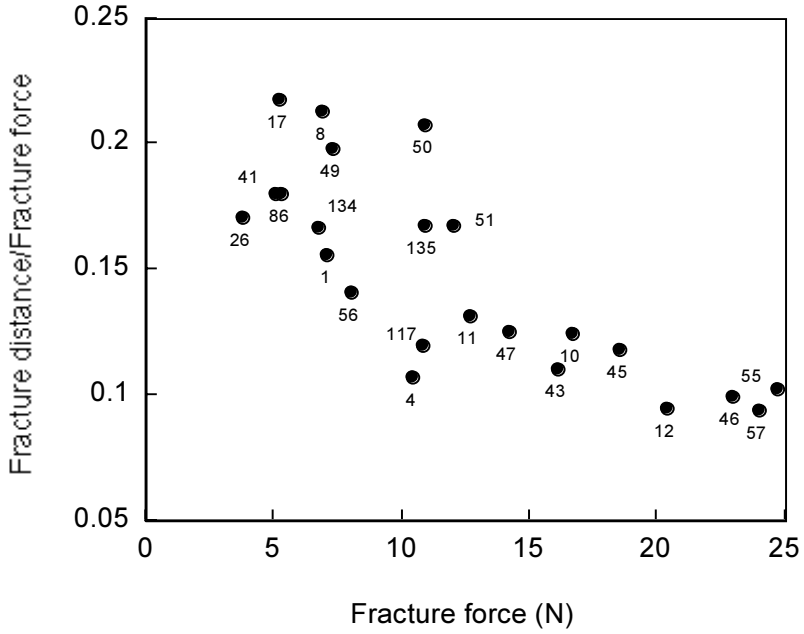

FIG. 4. Comparison of the fracture force and capsule wall elasticity of sesame lines. Data are means of 20 capsules.

3.4. Comparison between measurements

Sesame lines were compared in a combined PCA using mean values for seeds retained, endocarp/capsule radius, capsule wall/capsule radius, fracture force and fracture distance collected from the experiments above. Three principal component axes were required to provide a useful separation of the lines; even then the variables correlated poorly with any one axis (Table VI). The lines were most usefully separated by principal component axes 2 and 3 (Fig. 5). Sesame lines in the upper left hand quadrant of the graph had good seed retention, with moderately high capsule strength and elasticity, and moderately low endocarp and capsule width (Fig. 5, Table IV). These lines might provide a basis for breeding sesame lines with good seed retention.

TABLE VI. RELATIONSHIP BETWEEN THE PARAMETERS COLLECTED FROM THE PREVIOUS ANALYSES AND THE PRINCIPAL COMPONENT AXES

	Principal component 1	Principal component 2	Principal component 3
Seeds retained (%)	–0.217	–0.764	0.492
Fracture force	–0.491	0.37	0.433
Fracture distance	–0.516	0.358	0.236
Endocarp/capsule radius	–0.479	–0.046	–0.668
Capsule wall/capsule radius	–0.465	–0.385	–0.261
Variability explained by axis	56.3%	23.6%	11.4%

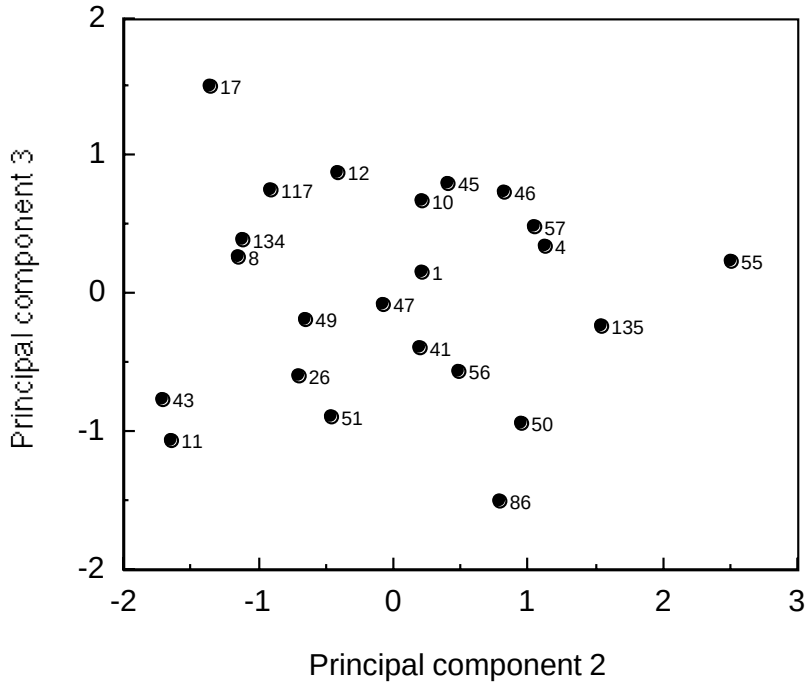

FIG. 5. The relationship between sesame lines determined by principal component analysis using data from capsule morphology, capsule anatomy and capsule break-strength experiments. The approximate relationships between the principal component axes and the parameters are shown.

4. CONCLUSION

This paper presents work in progress toward identifying particular sesame lines and traits which might be useful for hybridisation and selection in a breeding programme with the aim of developing lines with superior seed retention. Investigation of capsule morphology, capsule anatomy and capsule break-strength indicated that there is variation between the lines, and that some lines, particularly 8 (Kobayashi 393) and 17 (Kobayashi TK27), deserve further investigation. Lines with the *id* mutation were no better than other lines in any of the investigations, suggesting that genes other than *id* may contribute significantly to seed retention. Lines 1 and 4, commercially released lines by the CSIRO, did not fare well in any examination. There is substantial room for improvement in the CSIRO breeding programme. Work is under way to compare sesame lines in different environmental conditions with the aim of examining the relationship between seed retention, capsule anatomy and morphology, and environmental conditions.

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MUTATION TECHNIQUES IN SESAME (*Sesamum indicum* L.) FOR INTENSIVE MANAGEMENT: CONFIRMED MUTANTS

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Abstract

Seeds of four sesame cultivars, Muganli-57, Özberk-82, Çamdibi and Gölmarmara were irradiated in the range of 150–750 Gy doses of gamma rays in three different experiments. Irradiated seeds with their controls were sown in 1994, 1995 and 1997 to grow M_1. Three different harvesting procedures were applied to the M_1 populations, i.e., plant harvesting, branch harvesting and bulk harvesting. M_2 generations, therefore, were both grown as progeny rows and bulk populations. Potential mutants fitting the breeding objectives were selected after careful screening during the growing period; there were mutations for closed capsule, determinate growth habit, wilting tolerance, chlorophyll deficiency, hairy capsule and multicarpelate, sterility as well as in quantitative traits such as flowering time, capsule size, plant height. In M_3, the selected mutants with their normal looking sibs from the same progeny were grown again to confirm mutant traits in progeny rows of 2 meters length and 40 cm apart. After emergence, the plants within a row were thinned to 5 cm apart. Normal agronomic practices were applied to the nurseries. It was finally concluded that recovering unique induced mutants, such as closed capsules, is not a matter of "luck" but the result of growing large M_2 populations, preferably in plant progeny rows, and careful screening.

1. INTRODUCTION

Sesame is one of the important oilseed crops in the world [1]. There is an interest in growing sesame as a second crop after wheat in the cotton belt of Turkey. In order to increase its productivity, sesame cultivars suited to high input conditions of irrigated areas should be developed since it yields twice or three-times higher than in the non-irrigated areas [2]. However, the main restriction to its wider cultivation is the seed shattering at harvest, in spite of great efforts to improve characteristics of sesame for mechanised cultivation. Susceptibility to wilting and indeterminate growth habit are also important problems of sesame under intensive management conditions.

Therefore the final aim of this study is to develop sesame cultivars suited to intensive management. In this final report the results of three experiments are summarised and the confirmed mutants are presented.

2. MATERIALS AND METHODS

2.1. Parent material

Four cultivars, namely Muganli-57, Özberk-82, Çamdibi and Gölmarmara, were selected as parent material. Plant characteristics of the cultivars selected for irradiation were given in Table I. Muganli-57, which is the best available variety, needs smaller steps for improvement than the others. Çamdibi, which is a pure-line selection, has not been released as a variety.

TABLE I. CHARACTERISTICS OF SESAME CULTIVARS CHOSEN FOR IRRADIATION

Cultivars	Branching	Carpels/ per capsule	Capsules/ per axil	Seed color	Registered as variety in
Muganli-57	Multi	2	1	Yellow-brown	1986
Özberk-82	Multi	2	1	brown	1986
Çamdibi	Multi	2	3, or irregular	brown	–
Gölmarmara	Multi	2	1	white	1986

2.2. Mutagen treatment

Under this Co-ordinated Research Project we irradiated with gamma rays three different sets of the above mentioned cultivars, in three different experiments.

2.2.1. Experiment I

The mutagen treatment was applied in 1994. In that year we performed radiosensitivity tests due to lack of any data for Turkish sesame cultivars. Since this experiment has been insightful for the subsequent studies, the mutagen treatment and the M_1 growing procedures are described here in detail: Air-dried seeds of the sesame cultivars, *i.e*, Muganli-57, Özberk-82, Çamdibi, and Gölmarmara were treated with 0, 150, 300, 450, 600 and 750 Gy of gamma rays from a ^{60}Co source on 13 May 1994 at the FAO/IAEA Agriculture and Biotechnology Laboratory, Seibersdorf, Austria. About ten thousand seeds for each genotype x dose combination were irradiated. The irradiated seeds were taken to Antalya, Turkey by air and kept in a refrigerator (+4°C) until sowing time. The irradiated seed lots and untreated ones which served as controls, were sown in 5m rows on 21st and 22nd of June in 1994 in the Campus of Akdeniz University. The M_1 generation was grown under closer spacing (40 × 1 cm), low inputs (N, P, and K at 20 kg/ha) and late sowing in order to prevent multi-branching. An irradiated population was composed of 7–8 rows. After each irradiated population, one non-irradiated control row was sown. After sowing, sprinkler irrigation was applied, which is unusual in most of the environments but suitable in the travertine infertile soils of the Campus of Akdeniz University. Other details of growing M_1 were given elsewhere [3]. Emergence started 4 days after the first irrigation, and fifteen days later the emerged plants were counted as survivors. Before flowering and about one month after sowing, plant height was measured in 3 plants per row, what totals 24 plants per population. Days to first flowering (after first irrigation) was also recorded. The data obtained were expressed as percentages over the control and frequency polygons were drawn [3]. Three different harvesting procedures were applied in M_1. In the campus where plants were densely grown, 5 capsules were harvested from every surviving M_1 plant, i.e. *plant harvesting procedure.* In Aksu, where the stands were sparse, three capsules were harvested from the main stem and two basal branches, a total of 9 capsules, assuming that these plant parts arise from different initial cells, i.e., *branch (or cell) harvesting procedure.* The rest of the plants were bulked by cultivar x dose or only by cultivar, i.e., *bulk harvesting procedure* [4]. All capsules were threshed in the laboratory after drying for 3–4 days at 37°C.

2.2.2. Experiment II

To increase the probability in selecting desirable mutants we repeated the irradiation of the four cultivars that we focused on. This time we used only the two doses of gamma rays, which were found highly effective in the material irradiated in 1994, viz. 300 and 400 Gy. Air-dried seeds of the same cultivars were irradiated with 0, 300 and 400 Gy of gamma rays from a ^{60}Co source on 12 April 1995 at the Ankara Nuclear Agricultural Research Center (ANTAM). About 30 g of seeds for each genotype x dose combination were used for irradiation. The irradiated seeds were taken to Antalya and they were kept in a refrigerator (+4°C) until sowing time. The irradiated seed lots and untreated ones which served as controls were sown on 23 May 1995 in the Campus. The agronomic practices were as described in Experiment I. We harvested 7 capsules from about 1000 single plants from every population, separately. The rest of the plants for each dose x variety combination, where available, were harvested in bulk.

2.2.3. Experiment III

To select different types of desirable mutants we repeated the irradiation of the same cultivars mentioned in experiment II in 1997. In this experiment we applied only one dose of gamma rays, 400 Gy, which proved highly effective in the materials irradiated in 1994 and 1995. Air-dried seeds of the cultivars, Muganli-57, Özberk-82, Gölmarmara and Çamdibi were irradiated with 400 Gy from a ^{60}Co

source on 23 January 1997 in the FAO/IAEA Laboratory in Seibersdorf, Austria. About 50 g of seeds of each cultivar were irradiated. The irradiated seeds were taken to Antalya and they were kept in a refrigerator (+4°C) until sowing time. The irradiated and unirradiated seed lots were planted late, in mid-July 1997, to reduce branching. The agronomic practices were as described by Çagirgan [3]. We had planned to harvest the M_1 populations in bulk, but we could harvest most of them as single plants. We harvested 5–7 capsules from about 5,000 individuals of the irradiated cultivars. This material will be grown in the M_2 in the 1998 season in M_1 plant progeny rows and in bulk.

2.3. Growing M_2, selecting and confirming mutants

2.3.1. Experiment I

Since three different harvesting procedures were applied in the M_1, the M_2 generation was grown both in progeny rows and in bulk in the 1995 season. Branch-to-row and plant-to-row progenies were grown in the same manner: the seeds were sown by hand in progeny rows, 1m long and 40 cm apart. Bulk populations were grown in 20 m rows, spaced 45 cm apart. During the growing period various putative mutants were selected. M_3 progenies of such plants were grown in the 1996 season to confirm their breeding behaviour, in progeny rows 2 m long and 40 cm apart. After emergence, the plants were thinned to 5 cm spacing within the rows. The M_4 was grown on the same way, to increase the seed of the confirmed mutants and to reconfirm the contradicting results in M_3. In M_2–M_4 generations in the campus the seeds were sown to a dry seedbed then sprinkler-irrigated because of infertile travertine soil; 60–60–60 kg/ha N, P, K were applied at planting time. Weeds were controlled by hand.

2.3.2. Experiment II

Since we obtained a very wide spectrum of many independent mutants in experiment I, we focused only on those that are suited to intensive management, i.e. closed capsules, determinate growth habit and wilt tolerant. The M_2 was grown as M_1 plant progenies in rows 2 m long and 40 cm apart in 1996. The selected mutants were confirmed in M_3 in 1997 in the same plant density as in M_2. But the plants were thinned to a 5 cm spacing within the row. The M_4 generation with the mutants from this experiment will be grown in 1998 to increase the seed and reconfirm some mutants in complex characters.

3. RESULTS AND DISCUSSION

3.1. Radiosensitivity studies in M_1

Since there was no radiosensitivity research on Turkish sesame genotypes, we performed a dose–response study in Experiment I. The details of the study were given by Çagirgan [3] and summarized here (data not shown). The number of survivors in the irradiated populations decreased steadily with increasing doses of gamma rays from 150 Gy to 750 Gy. An unexpected number of survivors, higher than the control, was observed in the 300 Gy population of Özberk-82, possibly because of environmental bias. It is well known that various mutagens reduce the germinability of the seeds and thus reduce the survival rate. The survival depression effect of gamma rays was not very drastic up to 600 Gy. Doses higher than 450 Gy are not advisable since lower ones generate the desired genetic changes and cause less primary physiological damages. The result also showed that Muganli-57 and Özberk-82 are more resistant to gamma rays than Çamdibi and Gölmarmara. LD_{50} for these two groups of cultivars, was 600 Gy and about 500 Gy, respectively. The difference in radiosensitivity between the cultivar groups were evident in the higher doses. Although this difference was not noticed in M_1 plant height, it was observed in days to first flowering. There seems to be some variation in radiosensitivity among sesame cultivars. But this variation is small and it is not necessary to make complicated radiosensitivity tests, unless recent exotic cultivars are used for mutation induction.

The average plant height decreased in all cultivars with increasing radiation doses. Seedling growth reduction is one of the easiest and first observable effects in irradiated seeds. It has been well-documented that there is a good correlation between seedling injury and genetic injury over a wide range of doses with X ray, gamma rays, or neutrons [5]. When sesame seeds are irradiated with gamma rays, seedling height can be markedly reduced. The degree of reduction depends on the dose applied. Although sesame seeds were considered highly resistant to seed irradiation, there was an observable growth reduction in all the irradiated populations, even in the lowest dose of 150 Gy. At the highest doses, i.e. 600 and 750 Gy, the plants were generally stunted, as reported also by Rajput *et al*. [6].

Days to first flowering was delayed by higher doses of gamma rays. However, it was evident in the 150 Gy populations, that this lowest dose, induced slight earliness in flowering in all the cultivars. Anyanga [7] stated that flowering time was delayed, starting from treatments of 400 Gy. In our study the cultivar Çamdibi started to develop late flowering in the 300 Gy treatment. It was repeatedly determined by studying this character that Çamdibi and Gölmarmara cultivars were more radiosensitive than the other cultivars studied.

We conclude that the selected range of gamma ray doses fit well the Turkish sesame genotypes under study. Therefore there was no need to apply a wider range of doses as described by Pathirana and Subasinghe [8]. Considering all the results together it was clear that the 300 and 450 Gy doses were highly effective in inducing primary physiological damage in M_1, as opposed to the reports suggesting that sesame seeds are very resistant to irradiation and consequently encouraging the use of doses exceeding 400 Gy. It should be remembered that even in the lowest dose, 150 Gy, growth was reduced. At the highest two doses, very clear chlorophyll changes and drastic morphological anomalies in chimeric structure were observed in the M_1 plants. Last but not least, these chimeric chlorophyll changes are conducive to studies of primary damages, the chimeric structure of sesame as well as number of initial cells.

It is advisable to limit labour in the M_1 generation to a minimum when interested primarily in mutations for practical breeding purposes. It was found in this study that survivals (two weeks after sowing), plant height before first flowering and days to first flower were very suitable for dose-response studies, when measured at the proper time as done in this study. Since sesame grows well and is usually branched under good growing conditions, it is advisable, therefore, to grow the M_1 generation under low-input conditions. We managed this constraint by applying low fertiliser, late sowing and closer spacing (40 × 1 cm) on infertile travertine soils, which were found suitable for later studies.

3.2. Population size in M_2

Quite large M_2 populations were grown in 14,005 M_1 plant progeny rows in Experiment I and in 5,511 rows in Experiment II. In total, 2,943 M_1 plant progenies will be grown in the 1998 season (Table II). The M_2 populations were also grown as bulk in Experiment I, consisting of 102,400 plants [4], and Experiment II (plants not counted).

3.3. Confirmed mutants

Putative mutants were selected in M_2 and confirmed in M_3 and M_4 (only in Experiment I). All types of mutants deviating from their respective parent cultivars were selected in Experiment I and the mutant spectrum was reported by Çagirgan [4]. In Experiment II we focused only on mutants suitable for intensive management such as closed capsule, determinate growth habit and wilt tolerance. Some of them need further characterisation, especially those affecting complex characters. Confirmed mutants with their main identifying features were listed and grouped in Table III and each group discussed separately below.

TABLE II. NUMBER OF M_2 PROGENY ROWS IN THE THREE EXPERIMENTS

Parent cultivar	Experiment I		Experiment II		Experiment III*	
	Dose (Gy)	Total (1995)	Dose (Gy)	Total (1996)	Dose (Gy)	Total (1998)
Muganli-57	0	Control	0	Control	0	Control
	150	989	300	646	400	280
	300	944	400	802	–	–
	450	884	–	–	–	–
	600	424	–	–	–	–
	750	285	–	–	–	–
Sub total	–	**3 526**	–	**1 448**	–	**280**
Özberk-82	0	Control	0	Control	0	Control
	150	985	300	888	400	364
	300	975	400	976	–	–
	450	979	–	–	–	–
	600	540	–	–	–	–
	750	172	–	–	–	–
Sub total	–	**3 651**	–	**1 864**	–	**364**
Çamdibi	0	Control	–	Control	–	Control
	150	982	300	886	400	929
	300	929	400	509	–	–
	450	727	–	–	–	–
	600	517	–	–	–	–
	750	146	–	–	–	–
Sub total	–	**3 301**	–	**1 385**	–	**929**
Gölmarmara	0	Control	0	Control	0	Control
	150	975	300	484	400	1 370
	300	953	400	320	–	–
	450	722	–	–	–	–
	600	475	–	–	–	–
	750	402	–	–	–	–
Sub total	–	**3 527**	–	**804**	–	**1 370**
Total	–	**14 005**	–	**5 511**	–	**2 943**
Grand total	**(Experiment I+Experiment II+Experiment III)=22 459**					

* M_2 will be grown in 1998 season.

3.3.1. Closed capsule mutants

Reduction of seed loss at maturity and harvest by developing cultivars with closed capsules is the key to a successful cultivation of sesame suitable for mechanised harvesting. As known, the only available natural recessive gene for indehiscent capsules was found in Venezuela in the early 1940s [9]. Since then it could not be employed successfully in variety development because of many negative pleiotropic effects on the agronomic performance of the progenies developed [10]. In the two experiments we selected 8 independent mutants with closed capsules. The first 4 mutants were reported [4,11] in earlier communications. Still, the whole story of the closed capsule mutants is summarised here. The highest number of mutants (4) was obtained in Muganli-57. Three of them derived from Experiment I, and one mutant from Experiment II. The mutant, *cc-?*-4, has high sterility and hard, difficult to open capsules. Another mutant, *cc-?*-2, has closed capsules with slight opening on the tip, which is typical for this mutant. It is interesting to note here that the mutant selected in Experiment II, *cc-?*-6, was similar to the *cc-?*-2 selected in Experiment I, suggesting that it is possible

to repeat the induction of similar types of unique mutants. The *cc-?*-5 was interesting, in that it was selected in the M_3 for closed capsule from a multi-carpel mutant selected in M_2. The *cc-?*-9 is from the same source family of this selection, which open its multi-carpel capsules and shatter the seed but there are conjuctions among the carpels in the tips of capsules. Çamdibi yielded two similar looking mutants selected in two different irradiated seed lots. Only one closed capsule mutant was selected in Özberk-82 in Experiment I and Gölmarmara in Experiment II. As we concluded and reported before [3], 300 and 400 Gy dose range was effective in inducing closed capsule mutants (Table III). Finally we could select at least one mutant from all four Turkish cultivars, which we focused on, in the two different experiments. Despite of the pessimism in the literature, our results clearly show that selecting such unique mutants as closed capsule is not a matter of "luck" but of growing big enough populations and careful screening. We observed a lower percentage of recessive closed capsule mutants in the progeny rows than expected because of their lower vigour and competition ability compared with normal open capsule types. Although we could select our first closed capsule mutant, *cc-?*-1 in the bulked M_2 population of Çamdibi, it is advisable to arrange plant progenies in M_2 populations to screen for closed capsule instead of in bulk. If bulk harvesting of the M_1 is preferred for some reason, then the M_2 must be grown in a very well prepared seed bed with spaced planting, preferably every seed should be placed in a different hole. Ashri [12] grew several big M_2 bulk populations (4 hectares) of the Israeli sesame variety No.45, treated with gamma rays or EMS, but no closed capsule mutant was selected. These intensive efforts with sesame have been very insightful to us while planning the management of our M_2 populations. Therefore even negative results should be published to enable improvement of selection techniques in mutant populations.

Data on the yield, yield components and fertility levels of the closed capsule mutants are given in Table IV. All mutants gave lower seed yields than their parent cultivars. However *cc-?*-3 and *cc-?*-6 had better plant yields than the rest of the mutants. Plant yields of the independent mutants with similar phenotypes, i.e., *cc-?*-2 vs *cc-?*-6 and *cc-?*-1 vs *cc-?*-7, were different, which could be expected due to the heterogeneous experimental field and lack of replication. We stored the few Gölmarmara mutant plants as samples, so no data are available. Replicated performance trials will be performed in the 1998 season with the increased seeds of the mutants. The number of capsules per plant was generally higher in the closed capsule mutants then in their respective parent cultivars. We counted all the capsules having seed as potential fruits, although their size was not comparable to the parent cultivars'. The lowest capsule number per plant was obtained in *cc-?*-5, which was multicarpelate. Çamdibi has more than one capsule per leaf axil, and its mutants had a low number of capsules. The number of seeds was lower than their respective parent cultivars. The lowest value for the latter trait was noticed in *cc-?*-5, a multi carpel mutant. The highest fertility (%) was obtained in *cc-?*-6 (62.0 %) compared to Muganli-57 (88.8%). Line c*c-?*-4 had the lowest fertility value, 8.6 %, and also had a high threshability problem. The *cc-?*-3 was of the best threshability because of partial membrane development in the capsules. Thousand seed weight was also lower in the closed capsule mutants than their respective parents. However their seed sizes were in the acceptable range (Table IV).

In the 1997 season we set up a crossing nursery for allelism tests among the closed capsule mutants. However we were unsuccessful in completing crossing program due to heterogeneity in some of the mutant lines arising from outcrossing. This task will be repeated in the 1998 season.

We expect that these induced closed capsule mutants selected for the first time under this Co-ordinated Research Project will be very useful to make sesame a modern crop adapted to intensive management conditions with mechanised harvesting.

TABLE III. CONFIRMED MUTANTS SELECTED IN TURKISH SESAME CULTIVARS

Mutant	Parent cultivar	Dose (Gy)	Exp.No.	M_2 source	Seed	Characteristics
cc-?-1	Çamdibi	150-750*	I	9430001	M_5	Closed capsule, partial sterility
cc-?-2	Muganli-57	450	I	9413047	M_5	Closed capsule, slight opening in the capsule tip
cc-?-3	Özberk-82	300	I	9422059	M_5	Closed capsule, good fertility and threshability
cc-?-4	Muganli-57	450	I	9413806	M_5	Closed capsule, partial sterility
cc-?-5	Muganli-57	750	I	94M3-328	M_5	Closed capsule, selected from multi carpel mutant
cc-?-6	Muganli-57	300	II	9511609	M_4	Closed capsule, similar to cc-?-2
cc-?-7	Çamdibi	300	II	9531092	M_4	Closed capsule, similar to cc-?-1
cc-?-8	Gölmarmara	400	II	9542305	M_4	Closed capsule, partial sterility
cc-?-9	Muganli-57	750	I	9415000	M_5	Semi closed capsule, multi carpel, isogenic to cc-?-5
dt-?-1	Muganli-57	150	I	9411144	M_5	Determinate, similar to Ashri's dt-45
dt-?-2	Muganli-57	300	I	9412178	M_5	Determinate
dt-?-3	Muganli-57	400	II	9512368	M_4	Determinate
dt-?-4	Çamdibi	150-750	I	943000	M_5	Very large dense leaves, determinate
dt-?-5	Çamdibi	150-750	I	943000	M_5	Very large dense leaves, determinate
dt-?-6	Çamdibi	150-750	I	943000	M_5	Large leaves, fasciation, determinate
wt-?-1	Muganli-57	150	I	9411000	M_5	Tolerance to wilting, late flowering, vigorous
wt-?-2	Muganli-57	450	I	9413498	M_5	Tolerance to wilting
wt-?-3	Muganli-57	300	II	9511075	M_4	Tolerance to wilting
wt-?-4	Muganli-57	300	II	9511498 (1-3)	M_4	Tolerance to wilting
wt-?-5	Muganli-57	400	II	9512X1 (1-4)	M_4	Resistance to wilting, sterile segregants in M_2
wt-?-6	Muganli-57	400	II	9512398	M_4	Tolerance to wilting
wt-?-7	Çamdibi	150-750	I	9430000	M_5	Tolerance to wilting, chlorophyll colour,
wt-?-8	Çamdibi	150-750	I	9430000	M_5	Tolerance to wilting, vigorous,
mc-?-1	Muganli-57	450	I	9413215	M_5	Multi carpel
mc-?-2	Çamdibi	150-750	I	9430000	M_5	Multi carpel
mc-?-3	Çamdibi	150-750	I	9430000	M_5	Multi carpel, fasciation
mc-?-4	Çamdibi	150-750	I	9430000	M_5	Multi carpel, fasciation,
mc-?-5	Çamdibi	150-750	I	9430000	M_5	Multi carpel, fasciation
ch-?-1	Muganli-57	750	I	9515398-1	M_5	Chlorophyll mutation
ch-?-2	Çamdibi	150-750	I	9430000	M_5	Chlorophyll mutation
ch-?-3	Çamdibi	150-750	I	9430000	M_5	Chlorophyll mutation
ch-?-4	Gölmarmara	600	I	9444317	M_5	Stem colour?
hc-?-1	Muganli-57	300	I	9317000	M_5	Dense hairy capsule
hc-?-2	Özberk-82	750	I	9425328	M_5	Hairy capsule
hc-?-3	Özberk-82	400	II	9522160	M_4	Hairy capsule
hc-?-4	Özberk-82	300	II	9531941	M_4	Hairy capsule
st-?-1	Muganli-57	300	I	9412888	M_5	Sterile segregation
st-?-2	Muganli-57	300	I	9412930	M_5	Minute capsule segregation, no seed
st-?-3	Muganli-57	450	I	9413255	M_5	Sterile segregation, minute capsules
st-?-4	Muganli-57	450	I	9413495	M_5	Homozygous sterile, some few late capsule set
st-?-5	Muganli-57	600	I	9414356-1	M_5	Sterile segregation, minute capsules
st-?-6	Muganli-57	600	I	9414356-2	M_5	Sterile segregation, minute capsules
st-?-7	Özberk-82	300	I	9422055-1	M_5	Sterile; long capsule; late senescence; few large seeds
st-?-8	Özberk-82	450	I	9423867	M_5	Sterile segregation, hairy capsule
st-?-9	Özberk-82	600	I	9424655 (2,5)	M_5	Sterile, split corolla
st-?-10	Çamdibi	300	I	9432514	M_5	Sterile segregation, minute capsules
st-?-11	Çamdibi	300	I	9432724 (1,4)	M_5	Sterile segregation; many flowers + dark pink corolla
st-?-12	Çamdibi	300	II	9531878	M_4	No flowers, thin stem
lfl-?-1	Muganli-57	300	I	9412405	M_5	Late flowering, tall
lfl-?-2	Muganli-57	200	I	9316000	M_5	Late flowering, vigorous
cs-?-1	Özberk-82	150	I	9421127-1	M_5	Minute capsules
cs-?-2	Özberk-82	150	I	9421190-1	M_5	Minute capsules
cs-?-3	Özberk-82	600	I	9424615 (2,3)	M_5	Small flowers, minute capsules
cs-?-4	Çamdibi	300	II	9531268	M_4	Different capsule shape
cs-?-5	Çamdibi	450	I	9433079,33080	M_5	Minute capsules (homozygous, fertile)
cs-?-6	Çamdibi	600	I	9434623	M_5	Minute capsules
vgr-?-1	Özberk-82	300	II	9521913	M_4	Vigorous, needle shaped capsule tip, thick stem
vgr-?-2	Özberk-82	400	II	9522039	M_4	Vigorous
vgr-?-3	Özberk-82	400	II	9522923	M_4	Vigorous, long capsule (single plant)
vgr-?-4	Çamdibi	150	I	9431982-2	M_5	Vigorous
vgr-?-5	Çamdibi	600	I	9434594	M_5	Vigorous, high yielding ability

* Bulked over doses.

TABLE IV. YIELD PER PLANT, YIELD COMPONENTS AND FERTILITY LEVELS OF THE CLOSED CAPSULE MUTANTS

Parent cultivar/ mutant	Exp. Number	Dose (^{60}Co)	Yield/ plant (g)	Capsules/ plants, No.	Seeds/ capsule No.	Fertility (%)	1000 seed weight
Muganli-57	-	0	17.8	85	59.4	88.8	4.6
cc-?-2	1	450	1.2	138	27.7	35.0	3.6
cc-?-4	1	450	<1	181	38.7	8.6	*
cc-?-6	2	300	4.9	105	40.8	62.0	3.8
cc-?-5	1	750	<1	27	10.3	26.8	3.3
Özberk-82	-	0	17.5	82	64.9	95.0	3.5
cc-?-3	1	300	4.0	89	36.5	54.3	3.2
Çamdibi	-	0	23.8	136	65.2	90.5	4.1
cc-?-1	1	bulk	1.1	91	17.1	30.1	3.0
cc-?-7	2	300	2.3	121	36.1	32.8	3.0
Gölmarmara		0	*	*	*	*	*
cc-?-8	2	400	*	*	*	*	*

* Data not available.

3.3.2. Determinate mutants

Indeterminate growth habit causes non-uniform flowering and thus non-uniform ripening of the capsules. Determinate habit mutants including types of semi-dwarfism should be useful for dense planting. Because of better harvest index, these types may be grown successfully under low fertility conditions. The first determinate habit sesame mutant in the world was reported and described by Ashri [9,10]. Although we intensively focused on determinate habit and consequently selected 92 "determinate-looking" single plants in M_2, only three of them were confirmed to be true-breeding, i.e., *dt-?*-1, *dt-?*-2 and *dt-?*-3. The *dt-?*-1, selection from Muganli-57 irradiated with 150 Gy was very similar to *dt*45, described by Ashri [9,10]. It segregated for the determinate habit in M_2. From the segregation ratio and progeny testing it was evident that the determinate character was a true-breeding one. It was the second determinate mutant after Professor Ashri's *dt*45. The other two determinate mutant differed from the *dt*45. An agronomic performance and plant density trial was conducted with the true-breeding *dt-?*-1 mutant in a split-plot design with three replications in the 1997 season.

We have three more mutants with very large and dense leaves grouped as "determinate" since they have short flowering period. These mutant lines are under further studies to assess their exact growing habit.

3.3.3. Wilt tolerant mutants

Sesame is grown mostly on stored moisture and doubles its yield when additional irrigation is applied. However, irrigation causes wilt diseases [2]. Therefore developing wilt tolerant lines is another key factor for intensive cultivation of sesame. There is no adapted wilt tolerant material available to breeders in Turkey, so the solution is to induce mutations for this character.

We had planned to screen our mutant nursery when a natural epidemic of wilt occurred. The 1997 season was suited to screen wilt tolerance since most of the nursery was diseased. Some of the wilting tolerant-looking mutants were the lines selected for more vigour (Table III). They need more careful inspection. However one mutant, *wt-?*-5, selected from Muganli-57 for sterility segregation in M_2, had quite good wilt tolerance. It is very promising because there were four healthy M_4 lines selected from one progeny despite the fact that neighbouring lines were completely destroyed by wilting. A special wilt observation nursery will be set to confirm their tolerant behaviour under heavy disease pressure.

3.3.4. Multi carpel mutants

We selected seven multi carpel mutants with capsules having 8 locules (Table III). The vegetative and floral parts were fasciated in three mutants. Since the two mutants, derived from the 15B-328 line, with multi carpels had also closed capsules and semi-closed capsules, they were grouped with "closed capsule mutants".

3.3.5. Chlorophyll mutants

Chlorophyll mutants are easily obtained by induced mutations. Three different types of mutants from this category, mostly pale-green or yellowish green were confirmed (Table III).

3.3.6. Hairy capsule mutants

Hairy capsule mutants may be related to drought tolerance. Seven mutants in which the capsules and other plant parts were covered by dense hairs were selected. Four of them were grouped as "hairy capsule mutants" (Table III) and one, which also had male sterility, was grouped as "sterile".

3.3.7. Branching mutants

In this category, 6 unbranched or top-branched mutants were selected. Unbranched, heavy bearing types, should be suited to drill sowing in closely-spaced rows under intensive management conditions. However ideotypes with some basal appressed branching should be suited to less intensive management systems, where the seeds are broadcast [13]. Rajput et al. [6] reported interesting heavy bearing mutants similar to our case. These lines need further characterisation.

3.3.8. Sterile mutants

Development of male sterility mechanisms suitable for hybrid seed production is the key for hybrid cultivars for intensive management conditions. Different sources of genetic male sterility should also be useful for population improvement. Some interesting male sterility systems were described and their use in hybrid seed production was practised in some other programs [13, 14, 15]. We confirmed 12 mutants with different types of sterility: Steriles without flowers, *st-?*-12; Steriles with small capsules but without seed, *st-?*-2; steriles with small capsules, e.g., *st-?*-3; sterile with split corolla, *st-?*-9; sterile with few large seeds in long capsules, *st-?*-7; and most interesting one with many flowers with dark pink corolla. At least three of them are male sterile. Characterisation of this group is in progress.

3.3.9. Late flowering mutants

Two mutants selected from Muganli-57, *lfl-?*-1 and *lfl-?*-2, were confirmed and they were more vigorous and tall.

3.3.10. Capsule size or shape

Six mutants were confirmed under this category while others are grouped under various other categories.

3.3.11. Vigorous mutants

Five mutants were confirmed with their more vigorous growth habit. Some of them show higher yielding capacity.

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BREEDING SESAME FOR DISEASES AND SHATTER RESISTANT HIGH YIELDING VARIETIES WITH INDUCED MUTATIONS

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Abstract

"Suwon 144", derived from the cross between "Danbaeckkae" and mutant MY-74-2 and in spite of its higher yield and quality compared to the check variety, did not pass the nomination to the Committee of Main Crops New Varieties under the Ministry of Agriculture and Forestry, due to the decision of the committee to limit the number of new varieties in sesame as a minor crop in Korea. "Suwon 144" will be released again for a fifth year to RYT in 1998. 5,282 cross combinations and 4,341 lines including 1,388 crossings of F_1 were crossed and released to the experimental field of NCES in 1997. Mutants and their cross combinations were released and constituted more than half among them. Seeds of "Suwon 152" were treated with NaN_3 and tested for germinability. The other seeds were released and harvested in the experimental field and 419 mutant lines were selected among all the mutant lines. Mutants or materials from cross breeding with mutants occupied 71% (675) among a total of 952 promising lines in yield trials of OYT, PYT, AYT and RYT. For variability of NaN_3 induced genetic male sterile (GMS) mutants and development of restorer/s of GMS, GMS lines were planted, and male sterility (MS) expression evaluated on each line. The selected 4 MS lines with 50% MS were crossed in 22 combinations with 7 recommended varieties. For development of genic-cytoplasmic MS (GCMS) using NaN_3 induced GMS mutants, 40 recommended local Korean and introduced cultivars were crossed in 57 combinations with 4 selected GMS lines expressing 50% male sterility. Various and many sources of unique characteristics have been continuously created through induced mutations, such as determinate; dwarf; lodging,- *Phytophthora* blight- and shatter- resistant; indehiscent, seamless, taller, stronger thick stems, dense capsule bearing type, semi-dwarf, better maturity, male sterility, smaller seeds, pure white seed coat color and high yields. Lines with these induced desirable characteristics were taken immediately to crossing blocks and their descendants selected from M_2 to M_5 were released for testing. Those direct and indirect mutants selected among pedigree generations of mutation and cross breeding were included in OYT, PYT, AYT and RYT and constituted seventy one percent among all tested lines. Ongoing efforts to develop ideal varieties of sesame will be intensified in the future, using all methods of breeding including mutation induction. New NIL (near isogenic lines) of determinate, shatter resistant, indehiscent, seamless and ideal plant type of like baseball bat shaped semi-dwarf with non or few branched dense and thick capsule bearing will be developed through several repeated backcrosses. Studies to develop molecular markers through use of AFLP using NIL for screening usable important breeding target characters in earlier generation of F_1 or F_2 will commence soon with objectives not only to shorten the breeding period but also to save cost and labour.

1. INTRODUCTION

Sesame acreage in Korea increased from 40,000 ha in 1996 to 50,000 in 1997 with a higher national average yield of 680kg/ha. The national production of sesame increased due to the larger acreage and higher unit yield owing to the good climatic conditions of 1997 for sesame. Despite the higher national production in 1997 Korea still depends on importation of 70% of the national consumption of sesame.

Even though Korea is a small country in the global view of sesame production, a private Korean company started test production of sesame in Myanmar. It is expected that in the future such activities will broaden gradually the share of global sesame production of Korea, thus contributing to improved human food security in the world.

In 1997, "Suwon 144", an indirect promising sesame mutant, failed registration as a new commercial recommended variety in spite of its superiority in commercial traits and yield. This was caused by the regulation of having a limited number of 1-2 newly registered varieties of sesame per

year being a minor crop in Korea; thus two other varieties from traditional cross breeding and local collection were registered as new varieties. The general thinking in this matter should be changed as soon as possible to enlarge the farmers' choice of well-adapted and more remunerative varieties. Release should be possible if the variety nominated to the committee meets all the required conditions to pass registration as a new variety with improved traits of yield, quality, and disease- and pest-resistance.

2. RESULTS AND DISCUSSION

2.1. Mutants released under cross breeding, pedigree and yield trials

"Suwon 144" obtained from the cross of "Danbaeckkae" and the promising mutant MY-74-2, obtained from a Korean local variety "Yechon" treated with NaN_3 (2mM for 3hrs), was not registred despite its superiority, described in Table I. "Suwon 144" will be released again for a fifth year of RYT in 1998.

TABLE I. YIELD AND GROWTH CHARACTERISTICS OF PROMISING SESAME MUTANT "SUWON 144" IN 1997

Varieties	Years tested in RYT	No. locations	Days to maturity	Oleic acid (%)	Average yield in PYT & AYT (kg/ha)	Yield(kg/ha)			
						Mono cropping	Index	Second cropping	Index
Suwon 144	4	11	104	43.9	1,025	996	108	950	108
Yangbaeckkae	4	11	102	42.7	569	919	100	880	100

5,282 cross combinations and 4,341 lines including 1,388 crossings of F_1 were crossed and released to the experimental field of NCES in 1997 as described in Table II.

TABLE II. NUMBER OF SESAME COMBINATIONS, LINES AND PLANTS RELEASED AMONG PEDIGREE GENERATIONS AND YIELD TRIALS OF CROSS BREEDING INCLUDING CROSSES WITH INDIRECT MUTANTS IN NCES, SUWON IN 1997

Generation*	No. combinations	No. lines(plants)	No. mutant lines
Artificial cross	1,388		
F_1	1,392	(9,800)	
F_2	904	(452,000)	
F_3	664	2,141	
F_4	790	1,250	
F_5	144	950	
Sub-total	5,282	4,341(461,800)	
F_6(OYT)	-	830	660
F_7(PYT)	-	61	7
F_8(AYT)	-	36	5
F_9(RYT)	-	21	3
Sub-total	-	948	675
Total	5,282	5,289(461,800)	675

*OYT: Observational yield trial PYT: Preliminary yield trial.
AYT: Advanced yield trial RYT: Regional yield trial.

948 promising lines of cross breeding and crossed with mutants were released to OYT, PYT, AYT and PYT in 1997, of which 675 lines were mutants. In total 5,289 lines of F_3 to F_9 and 461,800 plants of F_1 and F_2 were planted and selected in 1997. 675 lines of them were direct or indirect mutants in origin; the list of the mutants was attached and presented in this report to the IAEA.

2.2. Mutants released under the pedigree nursery of mutation

Germination tests to check mutagen effects of NaN_3 on sesame seeds were carried out in sand filled pots following NaN_3 treatments in the laboratory. Percentage of germination, plant height, and length of first main leaf at the stage of second main leaf development were studied under three replications of 50 seeds each. Generally, in the experiments of 1995, 1996 and 1997, germination rate, plant height, leaf length and leaf width decreased due to the NaN_3 treatments.

The concentrations of sodium azide seemed to affect seedling growth more acutely than the duration of the treatments, as shown in Tables III, IV and V.

TABLE III. CHANGES OF DEVELOPMENT CHARACTERISTICS OF SESAME SEEDS OF 'SUWON 151' AND 'SUWON 152', GROWN IN SAND FILLED POTS IN SUWON IN 1995, AS AFFECTED BY DIFFERENT NaN_3 TREATMENTS

Treatments	Percent germination		Plant height(cm)		Leaf length(cm)		Leaf width (cm)	
	Suwon 151	Suwon 152	Suwon 151	Suwon 152	Suwon 151	Suwon 152	Suwon 151	Suwon 152
Control (0mM/0hrs)	88.7±11.5* A**	-	2.47±0.7A	-	1.71±0.02 AB	-	0.94±0.12 A	-
10/10	70.0±0 AB	62.7±49.2 AC	2.20±0 AC	1.70±0.56 BD	1.70±0 AB	1.33±0.21 AB	0.80±0 AB	0.80±0.36 A
20/10	32.7±9.2 CD	84.0±4.0 A	1.83±0.25 AD	2.03±0.38 AC	1.47±0.02 B	1.53±0.15 AB	0.80±0 AB	0.67±0.06 A
40/10	20.7±3.1 D	30.7±3.1 CD	1.47±0.42 D	1.47±0.21 CE	1.50±0 B	1.53±0.06 AB	0.80±0.10 AB	0.77±0.06 A
10/20	56.7±5.8 BC	81.3±8.1 A	2.03±0.06 AD	2.40±0.40 A	1.63±0.12 AB	1.73±0.21 A	0.83±0.06 AB	0.77±0.21 A
20/20	36.0±11.1C D	43.3±7.6 BC	1.77±0.15 BD	1.77±0.29 BD	1.50±0.01 B	1.63±0.06 A	0.80±0 AB	0.80±0 A
40/20	30.0±46.8C D	0	2.40±0.10 AB	0	1.80±0.20 A	0	0.95±0.05 A	0
10/30	31.3±7.0 CD	71.3±7.6A B	1.87±0.47 AD	2.17±0.12 AB	1.50±0.04 B	1.33±0.57 AB	0.80±0.17 AB	1.03±0.49 A
20/30	8.0±0 D	50.7±10.3 AC	1.70±0.20 CD	1.43±0.23 DE	1.53±0.06 B	1.43±0.12 AB	0.75±0.05 B	0.73±0.06 A
40/30	0	4.0±2.0 D	0	0.90±0 E	0	1.10±0 B	0	0.60±0 A
Average	41.56	53.50	1.971	1.733	1.594	1.454	0.830	0.771
LSD(5%)	30.14	31.62	0.578	0.521	0.224	0.422	0.150	0.426
CV(%)	41.9	33.7	16.9	17.2	8.1	16.6	10.5	31.5

* Standard deviation.

** DMRT = Duncan's multiple range test.

TABLE IV. DEVELPOMENT CHARACTERISTICS OF SESAME SEEDS OF 'SUWON 151' GROWN IN SAND FILLED POTS IN SUWON IN 1996, AS AFFECTED BY DIFFERENT NaN_3 TREATMENTS

Treatments	Percent germination	Plant height (cm)	Leaf length (cm)	Leaf width (cm)
SB* 5hrs	24.7±3.5** C***	5.18±0.98 A	2.37±0.24 A	1.30±0.23 A
SB 10hrs	37.0±5.3 BC	2.74±0.49 A	1.94±0.29 A	1.10±0.19 A
5/5	64.3±6.7 A	2.52±0.49 A	1.58±0.22 A	0.80±0.08 A
5/10	71.3±10.5 A	3.41±1.56 A	1.68±0.61 A	0.87±0.42 A
10/5	56.7±19.3 AB	3.67±0.67 A	1.76±0.31 A	0.97±0.11 A
10/10	59.3±6.8 A	4.06±2.76 A	1.96±0.97 A	1.02±0.48 A
Average	52.2	3.599	1.882	1.008
LSD(5%)	19.8	2.692	1.004	0.582
CV(%)	20.8	41.1	29.3	31.8

* Sorenson buffer solution.

** Standard deviation.

*** DMRT = Duncan's multiple range test.

TABLE V. DEVELOPMENT CHARACTERISTICS OF SESAME SEEDS OF 'SUWON 152' GROWN IN SAND FILLED POTS IN SUWON IN 1996, AS AFFECTED BY DIFFERENT NaN_3 TREATMENTS

Treatments	Percent germination	Plant height (cm)	Leaf length (cm)	Leaf width (cm)
SB* 10hrs	75.3±20.2** BC***	3.15±0.40 AB	1.75±0.11 B	0.92±0.03 A
SB 20hrs	58.0±3.5 C	3.27±0.15 AB	1.70±0.10 B	0.83±0.06 AC
10mM/10hrs	100.0±0.0 A	3.17±0.21 AB	1.43±0.06 C	0.77±0.06 C
20/10	83.3±6.4 B	3.53±0.40 A	1.67±0.21 BC	0.90±0.00 AB
30/10	24.0±6.9 D	2.57±0.38 BC	1.73±0.12 B	0.90±0.00 AB
10/20	80.7±8.3 B	3.23±0.38 AB	2.00±0.27 A	0.83±0.06 AC
20/20	12.0±6.9 D	2.10±0.30 C	1.57±0.06 BC	0.80±0.10 BC
30/20	14.0±5.3 D	1.83±0.74 C	1.63±0.12 BC	0.83±0.06 AC
Average	55.92	2.856	1.685	0.848
LSD(5%)	16.02	0.709	0.235	0.097
CV(%)	16.4	14.2	8.0	6.5

*, **, *** as in Table IV.

419 mutant lines were selected under the pedigree nursery of mutation in 1997 as shown in Table VI. The percentage of germination and morphological characters observed in M_1 treated with gamma rays and NaN_3, and growth characters of promising mutant lines of M_4 and M_5 are described in Table VII and VIII.

TABLE VI. RELEASED AND SELECTED SESAME MUTANT LINES AND PLANTS FROM THE INDUCED MUTATIONS PEDIGREE NURSERY, SUWON 1997.

Generation	Released		Mutagen	No. lines
	No. varieties	No. lines(plants)		
M_1	2	9 (12,000)	NaN_3, gamma rays	-
M_2	1	(4,000)	NaN_3	275
M_3	-	-	-	-
M_4	1	19	NaN_3	23
M_5	2	156	NaN_3	121
Total	6	175 (16,000)		

TABLE VII. CHANGES IN GERMINATION RATE AND MORPHOLOGICAL CHARACTERS IN SESAME M_1 PLANTS FOLLOWING SEED TREATMENTS WITH NaN_3 AND GAMMA RAYS IN SUWON 1997

Source varieties	Mutagen	% germination	Morphological characters
Suwon 151	control	95	-
Suwon 151	gamma rays 200 Gy	80	-
Suwon 151	gamma rays 300 Gy	80	-
Suwon 151	gamma rays 400 Gy	75	late maturity
Suwon 152	control (water/10 hrs)	80	-
Suwon 152	NaN_3 10mM/hr	60	-
Suwon 152	NaN_3 20mM/hr	50	-
Suwon 152	NaN_3 30mM/hr	40	-
Suwon 152	control (water/20 hrs)	85	-
Suwon 152	NaN_3 10mM/hr	80	shrinkage of upper leaves
Suwon 152	NaN_3 20mM/hr	-	-
Suwon 152	NaN_3 30mM/hr	-	-

TABLE VIII. PROMISING SESAME MUTANT LINES AND THEIR GROWTH CHARACTERS IN M_4 AND M_5 IN SUWON 1997

Generation	Source variety	Mutagen	Main characters
M_4	Chinbaeckkae	NaN_3 18mM/6 hrs	numerous capsules
	Chinbaeckkae	NaN_3 18mM/12 hrs	numerous & dense capsules, lodging tolerance
M_5	Suwon 131	NaN_3 2mM/2 hrs	numerous capsules *Phytophthora* blight tolerance
	Suwonkkae	NaN_3 6mM/4 hrs	*Phytophthora* blight tolerance tall & strong stem
	Suwonkkae	NaN_3 6mM/8 hrs	tall & strong stem

The numbers of sesame mutant lines selected among pedigree generations of mutation in 1997 are described in Tables IX, X, XI and XII.

TABLE IX. NUMBER OF HARVESTED M_1 SESAME PLANTS, 1997

Name of lines	Treatment	No. of plants harvested
SIM 97002 S151 γ 20	Suwon 151 γ rays 200 Gy	1000
SIM 97002 S151 γ 30	Suwon 151 γ rays 300 Gy	1000
SIM 97002 S151 γ 40	Suwon 151 γ rays 400 Gy	1000
SIM 97002 S152S10/10	Suwon 152 (NaN_3 10mM/10 hr)	1000
SIM 97002 S152S20/10	Suwon 152 (NaN_3 20mM/10 hr)	1000
SIM 97002 S152S30/10	Suwon 152 (NaN_3 30mM/10 hr)	1000
SIM 97002 S152S10/20	Suwon 152 (NaN_3 10mM/20 hr)	1000
SIM 97002 S152S20/20	Suwon 152 (NaN_3 20mM/20 hr)	1000
SIM 97002 S152S30/20	Suwon 152 (NaN_3 20mM/20 hr)	1000
Total	9	9000

TABLE X. NUMBER OF SESAME MUTANT LINES SELECTED IN M_2, 1997

Name of lines	Treatment	No. of lines released	No. of lines selected
SIM 96002 S151S10/5	Suwon 151 (NaN_3 10mM/5 hr)	1000	43
SIM 96003 S151S10/10	Suwon 151 (NaN_3 10mM/10hr)	1000	68
SIM 96004 S151S5/5	Suwon 151 (NaN_3 5mM/5 hr)	1000	63
SIM 96005 S151S5/10	Suwon 151 (NaN_3 5mM/10hr)	1000	71
Total	4	4000	275

TABLE XI. NUMBER OF SESAME MUTANT LINES SELECTED IN M_4, 1997

Name of lines	Treatments	No. lines released	No. lines selected
SIM 94001 ChbS2/2	Chinbaeckkae NaN_3 2mM/2hr	2	1
SIM 94002 ChbS2/6	Chinbaeckkae NaN_3 2mM/6hr	3	1
SIM 94003 ChbS2/12	Chinbaeckkae NaN_3 2mM/12hr	1	0
SIM 94005 ChbS6/6	Chinbaeckkae NaN_3 6mM/6hr	1	1
SIM 94006 ChbS6/12	Chinbaeckkae NaN_3 6mM/12hr	1	0
SIM 94007 ChbS12/2	Chinbaeckkae NaN_3 12mM/2hr	1	2
SIM 940010 ChbS18/2	Chinbaeckkae NaN_3 18mM/2hr	1	2
SIM 940011 ChbS18/6	Chinbaeckkae NaN_3 18mM/6hr	5	8
SIM 940012 ChbS18/12	Chinbaeckkae NaN_3 18mM/12hr	4	8
Total	9	19	23

TABLE XII. NUMBER OF SESAME MUTANT LINES SELECTED IN M_5, 1997

Name of lines	Treatments	No. lines released	No. lines selected
SIM 93001 S131S2/2	Suwon 131 NaN_3 2mM/2hr	12	11
SIM 93002 S131S2/4	Suwon 131 NaN_3 2mM/4hr	5	5
SIM 93003 S131S2/8	Suwon 131 NaN_3 2mM/8hr	6	0
SIM 93004 S131S6/2	Suwon 131 NaN_3 6mM/2hr	3	1
SIM 93005 S131S6/4	Suwon 131 NaN_3 6mM/4hr	2	3
SIM 93006 S131S6/8	Suwon 131 NaN_3 6mM/8hr	11	6
SIM 93010 S131S12/2	Suwon 131 NaN_3 12mM/2hr	2	0
SIM 93011 S131S12/4	Suwon 131 NaN_3 12mM/4hr	3	5
SIM 93013 SUSS2/2	Suwonkkae NaN_3 2mM/2hr	4	1
SIM 93014 SUSS2/4	Suwonkkae NaN_3 2mM/4hr	6	5
SIM 93015 SUSS2/8	Suwonkkae NaN_3 2mM/8hr	16	15
SIM 93016 SUSS6/2	Suwonkkae NaN_3 6mM/2hr	15	18
SIM 93017 SUSS6/4	Suwonkkae NaN_3 6mM/4hr	7	20
SIM 93018 SUSS6/8	Suwonkkae NaN_3 6mM/8hr	21	13
SIM 93019 SUSS12/2	Suwonkkae NaN_3 12mM/2hr	19	8
SIM 93020 SUSS12/4	Suwonkkae NaN_3 12mM/2hr	13	5
SIM 93021 SUSS12/8	Suwonkkae NaN_3 12mM/2hr	11	5
Total	17	156	121

2.3. Variability of GMS and its restorer and development of GCMS and its maintainer

In order to develop variability of GMS and the restorer (C line), and GCMS (A line) and the maintainer (B line) NaN_3 induced GMS mutants were pollinated with male fertile (MF) sister lines in the summer of 1996. The offspring were grown in the field in the 1997 summer season, to study the male sterility (MS) appearance rate in each cross combination. For development of variability of GMS lines and restorers of GMS, 4 lines with 50% MS were crossed with seven cultivars such as described in Table XIII.

TABLE XIII. CROSS COMBINATIONS OF SESAME AND HARVESTED CAPSULES OF EACH OF 22 COMBINATIONS IN SUWON IN 1997

Name of lines	Cross combinations	No. crossed flowers	No. harvested capsules	Remarks
SIGMS 97001	MS1/Yangbaeck	5	2	MS expression
SIGMS 97002	MS1/Suwon	4	2	- MS1 : 50%
SIGMS 97003	MS1/Ahnsan	6	3	- MS2 : 57%
SIGMS 97004	MS1/Suwon 151	6	4	- MS64 : 47%
SIGMS 97005	MS1/Suwon 128	3	2	- MS80 : 60%
SIGMS 97006	MS1/Kyungbuk 1	5	2	
SIGMS 97007	MS1/Yechon	4	3	
SIGMS 97008	MS2/Yangbaeck	7	4	
SIGMS 97009	MS2/Suwon	3	2	
SIGMS 97010	MS2/Ahnsan	4	1	
SIGMS 97011	MS2/Suwon 151	5	2	
SIGMS 97012	MS2/Suwon 128	5	2	
SIGMS 97013	MS64/Yangbaeck	6	3	
SIGMS 97014	MS64/Suwon	4	2	
SIGMS 97015	MS64/Kyungbuk 1	3	1	
SIGMS 97016	MS64/Yechon	5	4	
SIGMS 97017	MS80/Yangbaeck	6	3	
SIGMS 97018	MS80/Suwon	4	2	
SIGMS 97019	MS80/Ahnsan	6	3	
SIGMS 97020	MS80/Suwon 151	5	3	
SIGMS 97021	MS80/Suwon 128	4	3	
SIGMS 97022	MS80/Yechon	4	2	
Total	22	104	55	

TABLE XIV. CROSS COMBINATIONS OF LOCAL, RECOMMENDED AND INTRODUCED SESAME CULTIVARS WITH MF LINES OF GMS WHICH EXPRESSED 50% MS, IN ORDER TO DEVELOP GCMS AND MAINTAINER(B LINE), SUWON 1997

Name of lines	Cross combinations	No. crossed flowers	No. harvested capsules
SIGCMS 97001	Suwon 143/MF1	5	3
SIGCMS 97002	Suwon 143/MF80	6	2
SIGCMS 97003	Suwon 144/MF80	4	2
SIGCMS 97004	Suwon 147/MF1	3	1
SIGCMS 97005	Suwon 151/MF1	4	2
SIGCMS 97006	Suwon 151/MF64	4	3
SIGCMS 97007	Suwon 152/MF1	5	2
SIGCMS 97008	Suwon 152/MF2	3	1
SIGCMS 97009	Suwon 155/MF1	6	4
SIGCMS 97010	Suwon 155/MF2	4	2
SIGCMS 97011	Suwon 155/MF64	6	3
SIGCMS 97012	Suwon 155/MF80	4	2
SIGCMS 97013	Suwon 157/MF1	5	3
SIGCMS 97014	Suwon 157/MF64	4	3
SIGCMS 97015	Suwon 158/MF1	5	3
SIGCMS 97016	Iri 8/MF64	7	5
SIGCMS 97017	Iksan 10/MF64	4	3
SIGCMS 97018	Iksan 11/MF1	5	4
SIGCMS 97019	Suwon 153/MF64	3	2
SIGCMS 97020	Suwon 148/MF1	4	2
SIGCMS 97021	Sodun/MF1	5	3
SIGCMS 97022	Pungsan/MF1	6	4
SIGCMS 97023	Yangbaeck/MF1	4	3
SIGCMS 97024	Yangbaeck/MF64	7	5
SIGCMS 97025	Suwon/MF1	5	3
SIGCMS 97026	Suwon/MF80	6	4
SIGCMS 97027	Danbaeck/MF80	8	5
SIGCMS 97028	Suwon 21/MF64	5	4
SIGCMS 97029	Chinbaeck/MF1	4	2
SIGCMS 97030	Chinju/MF1	3	2
SIGCMS 97031	Ahnsan/MF1	5	4
SIGCMS 97032	Konheuck/MF1	6	4
SIGCMS 97033	Yusung/MF6	5	3
SIGCMS 97034	Yusung/MF80	4	2
SIGCMS 97035	Suwon 128/MF2	5	4
SIGCMS 97036	Suwon 128/MF64	4	3
SIGCMS 97037	Suwon 128/MF80	5	4
SIGCMS 97038	Boryung/MF1	3	2
SIGCMS 97039	Sukbo/MF80	6	4
SIGCMS 97040	Suwon 9/MF6	4	3
SIGCMS 97041	Suwon 9/MF1	4	3
SIGCMS 97042	Chinbo/MF64	5	4
SIGCMS 97043	Chinbo/MF80	4	3
SIGCMS 97044	Backsan/MF80	6	4
SIGCMS 97045	Chinbuk/MF64	5	3
SIGCMS 97046	Chilso/MF2	7	4
SIGCMS 97047	Chilso/MF80	7	3
SIGCMS 97048	PI-158061/MF1	6	4
SIGCMS 97049	PI-158061/MF64	6	3
SIGCMS 97050	Yuzhi-7/MF1	4	3
SIGCMS 97051	Yuzhi-7/MF80	4	3
SIGCMS 97052	Anthalya/MF64	5	2
SIGCMS 97053	Ubon/MF2	4	2
SIGCMS 97054	Turinoca/MF1	6	4
SIGCMS 97055	Malasara/MF2	3	2
SIGCMS 97056	Malasara/MF80	4	3
SIGCMS 97057	Mochan/MF64	4	2
Total	57	275	172

TABLE XV. CHARACTERISTICS OF GERMINATION AND GROWTH AND YIELD OF DISTRIBUTED VARIETIES IN RC MEETING ANTALYA TURKEY 1996 RELEASED AND INVESTIGATED IN NCES SUWON 1997

Varieties distributed	Field									Germinator			
	Plant height (cm)	Height 1st capsule position (cm)	No. of branches/ plant	No. of capsules/ plant	Yield (kg/ha)	Percent germination	Power germination (%)	Average days to germination	Germination coefficient	Germination (%)	Germination power (%)	Average days to germination	Germination coefficient
Polypetalous	45	-	-	-	-	20	20	13.5	7.4	78	33	21.1	4.7
N-113	55	-	-	-	-	20	20	13.0	7.7	100	89	11.0	9.1
NM-58	55	43	8.0	40.0	-	20	20	13.5	7.4	100	89	12.6	8.0
TRS-9	91	24	0.8	13.8	40	30	30	13.2	7.6	89	89	9.5	10.5
Y-1	78	24	0.4	16.7	40	25	25	16.2	6.2	33	11	7.0	5.9
Y-55	82	25	-	18.0	-	5	5	15.0	6.7	100	100	11.2	8.9
Gölmarmara	-	-	-	-	-	25	25	13.4	7.5	78	78	10.1	9.9
Ozberk	-	-	-	-	-	35	35	13.3	7.5	89	89	9.8	10.3
Mapan*	69	50	-	66.0	900	55	50	13.9	7.2	100	89	11.0	9.1
Camdibi	-	-	-	-	--	50	40	14.4	6.9	100	100	8.7	11.5
Bulk op1	36	10	2.2	10.7	200	20	15	15.5	6.5	100	89	10.8	9.3
Bulk op2	48	17	2.2	31.3	350	30	30	13.2	7.6	67	67	11.3	8.8
EC-34	71	34	1.5	23.7	-	5	5	15.0	6.7	33	0	22.3	4.5

For development of GCMS (A line) and the maintainer (B line), 40 Korean local, recommended varieties and introduced ones were crossed in 57 combinations with MF lines, which expressed 50% male steriles (GMS), and harvested 172 capsules in the field of NCES, Suwon, in 1997 and those are described in Table XIV.

3. CONCLUSIONS

The objectives of sesame breeding including mutation techniques are to obtain high yielding, pest- and disease- resistant cultivars with a higher commercial value. Sesame breeding in Korea has been trying to focus on these points. We have been developing some morphologically unique and valuable mutants through induced mutations resulting in high yielding and commercially registered mutant varieties, some of which are grown on about 30% of the Korean sesame area, which is expected to increase. The officialy released Korean commercial sesame varieties obtained by mutation techniques and their areas in 1997 are summarized in Table XVI.

TABLE XVI. AREAS OF SESAME CULTIVARS IN KOREA, 1997 SEASON

Varieties	Total	Pungsan	Yang-baeck	Suwon	Chin-baeck	Chinju	Han-sum	Sam-da	Ahnsan	Yu-sung	Dan-baeck	Local
Area(ha)	48,823	49	146	1,758	2,148	244	5,663	2,148	12,450	49	9,813	14,354
Area,%	100	0.1	0.3	3.6	4.4	0.5	11.6	4.4	25.5	0.1	20.1	29.4
Year of release		1996	1995	1992	1989	1988	1986	1986	1984	1984	1982	-
Source		Mutant	Mutant	Mutant	Cross	Cross	Cross	Local	Mutant	Cross	Cross	Local

(Data from Bureau Guidance & Technology RDA)

Induced sesame mutants from internal or external sources are bred to be registered as commercial varieties and are used in crossing in order to contribute as many promising mutant lines as possible for OYT, PYT, AYT and RYT and to increase the probability for development of registered commercial varieties. Various methods of breeding have been tried, exploring the use of mutations and concentrating on the development of new superior varieties. All sources including cross breeding, mutation techniques, GCMS and biotechnology will be focused and concentrated towards the development of superior varieties of sesame.

ACKNOWLEDGEMENTS

I thank in this paper all researchers including Prof. A. Ashri, who gave me seeds of their sesame mutants at the RCM in Antalya, Turkey in 1996. The data of released varieties in NCES field 1997 are described in Table XV. Unfortunately, the experimental conditions for germination were sub-optimal caused by earlier planting season than optimum without polyethylene film mulching. Some varieties did not even germinate at all. One of them — Mapan — showed excellent yield ability with 900kg/ha and was released to the crossing block in 1998.

SHATTER RESISTANCE IN SESAME

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Abstract

The majority of the world's sesame (probably over 99%) is shattering, and most of the harvest is manual. In a non-mechanized environment the last thing that farmers want is seed retention ("hold"). They want the seed to fall out as easily as possible. The amount of shattering desired is dependent on the method of harvest. By 1944 the first stage of mechanization was initiated. The indehiscent mutant found in 1943 showed in succeeding generations that it was controlled monogenically, and the homozygous recessive (*id/id*) gave indehiscence. Unfortunately, the *id* allele had pleiotropic effects including cupped leaves, twisted stems, short seed pods, semi-sterility, and low yield. Improvements in shatter resistance are relative within a specific program. For example, Sesaco has improved its shatter resistance each year, and still for the USA methods of harvest, further improvements are necessary to allow for better retention in adverse weather. This paper presents a methodology for quantifying shatter resistance so researchers can compare levels of shatter resistance between programs.

1. OVERVIEW OF SHATTER RESISTANCE BREEDING IN THE USA AND VENEZUELA

1.1. Background

In the tale of Ali Baba and-the-Forty Thieves, Ali Baba opens his cave full of riches by uttering the words, "Open sesame". In his day sesame was a very valuable crop — it provided vegetable oil and, in some civilizations, was used as money. When the sesame capsule opens it releases its riches — the seed. Since ancient times, the majority of sesame has been harvested manually: the plants are cut, shocked, dried, and then inverted, allowing the seeds to pour out. The opening or dehiscence of the capsule has therefore been an important characteristic of sesame. However, in mechanical agriculture, it is critical that the capsules retain as much seed as possible until the sesame plants enter the combines. This paper covers the efforts to mechanize sesame over the past six decades.

1.2. Terminology

Many terms have been used interchangeably to describe capsule dehiscence in sesame, which leads to seed shattering. In 1943 D.G. Langham [1] discovered an indehiscent mutation that held all of its seed (Fig. 1). He defined some lines that had some seed retention as semi-dehiscent or semi-indehiscent lines. In his research D.G. Langham used the term non-shattering (NSH) synonymously with semi-dehiscent. In the Texas A&M extension pamphlet [2], shattering is used synonymously with dehiscent, non-shattering with indehiscent, and semi-shattering with semi-dehiscent. However, M. Kinman and J. Martin [3] used the dehiscent terminology in technical documents.

In 1983 Sesaco began using four terms that were more understandable to the farmers in the USA: super-shattering (SUS), shattering (SHA), shatter-resistant (SR), and shatter-proof (SP). In 1986 D.G. Langham and D.R. Langham discovered a second mutation that held the seed completely and termed it seamless (Fig. 2).

1.3. Manual harvest

The majority of the world's sesame (probably over 99%) is shattering, and most of the harvest is manual. The sesame plants are cut at harvest maturity, tied into small bundles, and then stacked in shocks to dry. The details of the harvest vary from country to country and from area to area within countries. Some move the shocks to a threshing floor so that the seed that falls out can be recovered.

Others put plastic or cloth under the shocks in the fields to catch the seed. When the shocks are dry, they are turned upside down and struck with a stick or an implement to shake out all the seed. The different methods of harvest are covered thoroughly by E. Weiss [4].

In a non-mechanized environment the last thing that farmers want is seed retention ("hold"). They want the seed to fall out as easily as possible. The amount of shattering desired is dependent on the method of harvest. If the shocked sesame is placed over a threshing floor or over a plastic when it dries, the SUS types are preferable. In these types the capsules have no membranes and split completely (Fig. 3). If the plants are dried in the field with nothing underneath, there is a whole range of SHA-types (Fig. 4) that are useful to traditional farmers. The concept is that the capsules should hold the seeds as fully as possible until the farmers invert the plants.

1.4. Breeding for mechanized harvest

In the early 1940s, D.G. Langham [5,6] began a sesame program in Venezuela by improving the yield using the traditional manual harvest methods. By 1944 the first stage of mechanization was initiated. Swathers were used to cut the plants, and combines to thresh the shocks. In later years binders were used to bundle the material, but the shocking was still done manually. This approach is still used in parts of Venezuela.

In the late 1940s research programs were initiated in the USA in South Carolina [7], Nebraska [8], and Texas where R. Kalton [9] stated, "The shattering nature of presently available strains is the first and foremost obstacle to complete mechanization."

The indehiscent mutant found in 1943 showed in succeeding generations that it was controlled monogenically, and the homozygous recessive (*id/id*) gave indehiscence. Unfortunately, the *id* allele had pleiotropic effects including cupped leaves, twisted stems, short seed pods, semi-sterility, and low yield [1]. Other characters, unrelated to yield associated with indehiscence, are cupped cotyledons, enations on the underside of the leaves, enations on the flowers, and enations on the capsules. In the 1980s D.G. Langham began to refer to the indehiscent as ID. Some of the progeny had capsules where the tips opened (such as UCR 234 developed by D.M. Yermanos). These IDs that opened became known as IDO.

The seed from the *id/id* indehiscent type was disseminated throughout the world. Most breeders began crossing with other sesame lines, and many tried altering the chromosome numbers through tetraploids and interspecific crosses. In many of the more advanced progenies, the deleterious effects of *id* were modified, but it was still not possible to increase the yields to the level of the SHA cultivars. D.G. Langham came up with the idea to cross the indehiscent against 16 SHA lines; then cross those F_1s into 8 lines containing 2 indehiscent and 2 normals; then cross the new F_1s into 4 lines containing 4 indehiscent and 4 normals; then cross the new F_1s into 2 lines containing 8 indehiscent and 8 normals; and finally cross the new F_1s into 1 line containing 16 indehiscent and 16 normals. Multiple crosses were made of many of the possible permutations. This crossing design was done in conjunction with Martin and Kinman. There was enough seed to plant over 8 acres of F_2s to watch the segregation. Kinman and Martin planted their portion of the seed at Rio Farms in South Texas, and made selections at maturity. One of Martin's selections was purified in South Carolina and released as Palmetto. Kinman's first released ID variety was called Rio. Langham followed several avenues before settling on Genesa 2.

When there was enough ID sesame to put through a combine, another problem appeared — the capsules were so tough that many of them passed through the combine without opening and releasing their seeds. The combine was modified by adding rasp bars to be more aggressive. There was a marginal improvement, but the extra threshing damaged the seed. Over a short period of time the free fatty acid content increased and the seed soon became rancid.

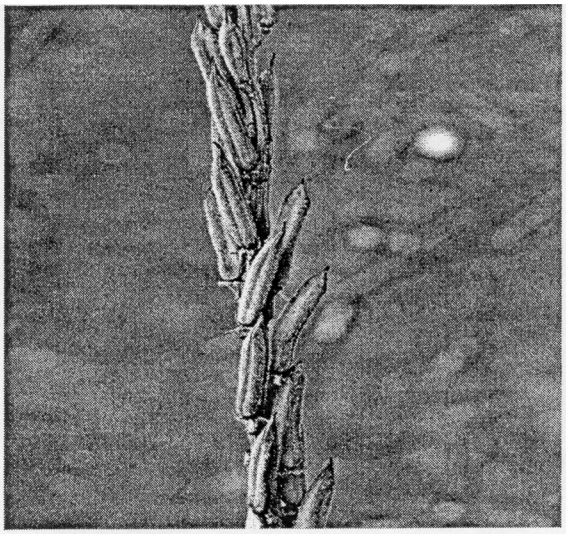

FIG. 1. Indehiscent sesame capsules

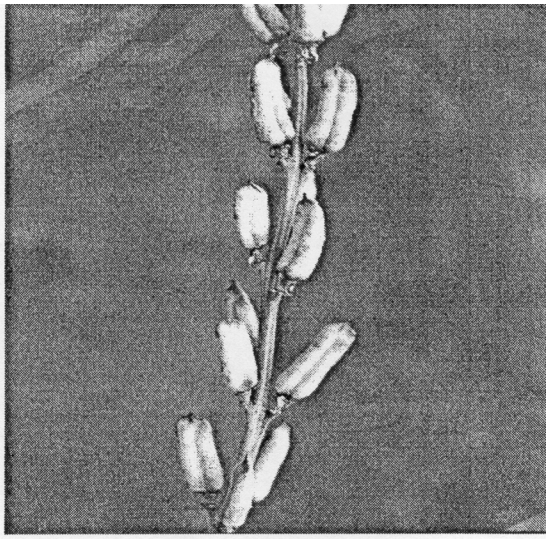

FIG. 2. Seamless sesame capsules

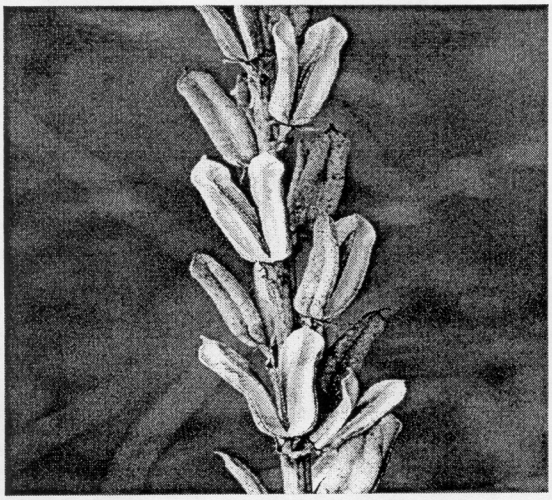

FIG. 3. Super shattering sesame capsules

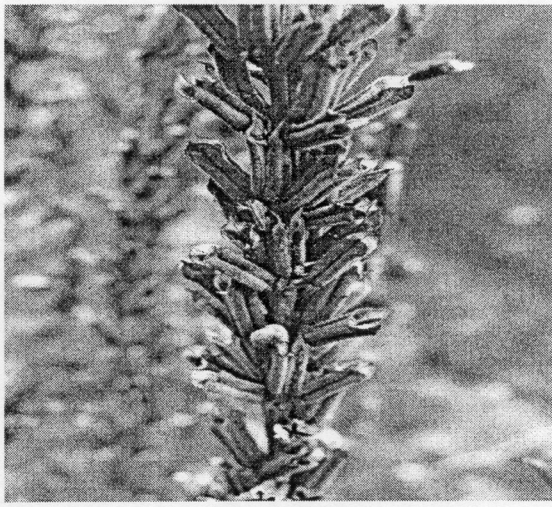

FIG. 4. Shattering sesame capsules

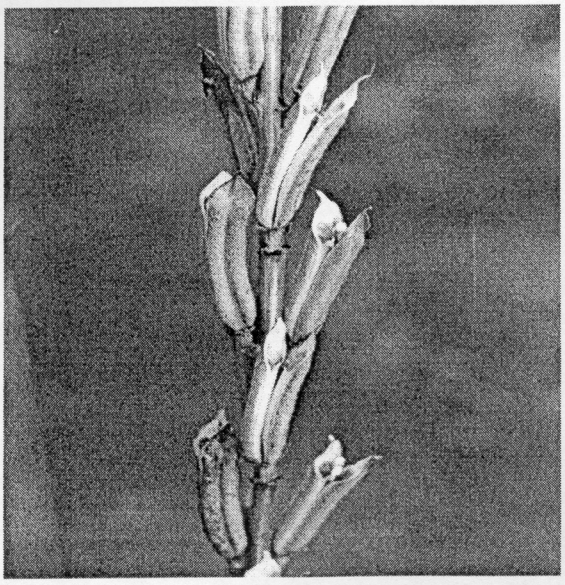

FIG. 5. Non-shattering sesame

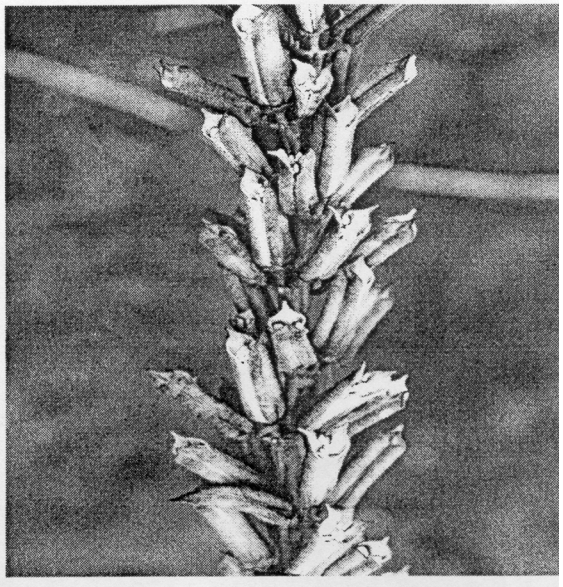

FIG. 6. Direct combine sesame type

Intense breeding to combine *id/id* with the papershell capsule resulted in the release in the USA of Baco and then Delco by Kinman. However, the yield and rancidity problems were still present, and few commercial acres were grown with ID varieties.

Both the USA and Venezuela continued parallel programs of trying to reduce the amount of shattering without using the *id* allele. In the late 1950s, D.G. Langham found that the placenta attachment was of increasing importance in developing hold, and he distributed seed with that character to many programs throughout the world, including Kinman and Martin. In much of the literature in the early 1960s, placenta attachment is discussed as an avenue to mechanize sesame. However, Yermanos [10] felt that as the seed matures, the placenta attachment gradually weakens and is obliterated when the capsule is completely desiccated.

In Venezuela varieties such as Criollo, Jaffa, Venezuela 51, Venezuela 52, and Guacara were released. B. Mazzani [11] continued Langham's breeding program there and released Aceitera, Inamar, Acarigua, Morada, Capsula Larga, Arawaca, Piritu, Glauca, Turen, and others. In the USA, researchers in Nebraska developed K10 and Early Russian (which later proved important in sesame breeding in the Republic of Korea). E. Collister of the Renner Foundation in Texas developed Renner 1 and 2. Kinman developed a good series of SHA lines: Llano, Margo, Dulce, Blanco, Paloma, and Oro, which were the majority of varieties grown in Texas and New Mexico in the late 1950s and early 1960s. In the end, most of his breeding lines were derivatives of Llano and Margo. The Texas sesame program was discontinued in the 1960s when the research funds in the USDA were cut, and seasonal manual labor from Mexico was halted by law. When Kinman's USDA work was terminated, he sent his advanced germplasm to Yermanos in California and to D. Rubis in Arizona. Yermanos continued working on the ID and developed R234. His concept was to increase the length of the capsule so that there would be more surface for the combines to crack the capsules open. Even with a small opening at the top of the capsule, there was still too much broken and damaged seed. He took the material to Sudan where they tried to develop ID varieties suited for the area. Yermanos [12] felt that the ideal sesame would be ID with a papershell capsule with a small opening and some placentation.

Most of Yermanos' contributions were in developing SHA lines that were used in Mexico — Eva and Calinda (also known as Cal Beauty). UCR-3 and UCR-4 were released, but were never widely grown commercially. Eva was the last variety planted in Northern Mexico where it was harvested by manual cutting and shocking and then thrown into combines. In 1991, the white fly infestation caused the termination of the sesame program in that area. Upon Yermanos' death in 1984, Mike Roose continued the program for several years, but did not release any varieties. The University of California at Riverside would not release any of Yermanos' material, and it may have lost its germination capacity by now. In 1981,Yermanos sent some of his material back to Texas A&M. The breeding was done by E. Whitely, G. McBee, O. Smith, and R. Brigham with Kinman as a consultant. Smith selected Eli and Roy out of the R234 material and Improved Baco. None of these ID varieties were grown commercially in Texas.

Brigham felt the ID was not going to work, and he placed the majority of his emphasis on the determinate mutant (*dt45*) induced by A. Ashri [13] in Israel. He did not develop any varieties before his retirement. Texas A&M would not release any of Brigham's material before or after his retirement in 1992. The status of that material is unknown.

In the 1980s, Yermanos and Mazzani in Venezuela tried using a desiccant to dry the sesame plants and then combining them directly, a method that was later used in Australia by Beech. Although still used in some areas of Venezuela and Australia, there are problems with the quality of the seed harvested by this method.

Most international meetings on sesame research conclude that development of shatter resistance is one of the most important objectives. For instance, at the First Australian Sesame Workshop in 1995

[14], the participants rated "plant improvement" as the number one priority and within that category rated "better seed retention characteristics at maturity" as the most important objective.

2. SESACO PROGRESS IN SHATTER RESISTANCE BREEDING

In 1978, Sesaco Corporation was founded with the goal of developing sesame as a crop in the USA. The starting point was the last material D.G. Langham developed in Venezuela and selected in Connecticut and California, the five Yermanos varieties, the last of the Kinman material, and part of the collection from the USDA Plant Introduction Service.

From 1978 to 1981, SHA and ID lines were tried, and in 1982 the first commercial ID-line was released - Sesaco 01 (S01). Although a vast improvement over other ID lines, it still could not compare with SHA lines in terms of potential yield. The seed harvested deteriorated quickly due to combine damage. The ID program was continued through 1984 while trying to improve the ratings on the following capsule characters:

— Capsule break (TB). Ease of breaking the capsule. Further crossing was done with papershell capsules despite S01 being the best papershell ID – better than Baco or Delco.
— Capsule fertility (TF). Amount of seed set. Most ID had fertility problems, but S01 generally had a full seed set.
— Capsule thresh (TT). Ease of the seed flowing out of the capsule when it was broken. This character presented two dilemmas: (1) As the capsule length was increased to allow more surface for breaking, the seeds had further to travel to exit the capsule. (2) The more papershell the capsule became, the easier it was to crimp the open end of the capsule and trap the seed inside.

In 1982, there was a breakthrough with the first of the NSH material (Fig. 5). Sesaco 02 could be swathed, left to dry in the field horizontally as it fell, and be picked up with a combine. No manual labor was required. In the ensuing years, Sesaco 03, 04, 07, 08, 09, 10, and 14 were released using the same technology.

In 1986, Sesaco developed mechanized varieties for Northern Mexico (Sesaco 50, 51, and 52). These varieties did not have enough shatter resistance to lay flat on the ground for drying; they were cut and shocked before feeding into the combine.

The seamless mutation (GS) found in 1986 showed in succeeding years that it was controlled monogenically, and the homozygous recessive (*gs/gs*) gave another closed capsule. However, there were still problems in using the gene commercially. The yield potential was low and the seeds were damaged in cracking the capsules in the combine. The low yield was due to fertility problems caused by missing stamens and lack of elongation of the stamens as the flowers opened and the stigma became receptive. Within a single plant on the same day deformed flowers and normal flowers could be found. The deformed flowers were dependent on the environment with fully fertile capsules in some locations in one year and semi-sterile in the same location the next year. In crossing the seamless with shattering types, modifying genes allowed the capsules to open at the tip (GSO).

Direct combine sesame was developed by Sesaco and released experimentally in 1988 as Sesaco 11. This type of seed retention allowed the plants to dry down in the field without cutting, swathing, or desiccation. The crop was then harvested directly with a combine. These types are characterized by capsules that hold all of their seed when the capsules first dry down (Fig. 6). Between 1988 and 1997 newer ‘Direct Combine’ (DC) varieties were released (Sesaco 15, 16, 17, 18, 19, 20, 21, and 22). Higher average yields could be obtained by swathing and combining these same materials since there was less exposure to weather.

Most sesame lines follow the same sequence of drydown. When the capsule begins to dry down, it has 51–60% moisture. Some capsules dry from their tip to their base, some dry from the base to the tip,

and others dry via patches throughout the capsule that expand and coalesce. In some cases, all three modes can be seen on the same plant. Usually after the capsule is brown (but still retaining some moisture), the tips of the capsules split along the sutures between the carpels. Ambient humidity has a clear effect on the degree of opening of the capsules. With rain or dew conditions, the capsules rehydrate and close up. When they dry again, they reopen. This continual opening and closing increases the extent of opening and can reduce the shatter resistance.

In all of the current lines, there is an opening at the top of the membrane. The seeds will begin to fall out of this opening when the capsules are inverted or shaken by wind. The angle of the top of the seed chamber and the amount of membrane opening determine the ease of the seed flow out of the chamber.

In order to improve shatter resistance in sesame, Sesaco studied the morphology of the capsules as they dried down. The starting point for the characters was published by D.G. Langham in 1956 [15]. The capsules were rated on a 0–8 scale for the following characters:

— Capsule split (TS). Extent of split between the carpels exposing the membranes but not exposing seed. This is measured from base to top of the seed chamber along the suture.
— Capsule opening (TO). Extent of opening between carpels with membranes opening enough to expose seed and/or seed chamber. This is measured from base to top of seed chamber along the placenta.
— Capsule membrane completeness (TM). Amount of missing membranes on capsule between the carpels. This does not include the membrane opening at the top of the seed chamber.
— Capsule constriction (TC). Degree of constriction of the capsule around the seeds as shown by the amount of seed remaining in the capsule after the placenta has been removed and the capsule has been inverted and twirled.
— Capsule placenta attachment (TP). Strength of placenta attachment as indicated by the amount of seed still attached to the placenta after the capsule has been inverted and twirled.

There were no lines found that had good ratings in all or most of the characters. A breeding program was initiated to combine these characters. As these were aggregated, the overall effect was measured in a hold (HLD) rating consisting of three digits each on a 0–8 scale:

— Upright seed retention (TI). Amount of seed present in the dry capsule with the capsule still remaining on the plant, measured by how close the seed is to the tip of the capsule.
— Inverted seed retention (KE). Amount of seed present in the dry capsule after the capsule has been gently removed from the plant, inverted, and twirled. Measured by how close the seed is to the tip of the capsule. The KE cannot exceed the TI.
— TO as defined earlier.

Although all three digits of HLD were important in locating parental material for breeding, the KE was the critical rating to determine the suitability for the three mechanical methods of harvest:

— Shocking: for mechanical/manual cutting, manual shocking, and mechanical combining, KE3 or better is required (and the TI should be as high as possible).
— Swathing: for mechanical swathing, leaving horizontal with no shocking, and mechanical combining, KE4 or better is required.
— Direct: for direct combining, KE6 or better is required.

The main drawback to the KE concept is that the ratings may change over time. Four stages of hold are used:

— 1st stage: when plant is first dry
— 2nd stage: 2 weeks after drydown with no adverse conditions such as wind or rain.
— 3rd stage: 1 week after exposure to brief adverse conditions.
— 4th stage: 1 month after drydown and extended exposure to adverse conditions.

Present Sesaco varieties used by farmers have sufficient KE through stage 3 as long as the winds are not severe (above 50 km/h). Development of lines that have KE6 or better at the 4th stage continues. In the fall in the South Central USA, there are years where successive storms can delay harvest 3–8 weeks.

The second drawback to the KE concept is that it is subjective. The KE on a line can vary from plant to plant and even within a plant. When there are differences between plants, the line must undergo further selection to stabilize the KE. Windy conditions can cause the lower capsules to have better KE than the upper capsules. In extreme winds, the plants bend over, the tops slap the ground, and then bend up. Thus the KE must reflect an average of the plant(s) rather than the best.

Since 1988, Sesaco KE ratings have been based on the direct combine method of harvest. Within the same line, KE ratings taken on swathed, horizontal materials are generally higher since the drydown of the plant is quicker (10–14 days versus 50–60 days), and the plants are not subjected to wind buffeting. KE ratings have never been taken for shocked, vertical materials, but it is postulated that the KE ratings would be similar to the swathed KE ratings with the TI ratings being substantially higher.

3. RECENT BREEDING STUDIES ON SHATTER RESISTANCE IN THE USA

The estimated shatter levels established in the Conclusions and Recommendations of the 1996 RCM held in Turkey [16] were:

— SUS – retains less than 10% of seeds set
— SHA – retains 10 to 50%
— NSH – retains 50 to 70%
— DC – retains 70 to 90%.

These percentages had been estimated based on Sesaco KE ratings. However, there was a consensus that there should be a quantitative method to determine that amount of shatter resistance.

In 1997 Sesaco began a project to quantify shatter resistance. Two tests were done: a "green" test was done by harvesting capsules at physiological maturity and a "dry" test was done by harvesting capsules after the plants were dry. Extensive weights and measurements were taken on the capsules using different methods to simulate natural conditions. The methodology, results, and analysis were distributed to the participants of 1998 RCM held in Thailand. The paper [17] was too lengthy to include in this document and thus was split into this paper and a second paper. The paper included 9 pages of data, 139 photographs of the capsules of all the lines tested, and graphs comparing shatter resistance to various plant and capsule characters. Additional data was in included in [18] distributed to the participants prior to the meeting.

In subgroup meetings the consensus was that quantification should be simplified and that the dry test provided the pertinent data to compare shatter resistance between sesame research programs. The following methodology is recommended:

— Between physiological maturity (the time when 3/4 of the seed is mature — the seed has attained maximum size and weight, seed color changes commence, seed line is visible, germination viable, and placenta attachment shrivels and darkens) and harvest maturity (first dry capsules), harvest 10 capsules from each line as follows: For single capsule lines, harvest 2 capsules from the adjacent nodes from 5 plants in the middle of the capsule zone. For triple capsule lines, harvest 2 capsules from the same leaf axil from 5 plants in the middle of the capsule zone. The plants should be in normal populations in the center of the rows or more than half a meter from end plants or plants at the edge of a gap, and should not be from a row on the edge of a planting block. The plants and nodes should be marked for future reference. A piece of colored yarn is a simple way of marking.
— Dry the capsules, thresh the seed, and weigh the seed. This weight becomes the Potential Seed Weight (PW).
— After the plants are completely dry, harvest 10 capsules from each plant used in the first step. The capsules should be harvested from the same nodes as the first ones. The thumb and index finger

should close the tip of the capsule to retain all of the seed. In most plants it is easier to twist the capsule off instead of pulling it off. This step depends on the type of farmer harvest methods. If the crop is shocked, the sample should be taken from the shock; if crop is swathed, the sample should be taken from the horizontal plants; if the crop is harvested direct, the sample should be taken from the plants in the field.

— Dry down all the capsules. Invert and twirl the capsules and weigh the seed that is released. This becomes the Unattached Seed Weight (UW).
— Thresh out the remaining seed in the capsules and weigh the seed. This becomes the Retained Seed Weight (RW).
— Determine the Upright Shatter Resistance (USR) — the percentage of seed held when the capsule is dry and upright. It is computed as follows: (UW + RW)*100/PW.
— Determine the Inverted Shatter Resistance (ISR) — the percentage of seed held when the capsule is dry and inverted. It is computed as follows: RW*100/PW.
— The data should include the population per square meter computed by counting the plants in a minimum 3 meter length in each of the lines where the sample capsules were taken. The data should reflect the stage of hold when the dry capsules are collected.
— Lines with active vivipary should not be included since they increase the shatter resistance by blocking the end of the capsule. Commercially this seed is also blocked in the capsule and will not be harvested.
— If a paper covers more than one harvest methodology, the USR and ISR terms should be modified as follows: SUSR and SISR for shocked, WUSR and WISR for swathed, and DUSR and DISR for direct combining.

Table I summarizes the DUSR and DISR from the data of D.R. Langham [17]. These are broken down by country of origin, the number of samples, range of DUSR, and range of DISR. The ID and GS lines are not included in the table.

TABLE I. SHATTER RESISTANCE USING DIRECT COMBINE METHODOLOGY

Country	Samples	DUSR	DISR
Afghanistan	1	49	8
China	6	15–75	0–2
India	7	0–71	0–11
Israel	3	14–81	4–16
Iraq	3	67–74	4–15
Japan	8	30–79	3–15
Rep of Korea	12	17–72	1–11
Mexico	2	51–90	6–7
Pakistan	1	70	25
Thailand	1	84	16
Turkey	2	9–66	3–6
Venezuela	2	15–79	5–18
Sesamum Foundation	3	57–88	1–25
Sesaco	83	38–100	0–99

Plant populations were not taken in lines, but the data from the yield samples shows an average population of 19.9 plants per square meter. There were 100 cm between rows. The dry capsules were taken during the 2nd stage of hold. Of the 83 Sesaco lines, 59 had a DISR of 80% or better. DISR 80 is comparable to DKE of 6. Sesaco has 4,055 lines with DKE 6 or better.

Table II summarizes the Sesaco varieties that have been released to farmers. The “Years” indicates the years the variety was grown by farmers. The “Harvest method” indicates the type of mechanization used in the harvest. Where there are two methods, the prevalent method is listed first.

TABLE II. SUMMARY OF SHATTER RESISTANCE IN SESACO VARIETIES

Variety	DUSR	DISR	Years	Harvest method
SESACO 1	100	100	82	Swathed (Indehiscent)
SESACO 2	82	1	83–87	Swathed
SESACO 3	59	12	85–86	Swathed
SESACO 4	96	88	84–87	Swathed, Direct
SESACO 5	66	21	84	Swathed
SESACO 6	89	42	84	Swathed
SESACO 7	80	38	85–88	Swathed
SESACO 8	91	48	86	Swathed
SESACO 9			85–86	Swathed
SESACO 10	78	31	88–91	Swathed
SESACO 11			88–95	Direct, Swathed
SESACO 12	76	3	86–87	Swathed
SESACO 14	89	0	89	Swathed
SESACO 15	89	79	90–91	Direct
SESACO 16	90	82	91–96	Direct
SESACO 17	100	95	93–98	Direct, Swathed
SESACO 18	100	95	94–96	Direct
SESACO 19	78	73	94–95	Direct
SESACO 20	100	88	95–97	Direct
SESACO 21	100	89	95–98	Direct, Swathed
SESACO 22	100	94	97–98	Direct, Swathed
SESACO 50	87	24	86	Shocked
SESACO 51	79	10	86	Shocked
SESACO 52	78	0	86	Shocked

The study distributed to the RCM participants graphed the distribution of shatter resistance to various capsule and plant characters. In those graphs, the shatter resistance was an average of the green capsule shatter resistance and the DUSR and DISR. Table III summarizes the correlations between the DISR and the characters. The table also provides minimum and maximum values for all characters from two groups, lines where DISR>80 and all lines combined.

TABLE III. CORRELATIONS BETWEEN DISR AND PLANT CHARACTERS

Character	Correlation of DISR to character	DISR >80% Minimum	DISR >80% Maximum	All DISR Minimum	All DISR Maximum
Seed weight per capsule	0.221	1.5	2.8	1.4	3.1
Empty capsule weight	0.087	0.9	2.0	0.8	2.3
Capsule length	–0.122	1.8	2.9	1.5	3.6
Capsule width 1	0.103	0.6	0.8	0.6	0.9
Capsule width 2	0.179	0.8	1.1	0.6	1.1
Capsule volume	–0.067	0.7	1.9	0.7	2.3
g per 1000 seeds	0.050	2.5	4.0	2.4	4.7
Seeds per capsule	0.308	52	85	47	89
Branching		None	many	none	Many
Capsules per axil		1	3	1	3
Physiological maturity	0.167	96	116	88	127
Plant height	0.212	113	168	60	175

As can be seen, DC shatter resistance has been transferred to large ranges of characters. It is anticipated that it could be moved to the full extent of the ranges, if desired. However, within the Sesaco breeding program, there are no objectives to extend the ranges with the exception of earlier physiological

maturity, lower plant height, and higher grams per 1000 seeds. It is not believed that any of the correlations are significant. The high correlations between DISR and seed weight per capsule and seeds per capsule are a reflection of high Sesaco selective pressure for high values in these characters. There are many shattering lines with high seed weight per capsule and seeds per capsule. Shatter resistance can be genetically moved to most shattering lines. There are a few exceptions that are termed "hold destroyers." These lines have been crossed numerous times with several high DISR lines with no resulting shatter resistant progeny. These "hold destroyers" do not have any unique capsule or plant characters that should have an effect on shatter resistance. However, they must possess a gene(s) that disrupts the union of shatter-resistance characters.

Based on the quantification, it is recommended that the shattering types be defined as follows:

— Super-shattering (SUS) – less than 10% SISR at stage 1
— Shattering (SHA) – 10 to 50% SISR at stage 1
— Non-shattering (NSH) – 50 to 80% WISR at stage 1
— Direct combine (DC) – greater than 80% DISR at stage 1
— Indehiscent (ID) – id/id genotype, retains all seeds
— Indehiscent open (IDO) – id/id genotype with some opening of the capsule
— Seamless (GS) – gs/gs genotype, retains all seeds
— Seamless open (GSO) – gs/gs genotype with some opening of the capsule.

4. CONCLUSIONS

There is a need to be able to quantify shatter resistance in order to be able to communicate between sesame breeding programs. Recently, researchers have declared that shatter resistance has been developed in their programs. Improvements in shatter resistance are relative within a specific program. For example, Sesaco has improved its shatter resistance each year, and still for the USA methods of harvest, further improvements are necessary to allow for better retention in adverse weather. This paper presents a methodology for quantifying shatter resistance so researchers can compare levels of shatter resistance between programs. A system of TI and KE should be used to subjectively evaluate the shatter resistance for initial screening of materials. Lines with desired TIs and KEs can then be subjected to quantification using USRs and ISRs. Both the subjective and quantitative systems should determine the amount of shatter resistance for the appropriate harvest method: shocking, swathing and leaving horizontal, or direct combining. The following terms can be used:

Harvest method	Subjective	Quantified
Shocking	STI/SKE	SUSR/SISR
Swathing/horizontal	WTI/WKE	WUSR/WISR
Direct	DTI/DKE	DUSR/DISR

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BREEDING FOR MECHANISED SESAME PRODUCTION IN AUSTRALIA

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Abstract

Introduction of sesame germplasm from Myanmar and Mexico was not satisfactory for successful development of the Australian sesame industry. Therefore, a national breeding programme was undertaken by CSIRO and the Northern Territory Department of Primary Industry and Fisheries (NTDPIF). The main traits considered for selection were latitudinal adaptatioin, temperature response, growth habit, determinacy, palatability, capsules per leaf axil, seed shattering and seed dormancy. The CSIRO breeding efforts started in 1989 with a hybridization programme using germplasm from Japan, Mexico, Myanmar, Rep. of Korea and Venezuela. This programme resulted in selection in the F_6 generation of branched types released under the names 'Beech's choice' and 'Aussie Gold'. The NTDPIF sesame breeding programme started in 1993 with hybridization of introductions. The Mexican cultivar 'Yori 77' was selected for release, and after several years of intraline selection the uniculm cultivar 'Edith' was released in 1996. Further breeding continues to improve seed retention and resistance to charcoal rot.

1. INTRODUCTION

Agronomic and variety evaluation trials in the period 1979–1982 showed that sesame could be satisfactorily grown in Australia [1]. The Burmese (Myanmar) cultivars, Hnani 25/160 and Hnan Dun, with few upright basal branches, had the best growth habit (Fig. 1c). Hnani 25/160 had better seed retention than Hnan Dun. Unfortunately, the seed quality of these cultivars was substantially inferior to that of the Mexican cultivars being traded in the world market, the seed being smaller and of undesirable colour (off white for Hnan Dun and brown for Hnani 25/160).

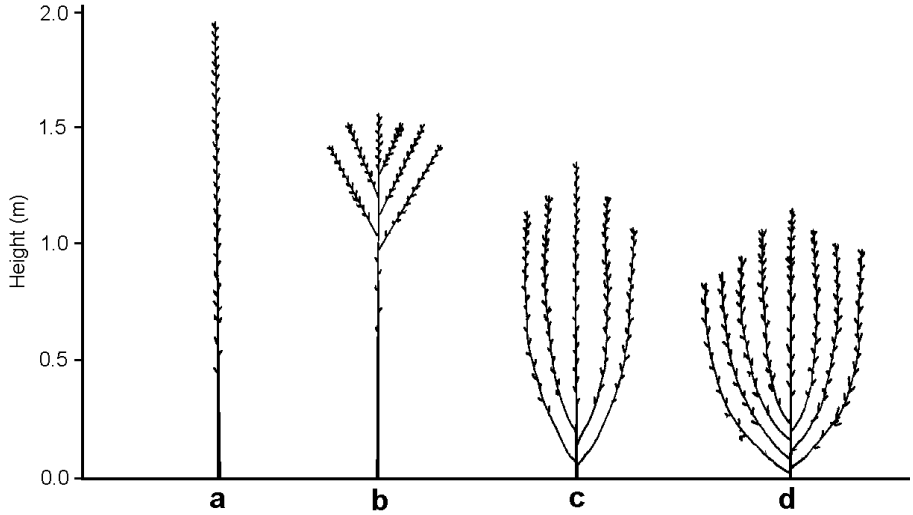

FIG. 1. Schematic diagram of sesame growth habits.

The Mexican cultivars were unadapted to mechanised production, being uniculm (Fig 1a), too tall (up to 2.5 m), prone to uneven maturity and to severe seed shattering. Another serious disadvantage of the Mexican cultivars was their susceptibility to phyllody, caused by a mycoplasma, when the insect vector of the latter was present in the production area.

In order to establish a successful sesame industry in Australia, there was an obvious need to combine the desirable features of the Burmese and Mexican cultivars by breeding. A breeding program would also need to produce varieties for the wide range of latitudes (14°S to 36°S) where sesame could be grown in Australia, particularly higher latitudes where climatic conditions were less variable and farmers were better resourced [2]. It was on this basis that a breeding program was undertaken by CSIRO with the support of Sesame Australia. Breeding with a more regional focus was also conducted by the Northern Territory Department of Primary Industry and Fisheries (NTDPIF). These programs are described in this paper.

2. TRAITS FOR SELECTION

Based on literature reports and observations on field trials a number of desired traits for incorporation in varieties for mechanised production was determined (Table I).

TABLE I. SELECTION CRITERIA FOR SESAME CULTIVARS SUITABLE FOR MECHANISATION.

Plant part	Selection criteria
Whole plant	Erect with few basal branches
	Growth cycle of 100-110 days
	Climatic adaptation: Drought tolerance
	Photoperiod insensitivity
	Cold tolerance (low base temperature)
	Low heat unit requirement (high latitude)
	Require >2500°C heat sum (low latitude)
	Resistance to phyllody
	Tolerance to pests and diseases
	Uniform leaf abscision
Seedling	Rapid germination over a wide temperature range
	Rapid seedling emergence
	Long radicle length for drought avoidance during establishment
Capsule	Single capsule per leaf axil
	Long narrow capsule with deep indent at top
	Synchronous maturation
	Good seed retention
Seed	White colour
	Size >3.2 g/1000 seeds
	Oil content > 54%
	Palatable with no distasteful flavours
	Easy to decorticate
	High content of anti-oxidants
	Dormancy > one month

Latitudinal adaptation. Few cultivars with broad adaptation are preferred to assist establishment of an industry. Photoperiod insensitivity (day neutrality) enables production over a wide range of latitudes and also flexibility of sowing date. There is substantial variation in photoperiod response in sesame, with selection for insensitivity being achieved by growing successive generations in summer in south east Queensland (27° latitude) and in winter in north Queensland (19° latitude).

Temperature response. Cultivars for higher latitudes need cool temperature tolerance (a low base temperature) for germination in cool soil and a low heat unit requirement to complete their life cycle. This trait occurs in Korean cultivars [3] such as Suweon 21 and Kwangsang used in our breeding program.

Growth habit. The shorter stature, branched habit (Fig 1c) is preferred for mechanised harvest. Plants with this habit are generally more even in maturity and their stems have a smaller diameter and are easier to cut than those of uniculm plants. Also, shorter stems feed through a harvester more easily than long stems. Selection for this trait is simple and it was available in the Burmese cultivars.

Determinacy. Indeterminate cultivars are better able to maximise yield over time where climatic conditions vary greatly from year to year, as in Australia, because they fully use available water. Conversely, determinate cultivars may yield better in dry years but in wet years they tend to remain green, and may produce secondary growth. In wet years chemical desiccation is less effective and mechanical harvesting impossible.

Plant and seed palatability. Although low palatability due to chemical compounds in plant vegetation can provide tolerance to insects, the same compounds occur also in seed where they can make the seed useless for tahini manufacture and of reduced value for other products. Selection for high palatability is essential to ensure marketability.

Capsules per leaf axil. Either one or three capsules can occur in each leaf axil. Under rainfed conditions in Nigeria and in a world survey, van Rheenen [4] found no relationship between number of capsules and seed yield. For crops grown free of water and nutrient stress, higher yields could be expected from three capsules per axil because of a greater 'sink' capacity. In Australia where most crops are grown dryland and water stress frequently occurs due to highly unreliable rainfall, it has been observed that multi-capsule cultivars have small seed and a high percentage of immature seed. The potential for irrigated sesame production is low because the crop cannot compete economically with alternatives such as cotton and soybean. Also, when sesame precedes cotton in a rotation, volunteer sesame plants in the cotton crop pose an unwelcome weed problem.

Shattering. Seed loss during mechanised harvesting can be a serious problem [5,6,7,8]. Use of indehiscent cultivars has proven unsatisfactory because of excessive seed damage, which leads to low germinability and high free fatty acid content [9], during the harvest process. An alternative approach, followed in Australian programs is to select for good seed retention within dehiscent capsules.

Seed dormancy. This trait is important, particularly for higher latitudes in Australia where maturing crops may be subjected to autumn showers. Dormancy protects seed from premature sprouting and quality deterioration and is thus essential for commercial reasons. Dormancy which occurs in Hnani 25/160 was used in the breeding program. Dormancy can be broken, when required, by heat treatment — 10 minutes at 60°C or 20 minutes at 50°C. Breaking dormancy is necessary in a breeding program when rapid generation turnover is planned.

3. CSIRO BREEDING PROGRAM

The program objective was to breed cultivars with a growth habit suited to mechanised harvest, 100–110 days crop duration, drought tolerance, photoperiod insensitivity, resistance to diseases, low shattering loss and high quality seed. While the primary aim was to develop cultivars able to produce economic yields when grown dryland, it was also desired that the material be responsive to irrigation and fertilisation. Details of the breeding program (outlined in Table II) and results achieved are described below.

Parental selection was made on the basis of origin and desired traits in order to include adaptation to a wide range of latitudes and to include material with both preferred agronomic characteristics and high seed quality. From a collection of 350 accessions, 18 cultivars were selected as parents (Table III). Mexican and Venezuelan cultivars had good seed quality and low latitude adaptation, Japanese and Korean cultivars provided adaptation to high latitudes whilst cultivars from the dry zone of Burma had the preferred plant type, drought tolerance and resistance to phyllody.

TABLE II. CSIRO SESAME BREEDING PROGRAM*

1989		Hybridisation in glasshouse (211 crosses)
1989–90	F_1	181 crosses grown at Lawes
1990	F_2	36 populations grown at Lansdown
1990–91	F_3	1990 populations grown at Dalby
1991	F_4	332 lines grown at Lansdown
1991–92	F_5	106 lines at Narrabri, Lawes, Biloela
1992–93	F_6	16 lines at Narrabri, Pittsworth, Biloela, Katherine
1992	F_7	2 lines for Plant Variety Rights (PVR) registration
1993		PVR granted on Aussie Gold and Beech's Choice

* Latitude of test sites indicated in text.

TABLE III. PARENT CULTIVARS USED IN THE HYBRIDISATION PROGRAM AND THEIR ORIGINS

Mexico	**Venezuela**	**Burma**
Instituto 15	Aceitera	Hnani 25/160
CIANO 27	Capsula larga	Hnan Dun
Yori 77		
Pachequeno		
Pachequeno selection	**Korea**	**Japan**
Teras 77	Kwangsang	Line 724
Cola de Borrego	Suweon 21	
Regional Canastra		
Regional Padilla Selection		
Anne		
Eva		

A total of 211 hybridisations produced 181 successful crosses. Hybridisations with Mexican cultivars as the female were mostly unsuccessful. When seed was set from crosses between Yori 77 and Burmese and Korean cultivars it was sterile.

All F_1 families and parents were grown in the field at Lawes (27°34'S) and of these, 36 were selected for advancement to F_2 following selection for phenology, growth habit and tolerance of phyllody. Hybrids with nil or minimal branching were highly susceptible to phyllody and all progeny of the Japanese line 724 were 100% susceptible.

F_2 populations were grown in an irrigated dry season nursery at Lansdown (19°36'S) where maturity ranged from 122 to 148 days. Single plants (1940) were selected on the basis of growth habit and white seed for advancement to F_3.

The F_3 lines were grown at Dalby (27°11'S) in an irrigated nursery sown in December 1990. Field selection of single plants within lines was for growth habit, maturity, seed retention, seed colour and flavour. 900 plants were harvested and further selection applied for seed yield, size and oil content and small floral nectaries[1] which reduced the number of lines advanced to F_4 to 332. Of these lines, 210 were germination tested at ten temperatures from 10 to 50° to identify lines with a low base temperature for growth. Of the 332 F_4 lines, 221 (66%) were derived from the cross Hnan Dun x Suweon 21 and its reciprocal.

[1] It was found that crosses between lines with a single capsule per axil and lines with three capsules per axil produced progeny with large floral nectaries. During threshing the nectaries separate from the stem and mix with the seed. Because of similarity in size they are difficult to separate from the seed and are thus a contaminant. Consequently, lines with large nectaries are commercially unacceptable.

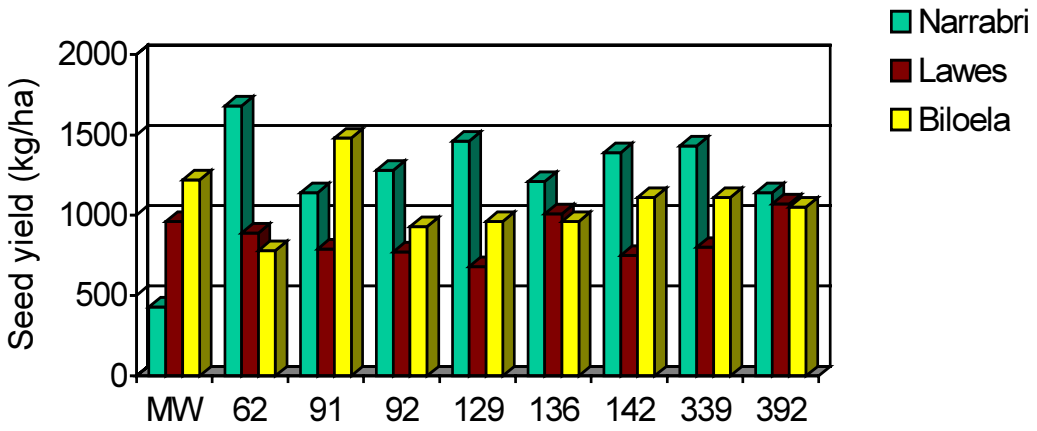

FIG. 2. Seed yield (kg/ha) of eight F_5 lines and cv. Magwe White grown at three locations.

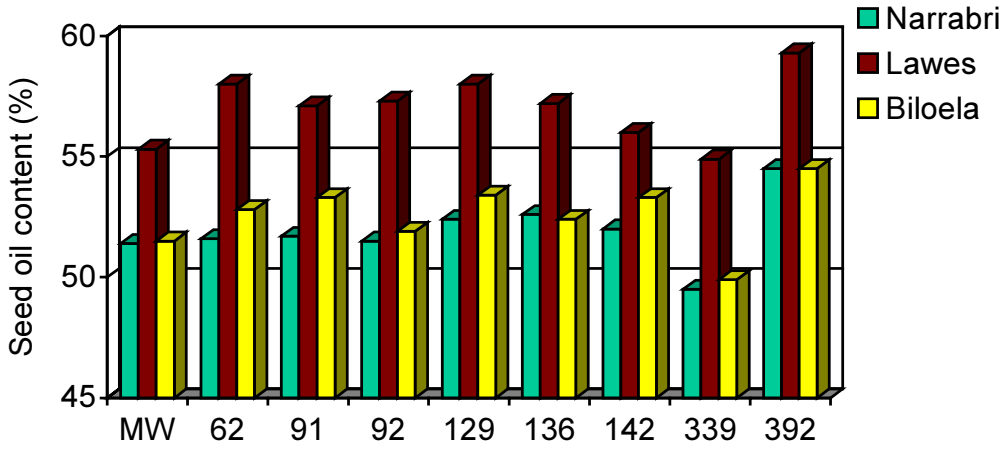

FIG. 3. Seed oil content (%) of eight F_5 lines and cv. Magwe White grown at three locations.

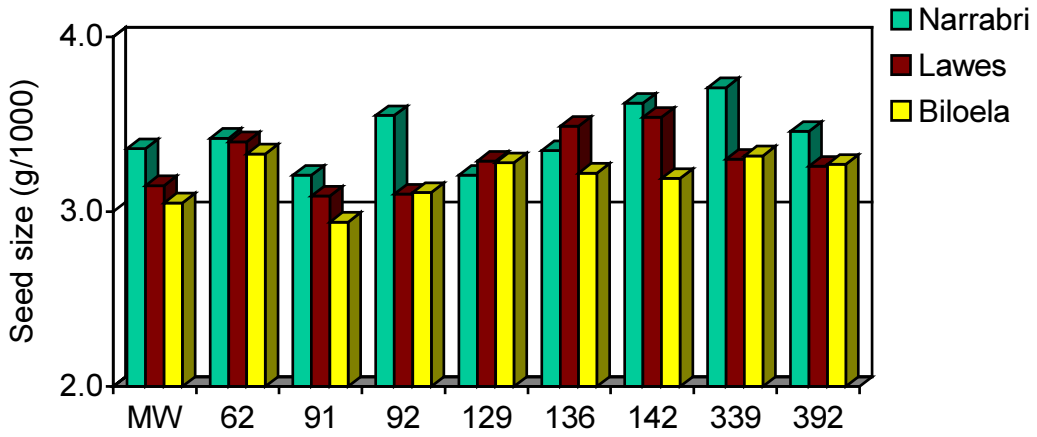

FIG. 4. Seed size (g/100 seeds) of eight F_5 lines and cv. Magwe White grown at three locations.

The F_4 generation was grown during the dry season at Lansdown and selected for establishment under low temperature, growth habit, plant height, seed yield and quality. Selection for broad adaptation was based on F_3 and F_4 maturity times; 106 lines were advanced to the F_5 generation.

Regional adaptation and the level of genotype X environment interaction were assessed in F_5 from trials grown at Lawes, Biloela (24°24'S) and Narrabri (30°13'S). Large differences between sites were recorded for seed yield, size and oil content (Figs 2–4). Seed yield was highest and oil content was low at Narrabri because of the high fertility of the soil. Conversely, seed oil content was high at Lawes with line 392 exceeding 59%. Selection reduced to 16 the number of lines advanced to F_6.

Further regional evaluation occurred in the F_6 generation with trials at Narrabri, Pittsworth (27°43'S) and a low latitude site at Katherine (14°23'S). Lines 91 and 339 were selected for release as Beech's Choice and Aussie Gold, respectively. Aussie Gold has been grown in Australia, Burma and Saudi Arabia whilst Beech's Choice is now being tested in Burma.

Concurrently with the above selection program, a series of crosses (Table IV) was made between F_2 plants to generate further recombination of genes controlling seed size, oil content and crop growth rate. Of 33 F_1 hybrids grown at Lansdown in 1991, 20 were advanced to F_2 and 18 to F_3. The crosses (Suweon 21 x CIANO 27) x (Suweon 21 x Hnani 25/160) and (Hnan Dun x Suweon 21) x (Suweon 21 x Hnani 25/160) provided more than half of the lines selected. Seed from F_3 lines was assessed for quality in Japan where it was favourably received. However, the breeding program was suspended due to lack of funds.

TABLE IV. PEDIGREES OF SECOND CYCLE CROSSES AND NUMBER OF PLANTS SELECTED FOR ADVANCEMENT TO THE F_3 GENERATION.

Female parent		Male parent		No. plants
Plant	Pedigree	Plant	Pedigree	Selected
29-170	Hnan Dun/ Suweon 21	29-167	Hnan Dun/ Suweon 21	0
29-167	Hnan Dun/ Suweon 21	29-296	Hnan Dun/ Suweon 21	1
160-26	Suweon 21/ CIANO27	78-41	Suweon 21/ Hnani 25/160	5
29-84	Hnan Dun/ Suweon 21	29-167	Hnan Dun/ Suweon 21	0
29-84	Hnan Dun/ Suweon 21	78-4	Suweon 21/ Hnani 25/160	2
78-85	Suweon 21/ Hnani 25/160	35-299	Hnan Dun/ Teras 77	0
29-80	Hnan Dun/ Suweon 21	78-85	Suweon 21/ Hnani 25/160	1
29-167	Hnan Dun/ Suweon 21	78-4	Suweon 21/ Hnani 25/160	0
29-209	Hnan Dun/ Suweon 21	78-11	Suweon 21/ Hnani 25/160	6
29-167	Hnan Dun/ Suweon 21	29-165	Hnan Dun/ Suweon 21	0
29-135	Hnan Dun/ Suweon 21	78-109	Suweon 21/ Hnani 25/160	3
29-296	Hnan Dun/ Suweon 21	160-26	Suweon 21/ CIANO27	0

4. NORTHERN TERRITORIES BREEDING PROGRAM

Initially, in the NTDPIF program a collection of introduced accessions was evaluated and the Mexican cultivar Yori 77 selected for release. Pachequeno was also considered well adapted [5,6]. Yori 77 was genetically variable and suffered high seed losses in commercial production so a program of intraline selection for improved growth, seed yield and seed retention was undertaken leading to the release of the uniculm cv. Edith in 1996.

To further improve seed retention, a backcrossing program was commenced in 1993–94 to incorporate the good seed retention of Hnani 25/160 into Edith (Table V). BC_3S_2 lines are currently being assessed in field trials. Because of problems experienced with hybridisation of Mexican cultivars and the high temperatures experienced at Katherine, modified crossing techniques were developed to facilitate this backcross program. Initially, the corolla and stamens of the female flower

were wholly removed and the subtending leaf excised at about the length of the pistil. The stigma was pollinated and leaf and pistil inserted into a section of drinking straw. A 75% success rate was achieved. Further improvement to 85% success was achieved by leaving the corolla in place and removing anthers and effecting pollination through an incision in the side of the corolla.

TABLE V. NTDPIF SESAME BREEDING PROGRAM, KATHERINE

1993–94		Hybridisation in glasshouse (233 crosses)
1994	F_1	171 crosses grown, backcrossed to cv. Edith
1994–95	BC_1	4 populations
1995	BC_1S_1	backcrossed to Edith
1995–96	BC_2	
1996	BC_2S_1	backcrossed to Edith
1996–97	BC_3	
1997	BC_3S_1	selfed with selection
1997–98	BC_3S_2	selection in field

5. DISCUSSION AND CONCLUSIONS

Progress was made in the development of cultivars for mechanised production in Australia. Beech's Choice and Aussie Gold have a branched growth habit, adaptation to a range of latitudes and high seed quality. But further research and breeding are required to improve seed retention and resistance to charcoal rot disease (*Macrophomina phaseoli*) which causes premature plant death and consequent yield loss when crops mature under drought stress.

Hnani 25/160 has featured prominently in both Australian breeding programs and in the Khon Kaen University program in Northeast Thailand. A selection from Hnani 25/160 has been released in Thailand as KKU3 [10]. Whilst Hnani 25/160 has good seed retention, the strong adherence of the seed to the septum is not entirely suitable for mechanised production as seed remains attached during threshing and may be lost through the back of the header. Variation in the level of seed retention has been observed in Hnani 25/160 and may be retrievable in progeny of hybrids with that cultivar as a parent. An ideal mechanism would be strong attachment of the uppermost seed which would provide a barrier to loss of detached seeds from the capsule. Mechanisms of seed retention are under study [11].

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SESAME MUTATION INDUCTION: IMPROVEMENT OF NON-SHATTERING CAPSULE BY USING GAMMA RAYS AND EMS

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Abstract

Improvement of non-shattering capsule by using gamma rays and EMS in the Kasetsart University Sesame Breeding Project has been carried out since November 1994. Seed treatments with gamma rays (500 Gy) and EMS (0.5 and 1.0%, 4 hrs) were used. Growth characteristics, delayed shattering and shatter resistance of capsule were investigated in M_2 through M_8 lines. The seed yield of thirty promising M_7 lines was evaluated in April 1997 at Suwan Farm, Pakchong , Nakorn Ratchasima. Most of the tested lines gave higher seed yields than the check variety, MK 60. M 6026 gave the highest seed yield (1,477 kg/ha). All the tested mutant lines had a longer period of growth during flowering (GF). However, three promising lines had a shorter flowering period (FP) and a degree of stem termination (DST) when they were planted both in April and August 1997. Based on the criteria of determinate growth studied, these mutant lines would be classified as having a determinate growth habit. Delayed shattering and shatter resistant capsule were obtained. It is noted that the promising mutant lines were obtained from EMS treatment. Thus, the study of these mutant lines revealed that the improvement of sesame by mutation breeding for reduced seed losses before or during the harvest can be successful.

1. INTRODUCTION

Yield potential in sesame can be substantially reduced due to capsule shattering or uneven capsules' ripening. Thus, breeding sesame varieties for shatter resistance is considered important in improving seed yield of sesame.

It has been generally agreed and recommended by FAO Expert Consultations that it is very important to develop sesame varieties which retain their seeds. The types of capsules with better seed retention are those that have indehiscence, strong placentation, limited tip opening, pinched capsule tips, delayed shattering, and upright capsules [1]. Also, development of uniform capsule maturation is required [2]. At present the commercial sesame cultivars have indeterminate growth habit with capsule shattering.

The Sesame Breeding Project of Kasetsart University has developed determinate sesame since 1988 by using determinate sesame lines which were developed by Ashri in 1981 [3]. Some promising determinate lines of our project gave a shorter flowering period of approximately 17 days. But these lines have shattering capsules. The project has been trying to improve sesame varieties for resistance to shattering since 1991 by using the indehiscent lines (*id/id*) of Yermanos. Sesame lines with delayed shattering were obtained from this program [4]. However, these delayed shattering lines have only black seed, single stem and low seed yield.

In November 1994, the Kasetsart University Sesame Breeding Project has proposed to use gamma rays and EMS induce capsule non-shattering. In addition, since October 1995, the project has included gamma rays treatment of F_1 seeds of the promising crosses from the experiment of breeding for delayed shattering and two indehiscent lines for improving non-shattering and high seed yield.

Due to the infection by bacterial leaf spot, *Pseudomonas syringae* pv. *sesami* and *Xanthomonas phaseolina* pv. *sesami* of the sesame lines in our project since 1995, the work of the project has been focused on this problem in 1997.

2. MATERIALS AND METHODS

2.1. Experiment 1: Improvement of non-shattering capsule by using gamma rays and EMS

Thirty M_7 lines lines were selected for testing their yielding ability and investigated for growth characteristics in April 1997. MK 60, the recommended variety of the Department of Agriculture was used as standard check. Based on shatter resistance and the plant having 1, 2 or 3 capsules at the top of stem, nineteen M_8 lines were selected for yield trial in August 1997. MK 60 and KU 18 were used as check varieties. M_7 and M_8 lines were grown in 4 rows of 4m with spacing of 50 x 10 cm in a randomized complete block design with four replications, at Suwan Farm, Pakchong, Nakorn Ratchasima.

Streptomycin at 50 ppm was used for control bacterial leaf spot. The seeds of these lines were soaked with streptomycin for 30 minutes before planting and the plants were sprayed with it at the flowering stage and subsequently at 14 days intervals until maturity [5].

The growth characters studied were modified from Foley et al. [6] and Lin and Nelson [7] are listed in Table I.

TABLE I. DEFINITION OF GROWTH CHARACTERS STUDIED

BF	– Date of beginning flowering. When 50% of the plants have at least one flower.
FP	– Flowering period. The number of days from beginning of flowering to the terminal flowering.
HTBF	– Height at beginning flower. Height, in cm, to the terminal node.
NOBF	– Number of nodes on the main stem at beginning of flowering.
TF	– Date of terminal flowering. When 50% of the plants have at least one flower on the main stem.
HTTF	– Height at terminal flowering. Height, in cm, to the terminal node.
NOTF	– Number of nodes on the main stem at terminal flowering.
DST	– Degree of stem termination. The increase in number of observable nodes on the main stem after beginning flower, (NOTF-NOBF).
GF	– Growth during flowering. (HTTF-HTBF).
HTM	– Height at harvest. Height, in cm, to the terminal node.

In classifying stem termination the GF values were used as follows:

GF <20 cm = determinate growth habit
GF ranged from 21–40 cm = semi-determinate growth habit
GF >40 cm = indeterminate growth habit.

The shatter characteristics investigated were delayed shattering and shatter resistance. Measurement of delayed shattering was done after all the capsules of the plant were ripe. Delayed shatter is assessed by the number of days that elapse from the first capsule's maturation until it splits. The shatter resistance is classified by using the concept of D.R. Langham (personal communication). The method for measuring shatter resistance on a 0–8 scale is as follows:

TI = 0–8 scale the amount of the seed in the capsule when it is upright
KE = 0–8 scale the amount of seed in the capsule when it is inverted
TO = on 0–8 scale the extent of opening of the capsule.

2.2. Experiment 2. Use of gamma ray to induce mutation in F_1 seeds and indehiscent lines to improve shatter resistance

F_1 seed of the four crosses of KKU1 x KUns 7018, KKU1 x KUns 7005, KUur 8012 x KUns 7014 and RS 6054 x KUns 7014 and two indehiscent lines (UCR 5010 and KU# 4) were treated with gamma rays at doses of 300 and 400 Gy.

M_1 seeds of these materials were grown in March 1996 at the greenhouse of Agronomy Department, Kasetsart University.

12 M_2 populations were sown in plots of 10 4m long rows, in spacings of 50 x 10 cm, in December 13, 1996. Each M_2 population consisted of approximately 400 plants. Selection has been done in M_2 and in successive generations. Pedigree selection was employed. Selection criteria were based on shatter resistance, resistance to bacterial leaf spot and good agronomic characteristics. Streptomycin was used to control bacterial leaf spot with the same procedure as in Experiment 1, in the M_3 and M_4 lines.

302 M_3 lines and one hundred and fifty M_4 lines were planted in April 21, and August 21, 1997 respectively. The M_2 through M_4 generations were grown at Suwan Farm, Pakchorg, Nakorn Ratchasima Province.

3. RESULTS AND DISCUSSION

3.1. Experiment 1

3.1.1. Seed yield

The data of seed yield reported in this paper were obtained from the April 1997 growing season. There was much damage from diseases in August 1997, so it was not possible to harvest seed yield. However, the growth characteristics of the plants in this experiment were recorded. Seed yield of the tested M_7 lines ranged from 915 to 1,477 kg/ha. Most of mutant lines had higher yields than the check variety. Most of tested lines had larger seeds than MK 60.

Days to flowering of these lines were similar except M 6027 and M 6045 which had longer flowering periods of 45 and 48 days, respectively. Mean seed yield and some agronomic characters of fifteen promising M_7 lines are shown in Table II.

TABLE II. MEAN SEED YIELDS AND SOME AGRONOMIC CHARACTERS OF FIFTEEN PROMISING MUTANT LINES (M_7) GROWN AT SUWAN FARM IN APRIL 1997

Line	Pedigree	Yield (kg/ha)	No. capsules/ plant	No. days to flower	No. days to maturity	No. nodes/ plant	Plant height (cm)	Wt. 1000 seeds (g)
M 6026	RS 6032-6-1	1,477	55	39	109	31.0	164	2.80
M 6045	KUur 7014-1-1	1,370	59	48	116	39.1	165	3.35
M 6017	RS 80001-4-1	1,362	56	33	116	30.4	134	3.20
M 6020	RS 6032-1-1	1,352	56	30	112	35.3	140	3.00
M 6039	RS 6028-5-2	1,352	54	32	108	30.3	126	3.20
M 6001-1	RS 8001-1-1-2	1,337	55	32	96	37.2	147	3.08
M 6027	RS 6032-6-2	1,327	63	45	110	32.9	174	2.50
M 6015	RS 8001-3-6	1,277	62	32	108	31.2	132	3.23
M 6006-1	RS 8001-1-6-1	1,243	52	32	102	33.6	142	3.15
M 6006-2	RS 8001-1-6-2	1,205	55	33	98	33.6	141	2.55
M 6041	RS 6028-5-3-2	1,202	56	33	103	35.5	142	3.03
M 6005	RS 8001-1-1-5	1,160	54	34	96	33.2	154	2.98
M 6010	RS 8001-2-6	1,157	57	33	109	28.8	127	3.05
M 6011	RS 8001-2-7	1,125	61	37	106	29.2	137	3.40
M 6013	RS 8001-3-1-1	1,115	57	32	108	32.8	134	3.43
MK 60	Check	1,031	56	32	110	32.4	123	2.82
LSD (0.05)		321	NS	NS	NS	NS	10.2	-
LSD (0.01)		-					13.6	-
C.V. (%)		18.16	13.16	5.509	10.14	9.30	10.68	14.62

3.1.2. Growth habit

In investigating the growth characteristics of thirty M_7 lines, it was found that all M_7 lines grew longer during flowering (GF). It ranged from 63 to 119 cm. Based on the GF value, all tested lines were classified as indeterminate. The range of flowering period (FP) was 18 to 31 days. Most of mutant lines had longer FP. However, there were three lines, M 6027; M 6026 and M 6064, that gave shorter flowering period at 18, 19 and 19 days, respectively.

Mean values of the growth characteristics of 15 promising lines are shown in Table III.

TABLE III. MEANS OF DAYS TO BEGINNING - (BF) AND TERMINAL - FLOWERING (TF), HEIGHT AT BEGINNING FLOWERING (HTBF), NODES AT FIRST - (NOBF) AND AT TERMINAL FLOWER (NOTF), HEIGHT AT TERMINAL FLOWER (HTTF), FLOWERING PERIOD (FP), DEGREE OF STEM TERMINATION (DST) AND GROWTH DURING FLOWERING (GF) OF 15 PROMISING MUTANT LINES GROWN AT SUWAN FARM IN AUGUST 1997

Line	BF	TF	HTBF	NOBF	NOTF	HTTF	FP	DST	GF
	(No. of days)		(cm)			(cm)	(days)	(nodes)	(cm)
M 6026	39	58	81	16.6	31.0	164	19	14.4	83
M 6045	48	72	84	14.3	39.1	165	24	24.8	81
M 6017	33	58	51	10.3	30.4	134	25	20.1	83
M 6020	30	58	52	9.6	35.3	140	28	25.7	88
M 6039	32	58	39	9.2	30.3	126	26	21.1	87
M 6001-1	32	58	44	8.9	37.2	147	26	28.3	103
M 6027	45	63	94	13.5	32.9	174	18	19.4	80
M 6015	32	55	48	8.7	31.2	132	23	22.5	84
M 6006-1	32	63	45	8.7	33.6	142	31	24.9	97
M 6006-2	33	63	44	8.4	33.6	141	30	25.2	97
M 6041	33	58	54	10.1	35.5	142	25	25.4	88
M 6005	34	58	55	10.8	33.2	154	24	22.4	99
M 6010	33	58	43	9.5	28.8	127	25	19.3	84
M 6011	37	58	45	9.2	29.2	137	21	20.0	92
M 6013	32	58	46	9.9	32.8	134	26	22.9	88
MK 60 *	32	58	38	8.0	26.0	123	26	18.0	85

* Indeterminate growth habit.

Means of the growth characteristics of nineteen M_8 lines are shown in Table IV. Flowering period (FP) of the tested lines ranged from 21 to 33 days. Most of these lines gave shorter FP than the check varieties. M 6026 and M 6027 still gave shorter flowering period than other lines. It had flowering period of 21 and 24 days, respectively. But it was 2 and 6 days longer compared to growing in April.

Growth during the flowering period (GF) of these M_8 lines exceeded 40cm. Thus, all tested lines were classified into indeterminate growth habit as in the growing season in April. But most of them gave shorter GF than the check varieties. Similar results were obtained in degree of stem termination.

To understand the determinacy of nineteen mutant lines the growth characteristics in two growing seasons were compared, in April and August 1997. Three characters including flowering period (FP), stem termination or growth during flowering (GF) and degree of stem termination (DST) used for identifying determinate growth habit are shown in Table V.

TABLE IV. MEANS OF CHARACTERS OF NINETEEN SELECTED MUTANT LINES GROWN AT SUWAN FARM IN AUGUST 1997

Line	BF	TF	HTBF	NOBF	NOTF	HTTF	FP	DST	GF
	(No. days)		(cm)	(No. of nodes)		(cm)	(days)	(nodes)	(cm)
M 6001-1	30	59	39	6.4	25.5	101	29	19.1	62
M 6005	26	59	45	8.2	26.4	130	33	18.2	85
M 6006-1	31	60	44	8.2	34.7	120	29	26.5	76
M 6006-2	30	59	40	6.9	33.5	119	29	26.6	79
M 6008	30	59	40	6.9	28.6	98	29	21.7	58
M 6009	30	60	44	8.0	32.8	111	30	24.8	67
M 6012	29	58	44	7.4	29.1	94	29	21.7	50
M 6013	30	59	45	7.5	30.3	106	29	22.8	61
M 6016	30	60	41	7.3	31.8	106	30	24.5	65
M 6020	29	57	42	6.9	35.2	112	28	28.6	70
M 6022	30	59	38	7.1	33.9	92	29	26.8	54
M 6026	39	60	59	10.1	30.4	134	21	20.3	75
M 6027	36	60	60	10.3	31.7	143	24	21.4	83
M 6029	30	59	42	7.0	31.6	118	29	24.6	76
M 6030	29	58	40	7.5	29.7	97	29	22.2	57
M 6066	30	59	36	7.2	32.6	105	29	25.4	69
M 6067	29	59	47	7.8	28.4	109	30	20.6	62
M 6068	30	59	31	6.8	31.6	103	29	24.8	72
M 6070	31	60	39	6.5	27.7	107	29	21.2	68
MK 60 (check) *	30	61	52	8.8	36.6	134	31	27.8	82
KU 18 (check) *	30	62	51	8.6	40.2	140	32	31.6	89

* Indeterminate growth habit.

TABLE V. MEANS OF FLOWERING PERIOD (FP), GROWTH DURING FLOWERING (GF) AND DEGREE OF STEM TERMINATION (DST) OF NINETEEN SELECTED MUTANT LINES GROWN AT SUWAN FARM IN APRIL AND AUGUST 1997

Lines	FP (No. of days)		GF (cm)		DST (No. of nodes)	
	April	August	April	August	April	August
M 6001-1	26	29	103	62	28.3	19.0
M 6005	24	33	99	85	22.4	18.2
M 6006-1	31	29	97	75	24.9	26.4
M 6006-2	30	29	97	79	25.2	26.6
M 6008	30	29	81	57	21.6	21.6
M 6009	30	30	104	67	30.9	24.8
M 6012	20	29	75	50	19.2	21.6
M 6013	26	29	88	60	22.9	22.8
M 6016	23	30	89	64	21.2	24.4
M 6020	28	28	88	70	25.7	28.2
M 6022	24	29	63	55	20.8	26.8
M 6026	19	21	83	74	14.4	20.2
M 6027	18	24	80	82	19.4	21.4
M 6029	20	29	119	76	35.4	24.6
M 6030	26	29	77	56	18.9	22.2
M 6066	26	29	64	70	22.2	25.4
M 6067	27	30	84	63	16.7	20.6
M 6068	27	29	94	72	18.5	24.8
M 6070	26	29	82	70	15.6	21.2
MK 60 (Check)*	26	31	85	82	18.0	27.8
KU 18 (Check)*	#	32	#	89	#	31.6

* Indeterminate growth habit.
# Not grown.

The flowering period of most of the lines grown in April was 1 to 3 days longer. But these lines had shorter GF in August. This is because most lines had longer growth for beginning flowering (BF) and plant height at beginning flowering (HTBF) in April. However, some lines such as M 6006-1, M 6006-2, M 6008, M 6009 and M 6020 gave the same or slightly different values for FP and DST.

Generally, sesame grown in April gave higher plant height than that grown in August in Suwan Farm. Thus, the GF and DST of nineteen mutant lines grown in April were greater than when grown in August. These results were similar to those obtained in our work on the development of determinate sesame program [8]. The percentage of GF or DST would be an approach to classify determinacy in our further research.

3.1.3. Shatter resistance

Delayed capsule shattering after maturity was obtained in almost all tested lines except M-6045. But this line gave high seed retention in capsule. Due to the disease's damage to the capsules, shatter resistance had not been measured.

Most of the promising mutant lines were obtained from the EMS treatments. Only two lines, M-6060 and M-6064 were obtained from the gamma ray treatment. The seed yield of these mutant lines exceeded the check variety, MK 60. This result suggests that by using improved lines for induced mutations it would be possible to obtain good plant types and high seed yield. Delayed shattering and shatter resistant capsules were also obtained in this research work. These mutants will be useful for the improvement of sesame for reducing seed loss and for adapting it to machine harvest.

3.1.4. Bacterial leaf spot

From the investigation on the infestation of bacterial leaf spot on capsule it was found that there are different levels of damage to the plants. Some capsules did not show the symptoms of disease. It may be better for the control of this disease to harvest only healthy capsules. Capsules of M_8 lines were harvested and the seeds will be panted in April 1998.

3.1.5. Others

Some plant characteristic different from parent lines were obtained from mutant lines; large and long leaf a large number of leaves per plant, long capsule, small capsule, short internode and good branching type.

3.2. Experiment 2

3.2.1. M_1 and M_2 generations

Germination percentage and plant morphology of M_1 plants were evaluated. The germination of M_1 seeds was 96% and abnormal plants were not obtained. However, sterile plants were found in the indehiscent lines whereas among the M_1 plants from the treated F_1 seeds they were not obtained.

In investigating the agronomic characteristics of the M_2 populations it was found that most M_2 plants of the cross KUur 8012 x KUns 7014 gave a good plant type and large capsules. The crosses KKU1 x KUns 7005 and KKU1 x KUns 7014 gave M_2 plants with three capsules per leaf axil, more than in the other crosses, in both gamma rays treatments (300 and 400 Gy). The KKU 1 variety has three capsules per leaf axil. It is noted that most M_2 plants with three capsules per leaf axil were obtained from the crosses in which KKU1 was a parent. A similar result was obtained in the delayed capsule shattering: more M_2 plants with delayed capsule shattering were obtained in the cross of RS 6054 x KUns 7005 than in other crosses. RS 6054 is the delayed shattering line. Similar results on delayed shattering were also obtained in Experiment 1. Thus, this would suggest that the induction of

improved materials with desirable characters by using gamma rays or EMS, will lead to considerable numbers of mutant plants with those desirable characters and high potential yield.

M_2 plants of the two indehiscent populations were evaluated for shatter resistance and plant morphology. Most of the M_2 plants showed cupped leaves with indehiscent capsule. Normal plants were obtained in a small number. These normal plants produced a low number of capsules per plant. It is noted that most M_2 plants of these two populations were highly susceptible to diseases including bacterial leaf spot. These M_2 plants were not selected.

3.2.2. M_3 and M_4 lines

The problem of bacterial leaf spot still occurred in our material although the seeds of these lines were soaked with streptomycin before planting. However, M_3 ines with good plant type, high potential yielding ability and shatter resistance were selected. Selection based on single plants rather resistant to bacterial leaf spot had been done and advanced for M_4 lines. Shatter resistance had not been measured because most of capsules were damaged with diseases. However, two promising lines showed higher shatter resistance. The degree of infection of bacterial leaf spot on the capsules of the M_4 lines differed between plants in the same line. Thus, the healthy capsules were harvested and will be advanced for M_5 lines.

From the results of experiment 1 and 2 in this study it is considered that the optimum population of M_2 is approximately 400 plants when the parental material used for inducing mutation is improved lines with desirable characters. The mutant lines with good plant type and high potential yielding ability will also be obtained.

4. CONCLUSION

The characteristics of the promising mutant lines obtained in this research are summarized in Table VI.

TABLE VI. PROMISING MUTANT LINES AND THEIR MAIN CHARACTERS

Line	Parent	Mutagen	Main character
M 6005	RS 8001	0.5% EMS	Branching at the middle of stem, delayed shattering
M 6011	RS 8001	0.5% EMS	Large capsule, delayed shattering
M 6015	RS 8001	0.5% EMS	Short internode, shatter resistance, large capsule
M 6021	RS 6032	0.5% EMS	Branching, delayed shattering
M 6026	RS 6032	0.5% EMS	Branching at the 2/3 of main stem
M 6040	RS 6028	0.5% EMS	Long leaf, long capsule
M 6041	RS 6028	0.5% EMS	Large and long leaf, delayed shattering
M 6045	KUur 7014	1.0% EMS	Large capsule, long leaf, shatter resistance
M 6054	KUur 7014	1.0% EMS	Large and long leaf, tall, shatter resistance

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SESAME IMPROVEMENT THROUGH MUTATION INDUCTION FOR REDUCTION OF SEED LOSS AT HARVEST (SEMI-SHATTERING CAPSULES)

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Abstract

In 1994, the study of sesame improvement for reduction of seed loss by mutation was conducted at Ubonratchathani Field Crops Research Center (UBFCRC). There were two experiments carried out to improve sesame capsule for non-shattering characteristics using gamma rays and fast neutrons. The first experiment was performed to study the effect of irradiation doses on sesame when applied at doses varying from 200 to 750 Gy. Results of the experiments showed that all sesame lines had LD_{50} levels between 300–750 Gy when irradiated with gamma rays, and 20–80 Gy with fast neutron. The second experiment was done to investigate the effect of irradiation on shattering types of sesame capsules. Three local varieties, Red Pitsanulok, Black Burirum and white Granuan were irradiated with 500 Gy of gamma rays.

In the dry season 1997–98, 24 plants of M_7 generation (black- and red- seeded lines) and 8 plants of M_5 generation (white-seeded lines) were selected for yield evaluation with three local varieties. The results show 3 shatter resistant lines, PMUB 1, PMUB 19 (both with shatter resistance scale 537) and GMUB 7 (with scale 637) in 1997–98 (772 in 1997) gave 27% higher seed yield than the original variety; 2 black seeded mutant lines BMUB 21 and BMUB 23 of which seed colour slowly fades and 2 mutant lines (GMUB 1, GMUB 3) with a high degree of tolerance to powdery mildew.

1. INTRODUCTION

Sesame is an economical oil crop, supplementing other main crops in Thailand. Demand is reflected in the high national farm price for sesame seeds of US $ 1/kg in 1997–98. Sesame exports from Thailand (seed and oil) are worth about US $8–12 million annually. The national sesame production is about 27,000 to 32,000 tonnes per annum, of which 45% is used for domestic consumption and 55% is exported. The production area is between 32,000 to 60,320 ha. There are 3 types of sesame seeds: white, black and red or brown which occupy 10, 25 and 65% of the sesame growing area, respectively. The brown and white seed types are grown in the North and Central regions while the black seeded type is mainly grown in the Northeast. 70% of sesame production comes from the North.

Sesame is normally grown in the rainfed areas of Thailand, in upland and mid lowland sites (before the rice crop). In the upland sites of the North and Central, the growing periods are in the early rainy season (March–May) and late rainy season (July). In the mid lowland sites of the Northeast and some parts of the North, farmers grow sesame in the early rainy season (February–April) before rice. The farmers broadcast the seeds, in this way the populations are high enough to control the weeds. The average yield is around 430–630 kg/ha [1].

The breeding programme has been in progress for many years. Since it was started, three sesame varieties were released by the Department of Agriculture, namely Roi-Et 1 (1984), Mahasarakham 60 (1987), and Ubonratchathani 1 (1993). Kasetsart University released one variety, KU 18 and Khon Kaen University, released three varieties, KKU-1, KKU-2 and KKU-3 in 1992 [2].

Plant breeding using mutation induction to develop good crop varieties has been carried on in Thailand on a rather small scale. Some activities on plant mutation have been carried on in some field crops, e.g. cotton, soybean, mung bean, peanut and sesame.

The research emphasis on sesame at Ubon Ratchathani Field Crops Research Centre (UBFCRC) in Thailand has been focused on varietal improvement. This includes development of appropriate cultural practices, disease/pest control, post-harvest technology, with main focus on sesame production. Performance of local and exotic germplasm is discussed, particularly utilization of

promising material in breeding programmes. Emphasis has been placed on the development of high yielding determinate and non-shattering types, possessing resistance to charcoal rot and bacterial wilt. Specified research projects have been taken up at the Center to promote sesame improvement.

Commercial sesame crops grown at present are of indeterminate growth habit and have dehiscent capsules. Indeterminate growth habit results in an extended period for crop maturation and the lower capsules dehiscing before the upper capsules mature. This character causes non-uniform ripening of the capsules, resulting in seed loss at harvest which can be very high, up to 50% [3,4].

The objectives of this project are :

- To induce genetic variability of sesame germplasm especially for those desirable characters such as indehiscent capsules, strong seed placentation or semi-shattering capsule, and other plant architectural characters leading to reduced seed loss.
- To evaluate the sesame lines derived from induced mutations for utilization in the sesame improvement program through hybridization.
- To investigate the effectiveness of radiation used in the project in inducing useful traits.

2. MATERIALS AND METHODS

Two experiments were conducted using gamma rays to induce mutations. Firstly, the study of sesame response to radiation doses which was done in April–July 1994, primarily in order to find the optimum dose for each sesame variety. Ten grams of sesame seed of each of ten local elites were irradiated with 300, 350, 400, 450, 500, 550, 600, 650, 700 and 750 Gy of gamma rays at the Department of Applied Radiation and Isotopes, Faculty of Science, Kasetsart University, Bangkok.

At the same time in 1994, 50 grams of each of two local varieties (Red Phitsanulok and Black Burirum) were irradiated with 500 Gy, and in 1995 white Granuan with the same dose. M_1 seeds obtained from this treatment were later sown in the field.

Another study was performed in 1996 to induce mutations in sesame by using fast neutron. Four sesame lines (Roi-et 1, Ubon-1, Gwa-Ta-Yar, and Local-7) were irradiated with 0, 20, 30, 40, 50, 60, 70, and 80 Gy of fast neutron. Germination rates of sesame seeds exposed to various doses of this radiation were recorded.

The selection for semi-shattering capsule was carried out in the M_2 (season 2), selection criteria were as follows: slight suture through the capsule, one-fourth suture through the pod, and the entire suture through the pod. lf semi-shattering pods were not found, M_2 plants would be used for other purposes, e.g. disease resistance source.

M_2 plants selection was continued on to M_5 where the desirable characteristics occurred, otherwise they were discarded. Later on the selection criteria were changed on the advice of D.R. Langham and were used in M_6 generation (for Burirum and Phitsanulok origin) and in the M_4 generation(for Granuan origin) .

The selection criteria (Table I) were to look at the scores of the whole number of seeds per mature capsule (brown capsule when it is upright), the number of seeds left per capsule when it is inverted and the amount of opening of the capsule. Each characteristic was scored on a scale of 0 to 8 for 0–80 seeds per capsule when it was upright, 0–8 for 0–80 seeds left per capsule after inverting, and 0–8 for 0–100 % of the whole suture of capsule opening.

Two experiments were conducted at UBFCRC in the late rainy season of 1997 (September 1997 –January 1998) in sandy loam soil (pH = 4.28, organic matter 0.74%, total N = 0.04%, available P = 64 ppm, exchangeable K = 27 ppm, extractable Ca = 144.6 ppm). The experiments were designed in RCB with three replications. The objective of the first experiment was to compare 24 mutant lines (M_7) with two local varieties. The second experiment was carried out to compare 8 mutant lines (M_5) with white local and shattering susceptible variety ‘Roi et 1’. Sesame seeds of each lines were sown in

TABLE I. CHARACTERISTICS AND USED SCALES FOR SEED RETENTION

*Scale (Shatter resistance scale)	1. No. of seed/pod (Upright position)	2. No. of seed/pod (Inverted position)	3. Length of capsule opening (% pod length)
0	0	0	0.0–10.0
1	10	10	11.0–20.0
2	20	20	21.0–30.0
3	30	30	31.0–40.0
4	40	40	41.0–50.0
5	50	50	51.0–60.0
6	60	60	61.0–70.0
7	70	70	71.0–80.0
8	80	80	81.0–100.0

50 cm row spacing in 5 m^2 plot and 15 days after emergence, they were thinned to 10 cm apart in the row. Fertilizer (23.5–23.5–23.5 kg of $N\text{-}P_2O_5\text{-}K_2O$/ha) was applied after thinning. The agronomic characters and seed yields of the lines were recorded at harvest.

3. RESULTS AND DISCUSSIONS

In the first experiment, the percentage of germination of sesame lines was tested both in the laboratory and in the field, during April–July 1994. The percentage of survival and mortality of the plants responded irregularly to the rates of gamma rays. The total number of germinated plants was found to be reduced after seed irradiation with gamma rays. Doses of gamma rays used were also not consistently related to the number of germinated plants. The cause of this inconsistent result was not clear. However, it was found that all sesame lines which have LD_{50} levels between 300 to 750 Gy are local varieties having related genetic background.

The differences between four sesame cultivars regarding poor germination rates after exposure to fast neutron were demonstrated. The LD_{50} was, however, not similar among sesame varieties but ranged between 30–80 Gy of fast neutron radiation. This variable response to neutron irradiation may probably be due to the different genetic background of sesame varieties e.g., 'Roi-et 1' is originally from Japan and 'Ubonratchathani 1' from Myanmar [5].

Twenty-four plants of M_6 generation (from Burirum and Phitsanulok origin) and eight plants of M_3 generation (from Granuan) were selected and evaluated for high yielding ability and some agronomic traits in a preliminary yield trial in the late rainy season in 1997. The characteristics of the M_6 lines and M_3 lines are shown in Tables I and II.

The shatter resistant characteristic of the selected plants was checked according criteria described by D.R. Langham [6]. However, one problem which our programme was facing was the loss of desirable plants due to charcoal rot cause by *Macrophomina phaseolina* and bacterial wilt incited by *Pseudomonas solanacearum*.

3.1. Shatter resistance — in dry season 1997

The shattering resistant lines of sesame were selected using criteria emphasizing the number of seeds left after inverting the capsule [6]. Lines with more than 40 seeds left in the capsules after they were inverted were selected. However, the number of seeds per capsule when upright and length of suture on pod were also taken into consideration. In the dry season of 1997 there were 5 lines of such character in Experiment 1, i.e. BMUB 6 (scale 745), BMUB 7 (scale 444), BMUB 14 (scale 443), BMUB 16 (scale 544) and BMUB 17 (scale 544) and 6 lines in Experiment 2, i.e. GMUB 1 (scale 552), GMUB 2 (scale 646), GMUB 4 (scale 746), GMUB 5 (scale 662), GMUB 6 (scale 746) and GMUB 7 (scale 772) (Tables II and III).

TABLE II. CHARACTERISTICS OF M_6 LINES (PLANTED ON 18 FEBRUARY 1997)

Lines*	Plant ht. (cm)	No. of branches	Seed** colour	1000 seed weight (g)	Days to harvest	No. seed/capsule		Scale of open capsules	Scale***
						Upright	Inverted		
PMUB 1	62	2	R	2.5	98	30	22	6	326
BMUB 2	95	2	BR	2.7	110	33	29	6	326
BMUB 3	74	2	B	2.8	110	52	34	5	535
BMUB 4	74	2	B	2.6	110	33	29	6	326
BMUB 5	87	2	B	3	98	40	35	6	436
BMUB 6	60	0	B	2.3	110	70	40	5	745
PMUB 7	86	2	R	2.6	110	48	40	4	444
BMUB 8	52	2	BR	2.9	110	34	24	6	326
BMUB 9	84	2	B	2.6	110	42	30	4	434
BMUB10	78	2	B	2.4	98	38	30	6	328
BMUB11	70	2	BR	2.6	98	45	35	5	435
PMUB12	93	4	R	2.6	110	34	27	5	325
PMUB13	63	3	R	1.9	98	30	25	5	325
BMUB14	64	2	B	2.5	98	47	46	3	443
PMUB15	53	1	R	2.4	98	26	24	4	224
BMUB16	71	4	B	2.4	98	52	43	4	544
BMUB17	71	0	B	3	110	54	42	4	544
BMUB18	78	1	B	3	110	43	35	5	435
PMUB19	71	0	R	2.5	98	30	20	5	325
PMUB20	68	3	R	2.6	98	39	30	5	335
BMUB21	52	0	B	2.6	110	33	10	6	316
PMUB22	80	2	R	2.5	98	37	24	6	326
BMUB23	67	4	B	2.5	110	42	22	6	426
BMUB24	80	2	B	3.2	110	37	18	6	316
Pitsanulok	102	3	B	2.92	90	78	24	8	728
Burirum	120	4	R	2.48	98	85	22	8	828

*MUB = Mutation in UBFCRC, P = Pitsanulok, B = Buri Rum.
** B = brown, R = red.
***combined numerical value (between 000 and 888) of three characters combined according Table I.

TABLE III. CHARACTERISTICS OF M_4 LINES (PLANTED ON 18 FEBUARY 1997)

Line*	Plant ht. (cm)	Branch	Seed** colour	1,000 seed weight	Days to harvest	No of seed/pod		Scale of open capsules	Scale***
						Upright	Invert		
GMUB 1	100	1	BR	4.1	100	54	50	2	552
GMUB 2	130	1	BR	3.9	100	63	45	6	646
GMUB 3	128	1	W	4	100	53	31	4	534
GMUB 4	100	0	W	4	100	73	47	6	746
GMUB 5	140	4	W	3.4	100	67	61	2	662
GMUB 6	67	0	BR	3	100	76	43	6	746
GMUB 7	119	0	W	3.4	100	76	70	2	772
GMUB 8	120	3	BR	3.3	100	38	20	8	328
Granuan	120	4	W	2.85	95	87	28	8	828

*MUB = Mutation in UBFCRC, G = Granuan.
** B = brown, R = red, W = white.
***As in Table II.

The results of the two experiments conducted in the late rainy season of 1997 were as below:

Experiment 1: The results showed that four mutant lines mature 7 days earlier than the original lines. Nine mutant lines gave higher 1000-seed weight than the two original lines, Red Pitsanulok and Black Burirum which have a 1000-seed weight of 2.5 and 3.6g, respectively. Eleven lines produced higher seed yield than these two original lines about 4–80%, and two black seed mutant lines (BMUB 21 and BMUB 23) with seed colour slowly fading, which make them suitable for cooking (Table IV).

TABLE IV. CHARACTERISTICS OF M_7 LINES (PLANTED ON 19 SEPTEMBER 1997)*

Lines	Plant ht. Cm	Branches/ plt., No.	Capsule/plt No.	1,000 seed weight, g	Seed yield kg/ha	% relative yield	Seed** colour	Days to harvest	Shatter*** resistance
PMUB 1	68 ab	1.1 ab	17 d	2.83 h-k	472 b-e	100.8	R	83	537
BMUB 2	68 ab	.4 b	12 ed	3.60 abc	293 e	62.5	B	90	427
PMUB 3	67 ab	.2 b	13 ed	3.30 de	500 b-e	106	B	90	417
BMUB 4	64 ab	.2 b	9 ed	2.90 h-k	414 b-e	88	B	90	527
PMUB 5	77 ab	.06 b	15 ed	3.80 a	843 a	180	B	90	417
BMUB 6	68 ab	2.6 a	15 ed	2.66 k	593 a-d	125	B	90	517
PMUB 7	69 ab	.7 b	15 ed	2.90 g-j	367 cde	77	R	90	417
BMUB 8	69 ab	0.4 b	12.7 ed	3.50 bcd	363 cde	77	B	90	417
PMUB 9	69 ab	.03 b	9 ed	3.06 fgh	702 ab	149	B	90	417
BMUB 10	72 ab	.26 b	13 ed	2.85 h-k	536 b-e	113	B	90	416
PMUB 11	69 ab	0.2 b	11 ed	3.66 ab	550 b-e	117	B	90	316
PMUB 12	69 ab	1.0 bc	17 d	2.93 k-I	491 b-e	104	R	90	526
PMUB 13	73 ab	1.3 b	17 d	2.25 l	322 de	68	R	83	626
BMUB 14	66 ab	.3 b	10 de	2.68 jk	419 b-e	89	B	90	617
PMUB 15	61 b	.9 ab	15 de	2.90 h-k	401 cde	85	R	83	627
BMUB 16	62 b	.2 b	9 de	2.93 f-I	525 b-e	112	B	90	417
PMUB 17	58 b	.2 b	11 de	3.56 bc	458 b-e	97.3	B	90	417
BMUB 18	63 ab	.2 b	10 de	3.53 bcd	610 b-e	86.6	B	90	417
PMUB 19	63 ab	.3 b	17 de	2.73 ijk	373 cde	78.6	R	83	537
PMUB 20	59 b	1.8 ab	13 de	3.38 cde	620 abc	132	R	90	517
BMUB21**	68 ab	.8 ab	13 de	2.90 h-k	540 b-e	114.6	B	90	517
PMUB 22	57 b	.7 ab	13 de	3.30 de	465 b-e	98.6	R	90	417
BMUB23**	68 ab	.4 b	10 de	3.01 fgh	657 abc	140	B	90	517
BMUB 24	63 ab	.2 b	6 e	3.15 efg	600 a-d	128	B	90	517
Pitsanulok	82 a	1.5 ab	12 de	2.43 l	281 e	60	R	90	517
Burirum	60 b	.3 b	7 e	3.16 ef	468 b-e	100	B	90	527
cv (%)	14.9	15.53	40	4.2	30.5				
G.M	66	0.6	12.7	3.079	487				

*In a column, means followed by a common letter are not significantly different at the 5 % level by DMRT.
** & *** as in Table II.

Experiment 2: The results showed that the mutant lines gave 1000- seed weights ranging from 3.21 to 4.43 g and six lines gave 6–54% higher seed yield than the white local varieties and the recommended varieties. Furthermore, two mutant lines (GMUB 1, GMUB 3) showed a high degree of tolerance to powdery mildew (Table V).

3.2. Shattering resistance in sesame : dry season 1997–1998

Experiment 1: It was found that the selected 5 shattering resistant lines from the dry season in 1997 were reduced to 2 lines in 1997–98 i.e. PMUB 1 and PMUB 19, both of which had shattering resistance scale 537. They were more resistant than the check variety 'Roi-Et 1'. The loss in shattering resistance in 1997–98 was possibly caused by drought which was more severe than in 1997.

Experiment 2: Only one shatter resistant line selected in this experiment, GMUB 7, scaled 637 in 1997–98 and 772 in 1997, whereas the shattering of the recommended variety 'Roi-Et 1' was scaled 727 and 'Granuan' (check) was scaled 517. Even though the selected line did not give a high score in the number of seeds left after inverting the capsules, its 1000-seed weight was higher than 'Roi-Et 1' and 'Granuan'. This may lead to higher yield. The experiments should be repeated as the sesame capsule shattering character depends not only on genetics, but also on environmental factors such as wind, light, relative humidity and cultural practices.

4. CONCLUSIONS

In this sesame breeding program for capsule shattering resistance using irradiation, 3 shatter resistant lines (PMUB 1, PMUB 19 and GMUB 7) were selected as they gave satisfactory shatter resistant performance. Furthermore, other desirable characteristics were also found, i.e. higher yield and 1,000 seed weight, fading colour of black seed coat (BMUB 21, BMUB 23). Two mutant lines

(GMUB 1, GMUB 3) were quite tolerant to powdery mildew. These lines will be used as germplasm for other breeding programs. However, the problems causing concern in the experiments were sesame stem rot and bacterial wilt. They caused losses in stands which had the desired characteristics. As a result, selection for disease resistance should be included in the breeding programme. Varietal improvement is needed all the time to serve human needs and mutation breeding is still advantageous. Co-operation among sesame research working groups would be help achieve successful mutation breeding programmes in the future.

TABLE V. CHARACTERISTICS OF M_5 LINES(PLANTED ON 19 SEPTEMBER 1997)*

Lines**	Plant ht. (cm)	1,000 seed weight (g)	No. capsules/ plant	No. branches /plant	Seed yield kg/ha	% relative yield	Days to harvest	Shatter*** resistance
GMUB - 1	82	4.43 a	19 ab	0.03 b	1063 a	154	115	527
GMUB - 2	85	4.01 bc	18 ab	0	841 a	121	102	427
GMUB - 3	85	4.30 ab	18 ab	0.06 b	733 a	106	111	527
GMUB - 4	74	4.15 ab	15 c	0	631 ab	92	102	527
GMUB - 5	80	3.56 d	18 ab	0	811 a	118	101	427
GMUB - 6	82	3.21 d	19 ab	0.06 ab	615 ab	89	111	626
GMUB - 7	85	3.81 cd	19 ab	0	875 a	127	99	637
GMUB - 8	96	3.80 cd	25 ab	0.40 ab	792 a	114	100	428
Granuan	80	3.05 e	28 a	0.43 ab	690 a	100	102	617
Roi-Et-1 (SUS)	80	2.68 f	22 ab	0.93 a	168 b	25	78	727
CV%	15	4.7	28	102.1	30.6			
G.M	83	3.7	20	0.281	722			

*As in Table IV.
**Granuan = white local variety, SUS = high shattering variety.
***As in Table II.

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GENETIC IMPROVEMENT OF *SESAMUM INDICUM* THROUGH INDUCED MUTATIONS

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Abstract

Pakistan is chronically deficient in the production of edible oils. To enhance local production of edible oils, a mutation breeding project entitled "Genetic improvement of *Sesamum indicum* through induced mutations" was initiated for developing high yielding and widely adapted varieties of sesame. Quite a few mutants having earliness, short stature, semi-indehiscence, compact plant type, heavy bearing and high seed yield have been developed. The true breeding mutant lines developed have exhibited impressive yield potential.

1. INTRODUCTION

Pakistan is chronically deficient in the production of edible oils. Domestic production is hardly sufficient to meet 31% of the demand of 140 million people (Table I). Thus the country is constrained to import edible oil in large quantities involving huge expenditure in hard earned foreign exchange (Table II) under such a situation it is imperative to adopt all appropriate measures to improve the domestic production and achieve self sufficiency in edible oils. Realizing the importance of induced mutations in improving crop plants [1] to supplement our conventional breeding programme of sesame, a mutation breeding project was initiated during 1989 entitled, "Genetic improvement of *Sesamum indicum* through induced mutations". From 1990 onward the project was partially supported by two FAO/IAEA Co-ordinated Research Projects: a. "Mutation Breeding of Oilseed Crops" under Research Contract No. 6210/RB (1990–1992), and b. "Induced Mutation for Sesame Improvement" under Research Contract No. 7761/RB (1994–1998). Results achieved under these Research Contracts are summarized in this report. Some preliminary evaluation results have been reported earlier [2–6].

TABLE I. SHARE OF DOMESTIC PRODUCTION AND IMPORT IN THE TOTAL AVAILABILITY OF EDIBLE OILS IN PAKISTAN

Year	Domestic production (×1000 tonnes)	Import (× 1000 tonnes)	Total availability (× 1000 tonnes)	Import as percent of total availability
1980–81	246	465	711	66
1981–82	260	624	884	71
1982–83	275	640	915	70
1983–84	200	751	951	79
1984–85	262	653	996	71
1985–86	344	815	1159	70
1986–87	347	687	1034	72
1987–88	379	959	1338	71
1988–89	358	859	1217	76
1989–90	304	940	1244	71
1990–91	399	960	1359	70
1991–92	458	1046	1504	70
1992–93	361	1231	1592	77
1993–94	352	1131	1483	76
1994–95	385	1390	1775	78
1995–96	528	1140	1700	67

Source: Agricultural Statistics of Pakistan.

TABLE II. EDIBLE OIL IMPORTS IN PAKISTAN

Year	Rupees (million)
1980–81	2610
1981–82	3670
1982–83	6440
1994–95	15000

2. OBJECTIVES

The main objectives of this project were to induce genetic variability and manipulate it in order to confer specific improvements such as:

- Earliness in flowering and maturity
- Medium/short stature
- Suitable plant type (uniculm, compact branching, short internodes)
- Disease resistance (Charcoal rot)
- Heavy bearing
- Indehiscent/semi-indehiscent types
- Wide adaptability
- High seed yield and oil content.

3. MATERIALS AND METHODS

The seeds of three uniform varieties, Pr.19-9, Pr.14-2 and S-17, were exposed to different doses of gamma irradiation, i.e. 0,100,200,300,400,600, and 800 Gy and fast neutron (N_f) i.e. 0,10, 20, 30, 40, 60 and 80 Gy. N_f treatment of the seeds was done at the FAO/IAEA Agriculture and Biotechnology Laboratories in Seibersdorf, Austria. The irradiated seeds were divided into two parts for laboratory and field studies.

3.1. Laboratory studies

For laboratory studies 100 seeds from the gamma rays and N_f treated material along with respective controls were planted into sterilized soil in plastic trays and placed in a germinator with temperature adjusted at 30°C. Germination counts were recorded from the 4th day after sowing till complete emergence. Two weeks after sowing the seedlings were uprooted, rinsed with water and placed in moistened paper towels. Measurements were recorded on 10 longest seedlings from all the treatments for seedling height and 50% lethal dose (LD_{50}) values for various varieties were determined according to the procedure described earlier [7].

3.2. Field studies

To grow the M_1 generation, the second lot of irradiated seeds was planted in the well prepared field. Various observations were recorded on 10 randomly tagged plants per treatment. At maturity 5 seeds were collected from each M_1 plant and bulked by treatments to form the M_2 seeds population.

The M_2 populations were thoroughly screened at all the stages of the crop growth in the field and desirable selections for various agronomic characters were made. To confirm their breeding behaviour, putative mutants were grown in plant progeny rows. One row from each of the respective source varieties was grown after every ten rows of mutant lines for comparison. On the basis of agronomic data and visual comparison, true breeding lines were selected. True breeding lines were further screened and evaluated in preliminary yield trials (PYT). Mutant lines showing better performance than the respective parent were identified for further evaluation in station yield trials (SYT), zonal yield trials (ZYT) and national uniform yield trials (NUYT).

4. RESULTS AND DISCUSSION

4.1. Radiosensitivity studies

Dose response studies were conducted to determine the optimum doses of gamma radiation for various varieties of sesame. Seedling emergence started on the 4th day after sowing in non-irradiated material, while in all the treated populations it was delayed. Germination rate in the irradiated material at different intervals was correspondingly delayed, with increasing doses of radiation (Table III). The depressive effect of radiation on the germination percentage was not marked up to 400 Gy. However, at 600 Gy and 800 Gy germination percentage was significantly reduced in all the varieties both under laboratory and field conditions.

TABLE III. SEED GERMINATION IN THE LABORATORY AT DAILY INTERVALS AS AFFECTED BY SEED IRRADIATION WITH GAMMA RAYS

Variety	Treatment	Days after sowing												Total No. of	Germination %	
		4	5	6	7	8	9	10	11	12	13	14	15	seeds germinated	Lab.	Field
Pr.19-9	Control	5	22	18	20	15	7	5	1	–	–	–	–	93	93	80
	100 Gy	–	16	15	10	13	10	12	10	6	3	–	–	95	95	80
	200 Gy	–	9	13	14	13	14	10	9	6	3	–	–	91	91	79
	300 Gy	–	6	16	23	19	9	8	4	3	2	–	–	90	90	65
	400 Gy	–	6	14	20	22	8	6	3	4	1	–	–	84	84	60
	600 Gy	–	2	3	5	8	6	6	8	2	3		–	43	43	43
	800 Gy	–	–	2	2	3	3	5	4	4	3	–		26	26	15
Pr.14-2	Control	4	20	21	18	15	11	5	2	–	–	–		96	96	81
	100 Gy	–	12	20	19	14	10	8	5	3	–	–	–	93	93	79
	200 Gy	–	10	22	15	16	11	10	8	3	3	–	–	96	96	71
	300 Gy	–	7	13	22	10	10	9	8	3	2	–	–	84	84	62
	400 Gy	–	5	8	20	20	15	5	4	3	2	–	–	82	82	82
	600 Gy	–	3	5	8	10	6	6	4	2	1	–	–	45	45	45
	800 Gy	–	1	4	4	5	6	6	4	4	2	–	–	36	36	21
S-17	Control	8	18	20	19	11	10	4	2	–	–	–	–	92	92	78
	100 Gy	–	10	16	23	18	10	8	5	2	–	–	–	82	82	73
	200 Gy	–	8	12	20	15	12	10	7	2	1	–	–	87	87	62
	300 Gy	–	6	10	16	15	14	12	8	2	2	–	–	85	85	53
	400 Gy	–	5	9	10	19	10	14	10	4	2	–	–	83	83	41
	600 Gy	–	3	3	5	7	8	10	10	5	1	–	–	52	52	32
	800 Gy	–	1	3	2	3	5	6	5	6	5	–	–	36	36	17

Seedling height data indicated that with increased dose rate seedling growth decreased and inhibition was more pronounced in variety Pr.19-9 followed by S-17 and Pr.14-2, respectively. However, 50% reduction dose (RD_{50}) for seedling height lies between 400 Gy and 500 Gy, except for variety S-17 (600 Gy) which seems fairly radio-resistant (Fig. 1).

4.2. M_1 germination

The treated seeds were planted in the field to grow the M_1 generation. At higher doses, i.e. 600 Gy and 800 Gy gamma rays and 60 Gy N_f, plant growth was generally stunted. Various observations were recorded on 10 randomly tagged plants per treatment. Results are depicted in Figures 2 and 3 for plant height. From M_1 studies the following conclusions were drawn.

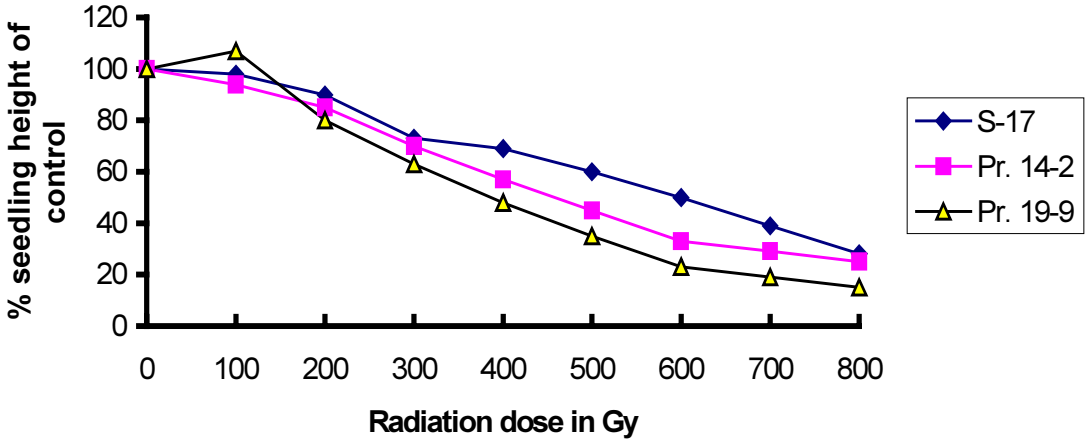

FIG. 1. Effect of seed irradiation with gamma rays on M_1 seedling height in sesame.

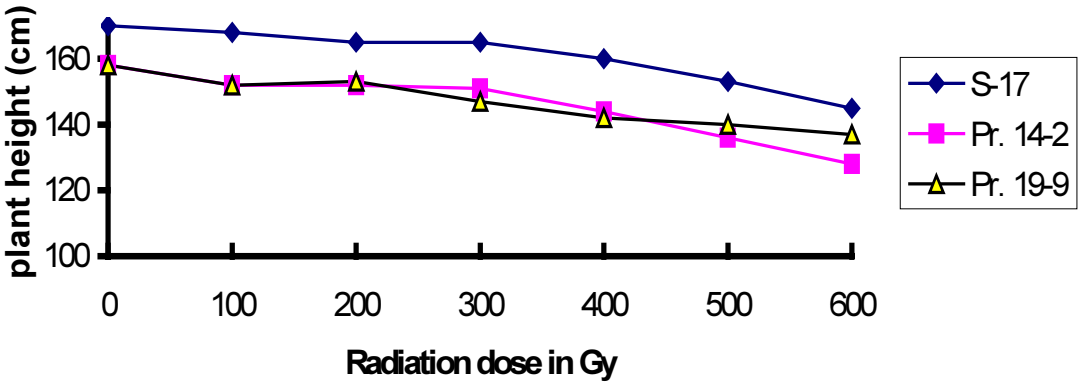

FIG. 2. Effect of gamma rays on M_1 plant height in sesame.

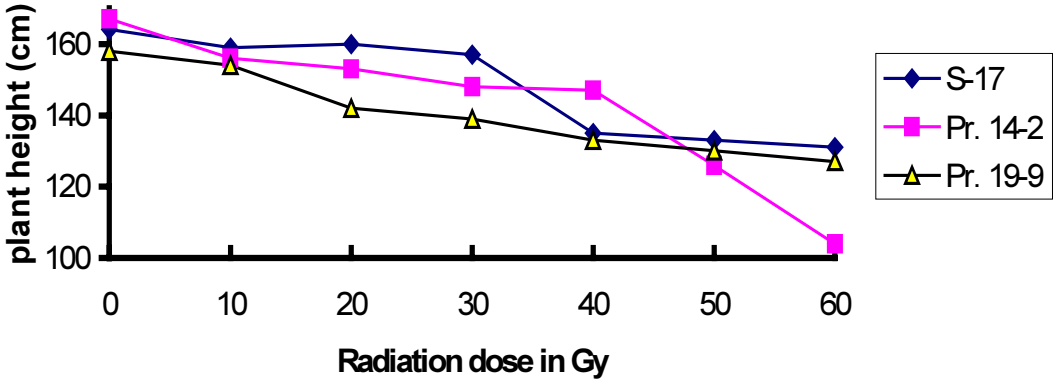

FIG. 3. Effect of fast neutrons on M_1 plant height in sesame.

1) Plant height (Figs 2 and 3), numbers of mature capsules per plant and seed yield per plant decreased in the treated populations.
2) Branches per plant and number of immature capsules per plant slightly increased in irradiated populations.
3) Flowering and maturity were delayed.

4.3. Selection of desirable mutants in M_2

In the treated M_2 populations 122 putative mutants were isolated for different desirable attributes (Table IV). The characteristics of the desirable plants were, early flowering, short stature, monostem (uniculm), semi-indehiscent type, compact plant type, heavy bearing and higher yield. Most selections on character basis were for monostem followed by early flowering, heavy bearing, short stature and semi-indehiscence. Mutation frequency on varietal basis was maximal for Pr.14-2, followed by Pr.19-9 and S-17.

TABLE IV. PUTATIVE MUTANTS SELECTED IN THE M_2 POPULALTIONS OF SESAME

Variety	Early flowering	Semi indehiscent	Short internodes	Long capsules	Mono stem	Compact plant type	Heavy bearing	Total
Pr.14-2	12	5	7	3	15	4	6	52
Pr.19-9	5	2	4	4	10	3	8	36
S-17	6	4	6	2	6	2	8	34
Total	23	11	17	9	31	9	22	122

4.4. Confirmation of true breeding lines (M_3)

On the basis of the data and visual comparisons 29 true breeding lines (seven from variety S-17, eight from variety Pr.19-9 and fourteen from Pr. 14-2) were selected for further screening and evaluation. Most of the M_2 selections (Table IV) segregated and did not breed true in M_3. Only 23.8% of the M_2 selections bred true for the selected attributes. Segregation to such a large extent could be due to polygenic nature of the characters under study [8]. The agronomic data of these true breeding lines, along with their identifying characters are presented in Tables V–VII. Two mutants with substantial improvement in fruiting were observed (Pr.14-2 HB-2 and Pr. 14-2 PB-1). Induced mutations also improved seed yield, which is a character governed by polygenes. Mutant Pr.14-2 MS-1, Pr.14-2 MS-2, Pr.14-2 EF-2 and Pr.19-9 MS-1 showed much superior seed yield potential than their respective source varieties.

4.5. Preliminary yield trial of true breeding mutants (M_4)

Twenty nine true breeding lines, selected for earliness, monostem, short internodes, compact branching, heavy bearing and high yield along with the source varieties (Pr.14-2, Pr.19-9 and S-17) were evaluated for seed yield performance in two separate trials.

4.5.1. Preliminary yield trial-I

Fifteen mutant lines developed from varieties Pr.19-9 and S-17 were evaluated in this trial. Mutant line Pr.19-9 MS-1 produced the highest seed yield (1533 kg/ha) followed by mutant line Pr.19-9 T-1 (1506 kg/ha). The source variety (Pr.19-9) gave the lowest seed yield (551 kg/ha). No significant differences in oil content were observed among the mutant lines and parent varieties (Table VIII).

TABLE V. AGRONOMIC DATA FOR TRUE BREEDING M_3 LINES DERIVED FROM VARIETY Pr.14-2 AND THEIR IDENTIFYING CHARACTERS

Mutant lines	Days to flower	Plant height (cm)	Branches per plant	Capsules per plant	Seed yield/ plant (g)	Identifying characters
Pr-14-2 (cont.)	46	146	2	51	6.05	–
Pr-14-2 T-1	50	190	3	80	11.04	Very tall
Pr-14-2 T-2	47	196	–	136	11.53	Very tall, monostem
Pr-14-2 HB-1	42	155	4	200	14.69	Heavy bearing, compact plant, profuse branching
Pr-14-2 HB-2	53	160	4	230	15.40	Heavy bearing, tall, high yield
Pr-14-2 D-1	48	87	1	143	13.30	Dwarf, short internodes, high yield
Pr-14-2 PB-1	55	173	5	232	19.94	Profuse branching, tall, high yield
Pr-14-2 PB-2	46	145	5	208	18.49	Profuse compact branching, high yield
Pr-14-2 PB-3	44	155	4	162	15.07	Profuse branching, short internodes, high yield
Pr-14-2 PB-4	48	130	4	122	13.00	Early flowering, high yield
Pr-14-2 EF-1	38	153	1	144	16.90	Early flowering,. profuse branching
Pr-14-2 EF-2	39	102	4	139	22.23	Short internodes, high yield
Pr-14-2 MS-1	48	108	–	228	31.40	Monostem, short stem, heavy bearing, high yield
Pr-14-2 MS-2	42	116	–	220	24.00	Monostem, heavy bearing, high yield
Pr-14-2 MS-3	43	145	–	134	19.00	Monostem, high yield

TABLE VI. AGRONOMIC DATA FOR TRUE BREEDING M_3 LINES DERIVED FROM VARIETY Pr. 19-9 AND THEIR IDENTIFYING CHARACTERS

Mutant lines	Days to flower	Plant height (cm)	Branches per plant	Capsules per plant	Seed yield/ plant (g)	Identifying characters
Pr.19-9 (cont.)	48	152	2	64	7.5	–
Pr.19-9 HB-1	46	148	4	139	15.5	Heavy bearing, profuse branching, high yield
Pr.19-9 T-1	55	185	4	195	19.5	Tall, profuse branching, heavy bearing high yield
Pr.19-9 PB-1	48	142	5	200	14.5	Profuse branching, heavy bearing, compact plant,
Pr.19-9 EF-1	35	110	–	94	10.7	Early flowering, monostem, short stature
Pr.19-9 D-1	44	74	3	150	13.5	Dwarf
Pr.19-9 D-2	49	92	4	75	11.5	Dwarf, profuse branching,
Pr.19-9 MS-1	50	160	–	210	20.0	Monostem, heavy bearing, high yield
Pr.19-9 MS-2	45	150	–	180	16.5	Monostem, heavy bearing, high yield

4.5.2. Preliminary yield trial-II

Fourteen mutant lines derived from variety Pr.14-2 were evaluated in this trial. Mutant line Pr.14-2 MS-1 produced significantly highest seed yield (1840 kg/ha) followed by Pr.14-2 MS-2 (1640 kg/ha) and Pr.14-2 EF-2 (1539 kg/ha). The parent variety Pr.14-2 produced the lowest seed yield (571 kg/ha). The oil content differences among mutant lines and parent variety were not significant (Table IX). On the basis of field performance, eleven high yielding mutants were selected from PYT I and II to be further evaluate in station yield trial during kharif 1993.

TABLE VII. AGRONOMIC DATA OF TRUE BREEDING M_3 LINES DERIVED FROM VARIETY S-17 AND THEIR IDENTIFYING CHARACTERS

Mutant lines	Days to flower	Plant height (cm)	Branches per plant	Capsules per plant	Seed yield/ plant (g)	Identifying characters
S-17 (cont.)	53	144	2	79	8.5	–
S-17 EF-1	41	147	4	135	11.5	Early flowering, heavy bearing, profuse branching
S-17 EF-2	39	138	3	110	11.3	Early flowering
S-17 St-1	48	110	2	106	14.6	Short stature
S-17 SM-1	55	152	–	156	16.4	Monostem, heavy bearing, high yield
S-17 SM-2	46	147	–	172	17.2	Monostem, heavy bearing, high yield
S-17 D-1	52	72	4	130	10.5	Dwarf, profuse branching,
S-17 S-1	49	136	2	145	16.2	Semi indehiscent

TABLE VIII. PRELIMINARY YIELD TRIAL I OF M_4 SESAME MUTANTS

Mutants/varieties	Days to 50% flowering	Seed yield (kg/ha)	Oil content (%)
S-17 (cont.)	55	600	53.15
S-17 EF-1	43	807	52.95
S-17 EF-2	40	802	53.00
S-17 St-1	49	1109	53.10
S-17 SM-1	57	1201	52.95
S-17 SM-2	51	1298	53.00
S-17 D-1	53	906	53.15
S-17 S-1	52	1201	53.10
Pr.19-9 (Cont.)	51	551	52.85
Pr.19-9 HB-1	48	1010	52.70
Pr.19-9 T-1	54	1506	52.60
Pr.19-9 PB-1	52	1018	52.60
Pr.19-9 EF-1	37	707	52.60
Pr.19-9 D-1	44	878	52.55
Pr.19-9 D-2	48	733	52.90
Pr.19-9 MS-1	54	1533	51.95
Pr.19-9 MS-2	47	1073	52.50

TABLE IX. PRELIMINARY YIELD TRIAL-II OF M_4 SESAME MUTANTS

Mutants/varieties	Days to 50% flowering	Seed yield (kg/ha)	Oil content (%)
Pr-14-2 (Cont.)	44	571	51.95
Pr-14-2 T-1	53	703	51.75
Pr-14-2 T-2	50	710	50.90
Pr-14-2 HB-1	45	1000	52.00
Pr-14-2 HB-2	56	1043	51.95
Pr-14-2 D-1	51	975	50.90
Pr-14-2 PB-1	58	1476	51.90
Pr-14-2 PB-2	49	1336	52.00
Pr-14-2 PB-3	47	1000	50.95
Pr-14-2 PB-4	51	965	51.90
Pr-14-2 EF-1	41	1100	51.97
Pr-14-2 EF-2	42	1539	52.00
Pr-14-2 MS-1	51	1840	51.90
Pr-14-2 MS-2	45	1648	51.75
Pr-14-2 MS-3	46	1330	51.80
LSD 5 %		53.62	
1%		72.27	

TABLE X. PERFORMANCE OF SESAME MUTANTS IN MICRO STATION YIELD TRIAL

Sr.No	Genotype	Days to 50% flowering	Seed yield (kg/ha)	Oil percentage
1	Pr 19-9 (Parent)	50	506.66 H	52.8
2	Pr 19-9 MS-1	52	1448.00 C	52.0
3	Pr 19-9 T-1	53	1411.66 C	52.4
4	S-17 (Parent)	54	531.66 H	53.0
5	S-17 MS-1	57	1113.33 F	53.0
6	S-17 MS-2	50	1168.33 EF	52.8
7	S-17 ST-1	51	598.33 G	53.1
8	Pr-14-2 (Parent)	53	537.00 H	52.0
9	Pr-14-2 MS-1	50	1678.33 A	52.0
10	Pr-14-2 MS-2	43	1549.33 B	51.5
11	Pr-14-2 MS-3	46	1201.66 E	52.0
12	Pr-14-2 EF-2	39	1470.00 C	52.0
13	Pr-14-2 EF-1	56	1336.66 D	51.8
14	Pr-14-2 PB-2	48	1168.33 E	52.0

4.6. Station yield trial (SYT)

On the basis of field performance from PYT-I and PYT-II, eleven high yielding mutants (two from Pr.19-9, three from S-17 and six from Pr.14-2) were evaluated along with their parents in station yield trial during kharif 1993. All the mutants realized two to three times increased seed yields than the respective parents (Table X). Mutant strain Pr.14-2 MS-1 produced significantly highest seed yield (1678 kg/ha) followed by Pr.14-2 MS-2 (1549 kg/ha), Pr.14-2 EF-2 (1470 kg/ha), Pr.19-9 MS-1 (1448 kg/ha) and Pr.19-9 T-I (1412 kg/ha). In oil content mutants and parents were at par.

4.7. Zonal yield trials (ZYT)

A set of 7 leading mutant lines giving better and stable performance in the station yield trial was evaluated in different ecological zones of south Pakistan, i.e. in the districts of Hyderabad, Mirpurkhas, Badin, Sanghar, Shikarpur and Umerkot for three years from 1995-97. The results were as described below.

4.7.1. Zonal yield trial 1995 (ZYT-1995)

Significant differences among the mean seed yields were observed at all the three locations. At Tandojam, mutant lines Pr.14-2 MS-1 and Pr.14-2 EF-2 produced highest and parallel seed yields (1204 kg/ha), followed by Pr.19-9 MS-1 (1157 kg/ha) and Pr.19-9 T-1 (1100 kg/ha). The check variety S-17 produced 972 kg/ha seed yield and ranked sixth at this location. The lowest seed yield (938 kg/ha) was produced by mutant line 8/109/92 (Table XI). At Umerkot, mutant line Pr.14-2 MS-1 produced significantly highest seed yield (2192 kg/ha) followed by Pr.14-2 MS-2 (1847 kg/ha) and Pr.14-2 EF-2 (1835 kg/ha). As compared to this S-17 gave 1461 kg/ha seed yield and ranked seventh. At this location mutants Pr.14-2 MS-2 and Pr.14-2 EF-2 yielded statistically parallel. Mutant line Pr.14-2 EF-2 produced significantly highest seed yield (1991 kg/ha) followed by Pr.14-2 MS-1 (1921 kg/ha) at Sanghar. At this location S-17 produced 1644 kg/ha seed yield and ranked fourth. The lowest seed yield (1296 kg/ha) was produced by mutant line 2/24/92.

Mean seed yield of the three locations indicated that Pr-14-2 MS-1 produced significantly highest seed yield (1730 kg/ha) followed by Pr.14-2 EF-2 (1677 kg/ha) and Pr.14-2 MS-2 (1573 kg/ha). However, these two mutant lines were statistically at par. The check variety S-17 produced 1359 kg/ha seed yield and ranked sixth.

TABLE XI. PERFORMANCE OF SESAME MUTNTS IN ZONAL TRIAL CONDUCTED DURING KHARIF 1995

	Seed yield, kg/ha			
Genotypes	Tandojam	Umerkot	Sanghar	Mean of 3 locations
S-17	972 cd	1461 b	1644 b	1359 d
2/24/92	949 d	1458 b	1296 c	1234 de
Pr 19-9	1100 ab	1674 b	1620 b	1465 cd
Pr14-2 EF-2	1204 a	1835 ab	1991 a	1677 ab
Pr-14-2 MS-2	1204 a	1847 ab	1667 b	1573 bc
Pr-19-9 MS-1	1157 ab	1739 b	1620 b	1505 cd
Pr-14-2 MS-1	1076 bc	2192 a	1921 a	1730 a
8/109/92	938 d	1660 b	1574 b	1391 d
Mean	1075.0	1733.25	1666.03	1491.65

4.7.2. Zonal yield trial 1996 (ZYT 1996)

The same set of seven leading mutants evaluated in ZYT last year [5] was again tested this year in different ecological zones of Sindh. At Tandojam location, mutant strain Pr.14-2 MS-1 gave significantly higher seed yield (1875 kg/ha) than mutant line 8/109/92. All other mutants were at par in seed yield with Pr.14-2 MS-1. The lowest seed yield (1181 kg/ha) was produced by mutant line 8/109/92 (Table XII). At Umerkot site most of the mutants exhibited good yield potential. Mutant line Pr.14-2 MS-2 produced maximum and significantly higher seed yield (2065 kg/ha) than mutants Pr. 19-9 MS-1, Pr. 19-9 T-1, 2/24/92, 8/109/92 and S-17. Mutants Pr.14-2 MS-1 and Pr.14-2 EF-2 were at par with Pr.14-2 MS-1. The check variety S-17 gave the lowest seed yield (1425 kg/ha). Sanghar/Khipro site was a poor yielding site and most of the mutant lines were at par in seed yield. Mutant Pr.14-2 MS-1 gave maximum seed yield (1645 kg/ha) which was significantly higher than mutant line 2/24/92. Mutant line 2/24/92 produced significantly lowest seed yield (1402 kg/ha). At Shikarpur location mutant line Pr.14-2 MS-1 produced significantly higher seed yield (1890 kg/ha) than Pr.19-9 T-1, 2/24/92, 8/109/92 and S-17. Whereas, mutants Pr.19-9 MS-1, Pr. 14-2 EF-2 and Pr. 14-2 MS-2 were at par in seed yield with Pr.14-2 MS-1. S-17 (check) produced significantly least seed yield in this group.

The overall mean seed yield of the four locations indicated that Pr. 14-2 MS-1 produced significantly higher seed yield than mutant lines 2/24/92, Pr.19-9 T-1, Pr.19-9 MS-1, 8/109/92 and S-17 (check). The mutant lines Pr.14-2 MS-2 and Pr.14-2 EF-2 were at par in seed yield with Pr.14-2 MS-1.

TABLE XII. PERFORMANCE OF SESAME MUTANTS IN ZONAL YIELD TRIALS CONDUCTED DURING KHARIF 1996

	Seed yield kg/ha				
Genotypes	Tandojam	Umerkot	Sanghar/Khipro	Shikarpur	Mean
S-17 (Check)	1273 AB	1425 C	1570 A	1346 D	1404 C
Pr 19-9 T-1	1551 AB	1460 BC	1595 A	1606 BCD	1553 BC
Pr 19-9 MS-1	1365 AB	1680 BC	1602 A	1676 ABC	1581 BC
Pr 14-2 EF-2	1690 AB	1785 ABC	1607 A	1780 AB	1716 AB
Pr 14-2 MS-1	1875 A	1807 AB	1645 A	1890 A	1804 A
Pr 14-2 MS-2	1667 AB	2065 A	1600 A	1745 ABC	1768 A
2/24/92	1782 AB	1547 BC	1402 B	1557 BCD	1572 BC
8/109/92	1181 B	1605 BC	1479 AB	1486 CD	1438 C

4.7.3. Zonal yield trials 1997 (ZYT-1997)

Mean seed yield showed considerable differences at all the four locations (Table XIII). Umerkot was highest yielding site (1277 kg/ha) and Badin remained poorest yielding site (860

kg/ha). At Badin mutant strain Pr.14-2 MS-1 exhibited highest seed yield (1089 kg/ha) followed by mutant Pr.19-9 MS-I (922 kg/ha). Minimum seed yield (667 kg/ha) was produced by mutant 2/24/92. At Mirpurkhas, mutant line Pr.14-2 EF-2 gave significantly highest seed yield (1377 kg/ha) followed by mutant Pr.14-2 MS-1 (1122 kg/ha). Mutant 2/24/92 again realized minimum seed yield (911 kg/ha). At Sanghar location mutant Pr.14-2 MS-1 produced significantly higher seed yield than most of the mutants and S-17 (check). Whereas, mutant Pr.19-9 T-I and Pr.14-2 MS-2 were at par in seed yield with mutant Pr.14-2 MS-1. Umerkot is higher yielding site where all the genotypes exhibited good yield potential. Mutant Pr.14-2 MS-I produced significantly highest seed yield (1644 kg/ha) followed by mutants Pr.14-2 MS-2 and Pr.19-9 MS-1 (1367 kg/ha). Check variety S-17 gave the lowest seed yield (1066 kg/ha).

Overall mutant strain Pr.14-2 MS-1 produced the highest seed yield (1333 kg/ha). Mutant line 2/24/92 was the lowest yielder (922 kg/ha).

TABLE XIII. ZONAL TRIALS OF SESAME MUTANT LINES (KHARIF 1997)

	Seed yield kg/ha				
Genotypes	Badin	Mirpurkhas	Khipro	Umerkot	Mean locations
S-17	733 BC	978 B	1178 BC	1066 C	989 EF
2/24/92	667 C	911 B	967 C	1144 BC	922 F
Pr-19-9	889 ABC	955 B	1300 AB	1167 BC	1078 CDE
Pr 14-2 EF2	889 ABC	1377 A	1422 A	1278 BC	1244 AB
Pr 14-2 MS 2	867 BC	1077 B	1300 AB	1367 B	1144 BC
Pr 19-9 MS-I	922 AB	967 B	1200 B	1367 B	1111 CD
Pr 14-2 MS-I	1089 A	1122 B	1467 A	1644 A	1333 A
8/109/92	867 BC	956 B	1100 BC	1189 BC	1022 DEF
Location mean	860	1042	1241	1277	1105

4.7.4. Performance of sesame mutants in zonal trials (1995-97)

The yield performance of the sesame mutants was tested over 3 years at 11 locations in Sindh (Table XIV). Mutant Pr.14-2 MS-1 ranked (1584 kg/ha) followed by mutants Pr.14-2 EF-2 (1567 kg/ha) and mutant Pr.14-2 MS-2 (1487 kg/ha). Check variety S-17 gave lowest yield (1231 kg/ha).

On the basis of better performance in zonal trials, mutants Pr.14-2, MS-1 and Pr.14-2, EF-2 were promoted in national uniform yield trials, 1/2 kg seed samples of both top yielding strains have been sent to the National Coordinator Oilseed Crops at Islamabad for NUYT 1998.

TABLE XIV. PERFORMANCE OF SESAME MUTANT STRAINS IN ZONAL TRIALS IN SINDH PROVINCE (1995-1997)

	Seed yield kg/ha				
Genotype	Summer 1995 Mean of 3 locations	Summer 1996 Mean of 4 locations	Summer 1997 Mean of 4 locations	Mean of 3 years	Rank
S-17 (Check)	1359 D	1346 D	989 EF	1231.33	8
2/24/92	1234 DE	1557 BCD	922 F	1237.67	7
Pr-19-9	1465 CD	1606 BCD	1078 CDE	1383.00	5
Pr 14-2 EF2	1677 AB	1780 AB	1244 AB	1567.00	2
Pr 14-2 MS 2	1573 BC	1745 ABC	1144 BC	1487.33	3
Pr 19-9 MS-I	1505 CD	1676 ABC	1111 CD	1430.67	4
Pr 14-2 MS-I	1730 A	1890 A	1333 A	1584.33	1
8/109/92	1391 D	1486 CD	1022 DEF	1299.67	6

4.8. Isolation, confirmation and evaluation of newly generated breeding material

For the continuous flow of segregating material, fresh seed was irradiated almost every year and newly generated material in M_2 generation was subjected to isolation of variants and

confirmation cum evaluation during subsequent generations. Newly developed true breeding mutants showing better performance in preliminary evaluation were further evaluated in comparatively larger plots. The results are summarized below:

4.8.1. Station yield trials (SYT)

1995 Ten high yielding mutants giving better performance in preliminary trials were promoted in SYT to evaluate their performance in comparatively bigger plots. Results given in Table XV show that mutant Pr.19-9/7/93 produced highest seed yield (2036 kg/ha) followed by Pr.19-9/70/93 (2000 kg/ha) and mutant Pr.19-9/151/93(1740 kg/ha).

1996 The same set of 10 mutants along with both parents was re-evaluated to confirm the results. Most of the mutants gave better performance. Mutants Pr.19-9/151/93, S-17/140/93 and S-17/146/93 gave poorer performance than their respective parents (Table XV). Mutant line Pr.19-9/7/93 gave significantly higher seed yield (1978 kg/ha) followed by Pr.19-9/70/93 (1941 kg/ha) and S-17/100/93 (1745 kg/ha). Oil content was at par with all the entries in trial.

1997 On the basis of performance during 1995 and 1996, 8 high yielding mutants were re-evaluated along with parents in SYT during 1997. As per results, mutant S-17/52/93 gave significantly highest seed yield (2522 kg/ha) followed by Pr.19-9/7/93 (2372 kg/ha) and S-17/100/93 (2339 kg/ha). No significant change in oil content was observed (Table XVI). On the basis of high yield potential evaluated in SYT, five mutants have been promoted to ZYT to test their yield potential and adaptability in different ecological zones of Sindh.

TABLE XV. PERFORMANCE OF SESAME MUTANTS IN STATION YIELD TRIAL (1995-96)

	1995		1996		Mean of two years	
Genotypes	Seed yield (kg/ha)	Oil %	Seed yield (kg/ha)	Oil %	Seed yield (kg/ha)	Oil %
Pr-19-9(Parent)	1333	51.6	1476	51.0	1405	51.3
Pr-19-9/7/93	2036	52.0	1978	51.6	2007	51.8
Pr-19-9/70/93	2000	52.4	1941	52.0	1971	52.2
Pr-19-9/140/93	1606	51.8	1567	51.5	1587	51.6
Pr-19-9/151/93	1740	52.0	1454	52.0	1597	52.0
S-17 (Parent)	1456	50.0	1549	51.6	1503	50.8
S-17/52/93	1667	50.0	1622	52.0	1645	51.0
S-17/100/93	1591	50.8	1745	51.0	1668	50.9
S-17/102/93	1556	50.6	1595	52.0	1576	51.3
S-17/132/93	1479	50.8	1627	51.5	1553	51.2
S-17/140/93	1406	50.6	1523	52.0	1470	51.3
S-17/146/93	1447	51.0	1506	51.8	1477	51.4

TABLE XVI. PERFORMANCE OF NEW MUTANTS OF SESAME IN THE STATION YIELD TRIAL DURING KHARIF 1997

Genotypes	Seed yield (kg/ha)	Oil content %
Pr-19-9 (Parent)	2269 A	50.5
Pr-19-9/7/93	2372 A	51.0
Pr-19-9/70/93	1678 B	50.0
Pr-19-9/140/93	2014 AB	52.0
Pr-19-9/151/93	2244 A	50.5
S-17 (Parent)	1597 B	51.0
S-17/52/93	2522 A	51.5
S-17/100/93	2339 A	50.5
S-17/102/93	2233 A	52.0
S-17/132/93	1597 B	51.0

4.8.2. Preliminary yield trials (PYT)

1995 Eleven true breeding mutants were planted in PYT along with the parents to evaluate their yield potential following RCB design with three replications. Mutant line S-17/74/94 produced significantly highest seed yield (2530 kg/ha) followed by S-17/69/94 (2361 kg/ha) and Pr.19-9/94 (1885 kg/ha). The parent varieties S-17 and Pr.19-9 produced 1759 and 1696 kg/ha, respectively (Table XVII).

1996 Thirteen true breeding lines along with three parents were evaluated in PYT in RCB design with three replications. Ten mutants gave better performance than their respective parents (Table XVIII). Mutant S-2/94 gave significantly highest seed yield (3150 kg/ha) followed by Pr.14-2-5/48/94 (2154 kg/ha) and Pr.14-2-104/3/94 (1867 kg/ha). In oil content all the genotypes were at par.

1997 The same set of 16 genotypes (13 mutants and 3 parents) was planted to re-evaluate and confirm the results. Mutant line Pr-19-9/132/94 gave maximum seed yield (2361 kg/ha) followed by mutant Pr. 19-9/100/94 and mutant Pr. 19-9/131/94 (2205 kg/ha). In oil content all the genotypes were at par (Table XIX).

TABLE XVII. PERFORMANCE OF SESAME MUTANTS IN PRELIMINARY YIELD TRIAL 1995

Genotype	Days to 50 % flowering	Seed yield (kg/ha)	Oil %
S.17 (Parent)	54	1759	50.6
S.17/6/94	53	761	51.0
S.17/18/94	54	1759	50.4
S.17/21/94	53	12.3	51.1
S.17/30/94	53	1135	52.0
S.17/65/94	52	1185	51.3
S.17/67/94	53	1485	50.6
S.17/69/94	53	2361	50.8
S.17/74/94	54	2530	50.3
S.17/122/94	52	1418	51.0
S.17/130/94	53	741	52.0
Pr.19-9 (Parent)	54	1696	50.6
Pr.19-9/94	53	1885	50.8
LSD 5%	89.8898		
1%	122.1790		

TABLE XVIII. PERFORMANCE OF SESAME MUTANTS IN PRELIMENARY YIELD TRIAL DURING KHARIF 1996

Genotypes	Seed yield kg/ha	Oil content %
S-17 (Parent)	1607	51.50
S-2/94	3150	51.00
S-7/94	1703	52.00
S-17-6/94	1805	52.30
S-22/94	1244	51.00
S-31-1/94	1735	50.50
S-33-10/94	1357	52.00
S-48/94	1219	51.80
Pr 19-9 (Parent)	1355	52.00
Pr 19-9-100/94	1671	51.50
Pr 19-9-126/94	1551	52.00
Pr 19-9-131/94	1671	50.70
Pr 19-9-132/94	1528	51.30
Pr 14-2-(Parent)	1496	51.00
Pr 14-2-5/48/94	2154	52.00
Pr 14-2-104/3/94	1867	51.00

Sesame appears to be very suitable material for inducing useful mutations [9,10] as soybean [8,11] and wheat [12]. As in soybean, induced mutations in combination with other methods of manipulating genetic variability can also be profitably exploited for improving the quantity and quality of oil in sesame [13]. Our studies have clearly demonstrated that induced mutations can successfully be utilized for altering and bringing improvements in sesame plants' architecture, resulting in considerable enhancement of economic yield. Quite a few mutants of sesame have been developed and evaluated extensively. The high yielding mutants (Pr.14-2 MS-1 and Pr.14-2 EF-2) are potential candidate varieties of sesame for the province of Sindh. Further extensive evaluation of other newly developed mutants in the pipeline will hopefully be useful in direct release of improved mutant varieties.

TABLE XIX. PRELIMINARY YIELD TRIAL 1997 (PYT-97)

Genotypes	Days to flower	Days to mature	Seed yield (kg/ha)	
S-17 (Parent)	61	131	1181	ABC
S-2	63	131	1389	ABC
S-7	59	128	625	BC
S-17-6-94	64	131	1528	ABC
S-22	56	129	1633	ABC
S-31-1	62	131	1564	ABC
S-33-10	56	129	1494	ABC
S-48	63	130	1042	ABC
Pr.19-9 (Parent)	61	131	1250	ABC
100/94	58	127	2292	A
126/94	58	127	1111	ABC
131/94	59	128	2050	AB
132/94	58	127	2361	A
Pr.14-2 (Parent)	57	127	1181	ABC
Pr.14-2 5/3/94	63	131	972	ABC
Pr.14-25/48/94	64	131	453	C

New germplasm has also been generated for agronomic traits. This germplasm will be utilized for breeding new cultivars of sesame through synergistic approaches [14] including recurrent irradiation and recombination breeding.

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INDUCED MUTANTS FOR THE IMPROVEMENT OF SESAME AND HYBRID SEED PRODUCTION

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Abstract

With an overall objective to develop hybrids in sesame, induced mutants were used in cross breeding and five initial yield trials were conducted. For obtaining the mutant hybrids, recessive morphological mutants were used as female, and check varieties as male parents. In each trial, seed yields of mutant hybrids were compared with: i) the original parent in which the mutants were induced, ii) best check variety and iii) best cultivar hybrid. Among 138 mutant hybrids evaluated between 1994 and 1997, 18 showed superiority. In the development of hybrids, it is also desirable to have male sterile lines. By irradiating seeds with 400 Gy gamma rays, four genetic male sterile mutants were isolated. One of them, TMST-11 appears to be promising for breeding programme showing 100% male sterility and characterised by dark green foliage. To study the percent outcrossing, a monogenic chlorina mutant which can be identified from the seedling stage, was used in experiments conducted for two years. Among open pollinated plants, 92–98% plants were found outcrossed. Based on plant to row progenies, percent outcrossing ranged between 0.0 to 13.8%.

1. INTRODUCTION

Sesame is an important edible oil seed crop grown in India on about 2.4 million ha. There is demand for sesame seeds for oil, confectionery and export purposes. However, seed yields in India are generally low (250 to 300 kg/ha). Through our mutation research, so far, 60 true breeding mutants were obtained from cvs N62-32, N-8, Phule Til-1 and Tapi. They were characterised, maintained and the inheritance pattern of some of the mutants was established [1–9]. One of the objectives of our research is to explore the possibility of developing hybrids in sesame using induced mutants. For this, experiments were conducted to: i) identify parents contributing to F_1 hybrid vigour for seed yield, ii) develop male sterile lines and iii) study the percent outcrossing. These results are presented here.

2. MATERIALS AND METHODS

2.1. Evaluation of existing mutants for heterosis

Between 1994 and 1997, each year a certain number of mutants were crossed with certain cultivars; these hybrids were designated as mutant hybrids (MHY). They were evaluated under irrigated summer (January to April) conditions in randomised yield trials with three to four replications along with check varieties and cultivar hybrids (CHY). Each treatment was sown in 3m long row with 30 and 15 cm spacing between rows and among plants, respectively.

2.2. Mutation induction in local varieties

Seeds of cv Tapi were treated with ethidium bromide(600 mg/100 ml water, 6 hr) and the M_1 generation was grown during 1993 rainy season (June to September). All the M_1 plants were screened for male sterile mutations within one week of first flowering. Variants for partial male sterility were selfed. In M_2 generation, segregating male sterile plants were back crossed with the parent and advanced to next generation for further studies.

Initially, dry seeds of cv Tapi were treated with 11 doses between 100 and 1100 Gy gamma rays. For each treatment 200 seeds were used. They were sown in seedling racks in four replications

of 50 seeds each and were kept under continuous illumination in the laboratory for ten days. Germination percentage and hypocotyl length of seedlings were recorded.

Following 400 Gy gamma ray treatment to the seeds of cv Tapi, a large M_1 generation was grown. At maturity, the lowermost capsules on the main stem were harvested plant-wise. Part of the M_2 generation consisting of 1,350 M_1 plant progenies in 1994–95 (December to March) and 1800 M_1 plant progenies during 1995 rainy season were grown. In the M_2 generation, variants for male sterility were marked within one week of first flowering. In plants having such variations, pollen sterility was studied under microscope by staining with acetocarmine. In the M_2 and subsequent generations, male sterile mutants were maintained by growing fertile sib plants as plant to row progenies. Segregations of fertile and sterile plants were studied and male sterile mutants were crossed.

Dry seeds of cv Phule Til-1 were irradiated with 600, 700 and 800 Gy gamma rays and the M_1 generation was grown during 1997(August to November). At maturity, capsules from individual plants were harvested as in the previous experiment.

2.3. Evaluation of cross pollination rates

Chlorina mutant (NM-54) was used as a marker to study the outcrossing percentage. Initially the mode of inheritance of the mutant was confirmed by crossing it with other cultivars and studying the segregation patterns in the F_2.

During 1994 summer, two field experiments were conducted. In the first, seeds (5g each) of cv Tapi and NM-54 were mixed and sown. In the second one, they were sown in alternate rows. During flowering, no attempt was made to prevent possible outcrossing. At harvest, only NM-54 plants were harvested individually. Besides, from each one of five NM-54 plants, 10 capsules were harvested at random separately. During 1994 rainy season, seeds were sown as plant to row and capsule to row progenies. Ten days after sowing, the phenotypes of the seedlings in each progeny row was recorded. The experiment was repeated during the following year. The frequency of outcrossing was calculated from these data.

3. RESULTS AND DISCUSSION

In our experiments, when some of the induced mutants were used in crosses, considerable heterosis for seed yield was observed in F_1 hybrids [10–12]. Since then, the possibility of developing hybrids has been explored. Between 1994 to 1997, five initial yield trials were conducted using MHY. In these trials, mostly recessive morphological mutants isolated from cvs N62-32, N-8, Phule Til-1 and Tapi, were used as female parents, with a view that in case if the mutant got selfed, the mutant trait could be distinguished among the F_1 hybrids. The yields of MHY were compared with the source cultivar of the mutant as well as with the best check used in the trial. In order to know whether the observed heterotic effect for yield in mutant hybrids was due to mutational events, MHY were also compared with the best CHY.

In the first trial, 16 mutants of cv N-8 were crossed with cv Tapi. During 1994 summer, MHY were grown along with 5 cvs including N-8. Compared to the best check N-8, 13 MHY gave significantly higher yields (Table I), ranging between 78 to 148%. The CHY, N-8 X Tapi, showed numerical superiority over N-8. Seven MHY gave significant increases over CHY (41 to 64% increase).

In the second trial (1995 summer), 44 MHY were evaluated along with 4 CHY and 3 cvs (Table II). All the mutant female parents were isolated from cv N-8. Compared to N-8, 31 MHY showed significant increases and three MHY over the best check N62-32 (48 and 53%). However, compared to the best CHY, N-8 x TC-25, 8 MHY showed numerical superiority (4 to 30%).

TABLE I. SEED YIELD OF 16 F_1 HYBRIDS OBTAINED BY CROSSING MUTANTS OF N-8 WITH CV TAPI (1994 SUMMER)

Hybrid/cultivar	Seed yield (kg/ha)	% Increase over best	
		Check	Cv. hybrid
Mutant hybrids:			
NY-21 X Tapi	1612	148	64
NM-67 X Tapi	1603	147	63
NM-54 X Tapi	1497	131	52
NM-77 X Tapi	1439	122	46
NM-85 X Tapi	1427	120	45
NM-31 X Tapi	1412	118	43
NM-26 X Tapi	1392	114	41
NM-87 X Tapi	1354	109	37
NM-28 X Tapi	1328	105	35
NY-9 X Tapi	1328	105	35
NM-71 X Tapi	1244	92	26
NM-80 X Tapi	1230	90	25
NM-58 X Tapi	1156	78	17
NM-57 X Tapi	982	51	–
NM-65 X Tapi	907	40	–
NY-9M X Tapi	517	-20	–
Cultivar hybrid:			
N-8 X Tapi	985	52	–
Check cultivars:			
N-8	649		
T-12	640		
TC-25	462		
Tapi	437		
Phule Til-1	414		
C.D. at 5%	387		

In this trial (1995 summer), 41 MHY, 6 cvs and 4 CHY (Table III) were evaluated. All the female parents of MHY were originally derived from cv N62-32. When compared with cv N62-32, 13 MHY showed significantly higher yields. Among these, 5 MHY were mutant x parent hybrids. When compared with the best check Phule Til-1, 3 MHY showed significant yield increases (104 to 129%) and against best CHY N62-32 x TC-25, two mutant hybrids showed numerical superiority (4 to 10%).

In the fourth yield trial (1996 summer), 38 MHY were evaluated along with 6 cvs and 3 CHY (Table IV). All the female parents of MHY were obtained from cv Phule Til-1. Compared to this cv, 6 MHY gave significant yield increases and one of MHY was mutant x parent. In this trial the best check cv N62-32 was superior over best CHY, Phule Til-1 x N62-32. Although 7 MHY showed numerical superiority (5 to 50%) over CHY, only one MHY showed superiority over best cultivar (10%).

This trial (summer, 1997) was conducted with a view to confirm the superiority of 7 MHY of the first trial along with 6 cvs. Cv Tapi was crossed to 7 mutants of cv N-8 (MHY) and with N-8 (CHY). Compared to i) N-8, ii) best check, N62-32 and iii) CHY, only one MHY showed numerical superiority (Table V). In general, yield levels in this trial were low due to aphid attack at the seed filling stage and no conclusions could be made.

TABLE II. SEED YIELD OF 44 F_1 MUTANT HYBRIDS USING MUTANTS OF N-8 (SUMMER, 1995)

	Hybrid/cultivar	Yield (kg/ha)	% Increase over best	
			Check	Cv hybrid
Mutant hybrids:	NM-80 X N62-32	1819	53	30
	NM-28 X N62-32	1428	40	10
	NM-77 X N62-32	1283	33	–
	NM-54 X N62-32	1218	29	–
	NM-26 X N62-32	1126	24	–
	NM-71 X N62-32	625	–	–
	NM-80 X T-12	1677	49	24
	NM-26 X T-12	1654	48	23
	NM-58 X T-12	1438	40	12
	NM-31 X T-12	1428	40	10
	NM-77 X T-12	1225	30	–
	NY-21 X T-12	1184	27	–
	NM-28 X T-12	1169	26	–
	NM-67 X T-12	1025	16	–
	NM-65 X T-12	1021	16	–
	NM-85 X T-12	876	2	–
	NM-71 X T-12	875	2	–
	NM-74 X T-12	632	–	–
	NM-31 X Phule Til-1	1453	41	12
	NM-54 X Phule Til-1	1197	28	–
	NM-28 X Phule Til-1	1101	22	–
	NY-21 X Phule Til-1	987	13	–
	NM-85 X Phule Til-1	947	9	–
	NM-58 X Phule Til-1	938	9	–
	NM-77 X Phule Til-1	814	–	–
	NM-74 X Phule Til-1	760	–	–
	NM-26 X Phule Til-1	687	–	–
	NM-26 X Phule Til-1	448	–	–
	NM-71 X Phule Til-1	216	–	–
	NM-65 X TC-25	1326	35	4
	NM-85 X TC-25	1192	28	–
	NY-21 X TC-25	1132	24	–
	NM-67 X TC-25	1108	23	–
	NM-77 X TC-25	1085	21	–
	NM-31 X TC-25	1070	20	–
	NM-58 X TC-25	1008	15	–
	NY-9 X TC-25	947	9	–
	NM-74 X TC-25	901	4	–
	NM-54 X TC-25	870	1	–
	NM-71 X TC-25	482	–	–
	NM-54 X Tapi	1080	20	–
	NM-77 X Tapi	1022	16	–
	NM-26 X Tapi	728	–	–
	NM-71 X Tapi	201	–	–
Cultivar hybrids:	N-8 X TC-25	1281		
	N-8 X N62-32	816		
	N-8 X Tapi	680		
	N-8 X Phule Til-1	658		
Check cultivars:	N62-32	861		
	TC-25	433		
	N-8	302		
	Tapi	216		
	C.D. at 5%	633		

TABLE III. SEED YIELD OF 41 F_1 MUTANT HYBRIDS USING MUTANTS OF N62-32 (SUMMER, 1995)

	Hybrids/cultivars	Yield (kg/ha)	% Yield increase over best	
			Check	Cv hybrid
Mutant hybrids:	N-157 X N62-32	1589	129	10
	N-106 X N62-32	1170	60	–
	N-57 X N62-32	1065	54	–
	N-170 X N62-32	1051	51	–
	N-112 X N62-32	959	38	–
	N-29 X N62-32	807	16	–
	N-115 X N62-32	550	–	–
	N-169 X N62-32	491	–	–
	N-57 X TC-25	1496	116	4
	N-29 X TC-25	1064	53	–
	N-170 X TC-25	1043	50	–
	N-169 X TC-25	894	29	–
	N-171 X TC-25	691	–	–
	N-112 X TC-25	644	–	–
	N-115 X TC-25	628	–	–
	N-93 X Tapi	1412	104	–
	N-57 X Tapi	1065	54	–
	N-157 X Tapi	984	42	–
	N-169 X Tapi	879	27	–
	N-29 X Tapi	798	15	–
	N-171 X Tapi	779	12	–
	TTL-3 X Tapi	760	10	–
	N-105 X Tapi	757	9	–
	N-147 X Tapi	751	8	–
	N-170 X Tapi	704	1	–
	N-106 X Tapi	646	–	–
	N-238 X Tapi	610	–	–
	N-112 X Tapi	577	–	–
	N-17 X Tapi	563	–	–
	N-115 X Tapi	463	–	–
	N-170 X Phule Til-1	1212	75	–
	N-57 X Phule Til-1	858	24	–
	N-157 X Phule Til-1	825	19	–
	N-112 X Phule Til-1	732	6	–
	N-29 X Phule Til-1	607	–	–
	N-57 X T-12	1109	69	–
	N-157 X T-12	734	6	–
	N-238 X T-12	677	–	–
	N-29 X T-12	636	–	–
	N-170 X T-12	555	–	–
	N-112 X T-12	493	–	–
Cultivar hybrids:	N62-32 X TC-25	1442	108	
	Phule Til-1 X N62-32	1301	88	
	N62-32 X Tapi	1064	53	
	T-12 X N62-32	736	6	
Check cultivars:	Phule Til-1	694		
	TC-25	568		
	N-8	533		
	N62-32	360		
	T-12	333		
	Tapi	223		
	C.D. at 5%	545		

TABLE IV. SEED YIELD OF 38 F_1 HYBRIDS USING MUTANTS OF PHULE TIL-1 (SUMMER, 1996)

	Hybrids/Cultivars	Yield (kg/ha)	% increase over best	
			check	Cv hybrid
Mutant hybrids:	Y-1 X T-12	1539	10	50
	PY-43 X T-12	928		
	PY-76 X T-12	888		
	Y-55 X T-12	883		
	DTF X T-12	859		
	PY-57 X T-12	782		
	Y-55 X N62-32	1279	–	25
	DTF X N62-32	1024		
	Y-1 X N62-32	951		
	PY-76 X N62-32	803		
	PY-43 X N62-32	760		
	Y-3 X N62-32	750		
	Y-20 X N62-32	658		
	PY-57 X N62-32	636		
	Y-1 X TC-25	1225	–	20
	PY-76 X TC-25	1129	–	
	Y-20 X TC-25	799		
	PY-43 X TC-25	752		
	PY-57 X TC-25	425		
	PY-76 X Phule Til-1	1163	–	14
	Y-1 X Phule Til-1	980		
	DTF X Phule Til-1	812		
	PY-43 X Phule Til-1	806		
	Y-3 X Phule Til-1	756		
	Y-55 X Phule Til-1	623		
	PY-57 X Phule Til-1	607		
	Y-1 X Tapi	1159	–	13
	Y-55 X Tapi	1076	–	5
	Y-66 X Tapi	959		
	PY-43 X Tapi	803		
	DTF X Tapi	725		
	Y-3 X Tapi	680		
	PY-57 X Tapi	679		
	Y-20 X Tapi	674		
	PY-76 X Tapi	597		
	Y-35 X Tapi	587		
	TSE-481 X Tapi	571		
	Y-33 X Tapi	544		
Cultivar hybrids:	Phule Til-1 X N62-32	1025		
	Phule Til-1 X T-12	809		
	Phule Til-1 X Tapi	587		
Check cultivars:	N62-32	1403		
	N-8	801		
	Phule Til-1	731		
	Tapi	495		
	T-12	470		
	TC-25	409		
	C.D. at 5%	422		

TABLE V. SEED YIELD IN N-8 MUTANT HYBRIDS AND CHECK VARIETIES (1997 SUMMER)

Hybrids/cultivars	Yield (kg/ha)	Percent increase over best	
		check (N62-32)	Cv hybrid (N-8 X Tapi)
Mutant hybrids:			
NM-31 X Tapi	850	64	8
NM-54 X Tapi	541	14	
NY-21 X Tapi		488	3
NM-85 X Tapi	476		
NM-26 X Tapi	440		
NM-67 X Tapi	381		
NM-77 X Tapi	354		
Cultivar hybrid:			
N-8 X Tapi	785		
Check cultivars:			
N62-32	476		
N-8	448		
T-12	361		
Tapi	285		
Phule Til-1	234		
C.D. at 5%	374		

In the initial evaluation done to screen superior MHY, it was of interest that some of the mutant x parent hybrids showed superiority over the original parent. Micke [13] described such a phenomenon as monogenic heterosis when heterosis was observed in hybrids of parent x mutant where the mutant differed from the parent in one trait (inherited as monogenic recessive). Micke [13] also pointed out that most of the induced mutants, besides the most obvious trait might also carry a number of other mutations that were phenotypically less obvious, but might influence the vigour of its hybrids. With his experiments with peas, Gottschalk [14] opined that the heterosis-like behaviour observed in MHY in peas was either due to heterozygosity for one single gene or for a small group of mutated genes.

In the present studies, rigorous screening was done to select the best MHY by comparing their yields with the i) parent of mutants, ii) best check and iii) best CHY. As a result, 18 out of 138 MHY evaluated, showed superiority. It appears to be obvious that the recessive mutants were responsible for high heterotic effect when used in the hybrids either with their parent or other cultivars.

Based on reports from Prof. Ashri's laboratory [15, 6] on groundnut, ethidium bromide had been used since 1991 as mutagen for isolating possible male sterile mutants (Murty, unpublished data). Since, the mutagen was anticipated to induce mitochondrial mutations, screening for possible cytoplasmic male sterile mutants had been carried out in the M_1. Among 9,000 M_1 plants grown, eight plants showed different degrees of male sterility within flowers and among anthers. Only such variant plants were harvested individually and in the M_2, plants were once again screened for male sterility. Out of eight, two plant progenies segregated for fertile and male sterile plants (2 sterile out of 28 and 6 out of 28 plants). In the subsequent generations, stable male sterile mutants could not be obtained. It was then decided to use physical mutagen to get male sterility.

In the laboratory studies, there seemed to be stimulation effect with 100 Gy gamma rays for hypocotyl length. Beyond 100 Gy there was a relative reduction with increase in doses (Table VI). These differences were highly significant from 400 Gy to 1100 Gy, over the control. The maximum reduction of hypocotyl length was noticed in 1100 Gy treatment. Percent seedling mortality also increased from 1.63 (100 Gy) to 65.24% (1100 Gy) which was significantly higher from 600 Gy dose and above.

TABLE VI. HYPOCOTYL LENGTH AND SEEDLING MORTALITY IN TEN DAY OLD SEEDLINGS FOLLOWING GAMMA RAY IRRADIATION OF SEEDS OF CV. TAPI

Treatment	Hypocotyl length (cm)	% increase over control	% seedling mortality
Control	4.49	–	0.00
100 Gy	5.02	+11.8	1.63
200 Gy	4.42	– 1.6	5.59
300 Gy	3.86	–14.0	6.28
400 Gy	3.55**	–20.9	7.88
500 Gy	3.33**	–25.8	9.64
600 Gy	2.35**	–47.7	14.45*
700 Gy	2.34**	–47.9	19.39**
800 Gy	1.69**	–62.4	28.16**
900 Gy	1.62**	–63.9	54.99**
1000 Gy	1.53**	–64.6	52.66**
1100 Gy	1.33**	–70.4	65.24**
C.D. at 5%	0.67	–	10.80
1%	0.90	–	14.54

* and ** indicate significant differences over unirradiated control at 5% and 1% probability levels, respectively. Means are based on 50 seeds each, of four replications.

TABLE VII. SEGREGATION FOR FERTILE AND TMST-11 MALE STERILE MUTANT PHENOTYPES

No. of progenies studied	Phenotypic segregation		Ratio	X^2	P
	Fertile	Sterile			
M_2 generation:					
1	8	1			
M_3 generation:					
1	85	0			
6	220	19			
1 non-segregating and 6 segregating lines			1:2	1.0944	10-20
M_4 generation:					
6	212	0			
22	641	169	3:1	7.5893	>5
6 Non-segregating and 22 segregating lines			1:2	1.7533	10-20
11	384	0			
20	558	158	3:1	3.2849	5-10
11 Non-segregating and 20 segregating lines			1:2	0.7124	30-50
5	153	0			
17	402	114	3:1	2.3256	10-20
5 Non-segregating and 17 segregating lines			1:2	1.1192	20-30
4	161	0			
14	362	68	3:1	19.3519	>5
4 Non-segregating and 14 segregating lines			1:2	1.0000	30-50
9	304	0			
11	245	65	3:1	2.6882	10-20
9 Non-segregating and 11 segregating lines			1:2	1.1873	20-30
13	352	0			
19	526	112	3:1	18.8610	>5
13 Non-segregating and 19 segregating lines			1:2	0.7428	30-50
Pooled data of M_3 & M_4:					
49 Non-segregating and 108 segregating lines			1:2	0.3122	50-70

TMST-11 is characterised by dark green foliage and 100% sterile anthers.

Based on laboratory experiments, 400 Gy gamma rays with about 20% seedling height reduction, was chosen as the treatment for growing the M_1 in the field. In the M_2, male sterile variants were marked by making observations for morphological variations in stamens and anthers such as rudimentary stamens, green anthers, partially or fully shriveled anthers etc. on the day of flower opening. In all, 25 such sterile variants were identified. Of these only 4 bred true for the male sterility subsequently. Detailed studies carried out on these mutants, designated as TMST-11, TMST-10, TMST-15 and TMST-103, were as follows:

TMST-11: The mutant can be identified in 15 day old seedlings due to its dark green foliage. It had 100% male sterility due to presence of four staminodes. When observed under the microscope, there were no pollen grains and the anthers remained green in colour. However, repeated crossings didn't help in seed setting. Hence, fertile sib plants were individually harvested to advance to subsequent generations. The segregation for male sterile plants from M_3 and M_4 (Table VII) indicated that the mutant trait was controlled by one pair of recessive genes. The level of female fertility in the early generations was very poor. It started improving by producing 2 to 10 fertile seeds per capsule on crossing, however the germination was poor. In the M_6, the germination was improved when the mutant was crossed with sibs, parent and other germplasm. During 1998 summer, F_1 generation is being grown in the field.

TMST-10: In the M_2, one out of three surviving plants in a progeny had profuse flowering with hundreds of small female flowers. The stamens were either rudimentary or not existing. Repeated crosses with the sibs and parent plants did not help in seed setting. Hence, the two fertile sib plants were carried forward to the M_3. The segregation for fertile and male sterile plants in the M_3 and M_4 generations (Table VIII) indicated that the mutant trait is governed by one pair of recessive genes.

TMST-15: Although the mutant is phenotypically similar to its parent, cv Tapi, TMST-15 is both male and female sterile. The segregation pattern from M_3 to M_4 indicated that the male sterility trait of the mutant appears to be governed by duplicate recessive genes. However, phenotypes segregated in a modified ratio of 15.5 fertile: 0.5 sterile (Table IX) instead of 15:1.

TABLE VIII. SEGREGATION FOR FERTILE AND TMST-10 MALE STERILE MUTANT PHENOTYPES*

No. of progenies studied	Phenotypic segregation		Ratio	X^2	P
	Fertile	Sterile			
M_2 generation:					
1	3	1			
M_3 generation:					
2	69	13	3:1	4.9480	>5
M_4 generation:					
21	342	0			
9	83	23	3:1	0.6163	30–50
12	180	15	15:1	0.6923	30–60
21 N.Sg.**, 9 Sg**. For 3:1 & 12 for 15:1			7:4:4	0.5893	30–50

*TMST-10 is characterised by bunches of vary small female flowers.
**N Sg = non-segregating, Sg = segregating.

TABLE IX. SEGREGATION FOR FERTILE AND TMST-15 MALE STERILE MUTANT PHENOTYPES*

No. of progenies studied	Phenotypic segregation		Ratio	X^2	P
	Fertile	Sterile			
M_2 generation:					
	9	1			
M_3 generation					
1	36	0			
8	249	8	15.5 : 0.5	0.0000	100
M_4 generation					
19	332	0			
6	127	6	15.5 : 0.5	0.7966	30–50
Pooled data of M_2 to M_4					
	385	15	5.5 : 0.5	10.5161	30–50
non-segregating 20 : 15 segregating progenies			7:8	1.5720	20–30

*In TMST-15 both male and female flower parts are sterile and plants resemble parent.

TMST-103: All plants in one of the M_2 progenies were segregating for fertile and sterile pollen grains. Certain flowers had green anthers also. Hence, such flowers were selfed. At maturity, the selfed capsules and whole plants were individually harvested. In the subsequent generation, they were grown as capsule to row and plant to row progenies and pollen was analysed. The capsule and plant progenies continued to segregate. When compared to the M_2, there was a reduction for percent pollen sterility and percent green anthers in the M_3 (Table X).

In order to widen variability for male sterility, further mutation experiments were carried out. From the gamma ray treated M_1 generation, 1567 plants from 600 Gy treatment, 1015 from 700 Gy and 354 of 800 Gy were individually harvested. The M_2 generation is to be grown during 1998 rainy season.

In sesame, male sterility was reported by Osman and Yermanos [17] which had proved useful for the hybrid seed production [18]. Male sterility was also induced by spraying gametocides [19]. By 50 Gy gamma ray seed treatment, mutants segregating for pollen sterility were obtained in M_1 generation [20]. Reviewing genetic male sterility, Gottschalk [21] was of the opinion that male sterility could be caused by genes due to partial or complete transformation of stamens into carpels in many species. The gene action would lead to transformation of bisexual flowers of a species into unisexual ones. In strictly self-pollinated species these mutants were usually seed sterile with the exception of *Triticum* mutant. In the present male sterile mutants, the segregation pattern indicated that TMST-10, 11 and 15 were genetically controlled mutants. In TMST-10, the stamens were considerably reduced in size or even absent. Probably the gene action in this case might be similar to Gottschalk's suggestion[21]. In the case of TMST-11, there was no seed sterility. At present, allelic relation of TMST-11 and the natural mutation studied at U.C. Riverside [17] is not known.

The mutant NM-54 could be identified easily as the leaves remain yellow from seedling stage to harvest, compared to green leaves seen all throughout in Tapi and other cultivars. When NM-54 was crossed to four other cultivars all the F_1 plants were green indicating the dominance of green leaves over chlorina trait. In F_2 generation, seedlings segregated in a ratio of 3 green : 1 chlorina (Table XI), confirming that chlorina trait of NM-54 is monogenically controlled, with chlorina recessive to green. Hence, in the experiments on outcrossing, the segregation for green seedlings among NM-54 progenies was considered due to outcrossing. Based on the segregations in the plant and capsule progenies (Table XII), it is seen that there were no big differences in the results whether the seeds were initially mixed and sown or grown in alternate rows. However, there were differences for outcrossing percentages between plant and capsule progenies. Among the open pollinated plants, 92 to 98% plants were outcrossed. On the other hand 32 to 65% capsules were outcrossed. Based on

TABLE X. SEGREGATION FOR FERTILE AND MALE STERILE POLLEN GRAINS IN MALE STERILE MUTANT TMST-103

Plant No.	Pollen grains No.		Pollen sterility %	% green anthers in total studied
	Fertile	Sterile		
M_2 generation:				
1	1323	639	33	19
2	1833	889	33	25
3	1501	632	30	25
4	891	695	44	15
5	1983	891	31	10
6	1008	893	42	25
7	1564	888	36	10
8	1710	857	33	10
9	1333	853	39	20
10	1486	776	34	20
11	736	556	43	35
12	1878	1325	41	20
13	1298	805	38	20
14	1546	888	37	20
Mean	1435±99	828±49	37±1	19±2
M_3 generation:				
Plant bulks progenies:				
	941	123	12	25
	1209	121	9	0
	887	87	9	0
	747	70	9	0
	958	84	8	0
	581	156	21	0
	810	75	8	0
	156	57	27	25
	413	90	18	25
	196	132	40	0
	495	26	8	0
Mean	673±100	94±11	11±2	7±4
Selfed capsules progenies:				
	879	62	7	0
	297	86	22	25
	932	77	8	0
	391	72	16	25
	807	67	8	0
	523	31	6	25
	714	138	16	0
	667	122	16	17
	535	56	10	0
	348	120	26	0
	101	120	54	0
Mean	464±81	82±12	17±4	8±4

plant to row progenies, the outcrossing percentage ranged between 0.0 and 13.8% with an average between 2.0 to 4.0% while in capsule to row progenies, the outcrossing percentage ranged between 0.0 to 46.7% with an average between 1.8 to 7.4%.

TABLE XI. SEGREGATION OF NM-54 (CHLORINA) AND GREEN SEEDLINGS IN THE F_2 GENERATION

Cross	Frequency of phenotypes		Total	X^2	P
	Green	Chlorina		3:1	
NM-54 X TC-25	314	121	435	1.841	0.20–0.10
NM-54 X Tapi	275	85	360	0.370	0.70–0.50
NM-54 X T-12	98	39	137	0.878	0.50–0.30
NM-54 X N62-32	300	115	415	1.635	0.30–0.20
Pooled	987	360	1,347	2.140	0.20–0.10

In the case of plant progenies, outcrossing depends mainly on the ratio between the number of outcrossed flowers and total number of self pollinated flowers per plant. Consequently, the maximum outcrossing recorded in plant progenies is lower. Since, each cross can result in about 50 seeds, capsule progenies showed as expected higher outcrossing rate than plant progenies. As a result, maximum range and average outcrossing was recorded in capsule progenies. Outcrossing in sesame reported by many researchers ranged between 0 to about 10% and even up to 65% under particular environmental conditions [22]. When recessive and dominant traits were grown in alternate rows [23], the mean natural cross pollination rate was 12.8% (range 6.1 to 20.1%).

TABLE XII. OUTCROSSING FREQUENCY IN PLANT AND CAPSULE PROGENIES OF CHLORINA FROM TWO EXPERIMENTS

Number of progenies per progeny			Mean frequency of phenotypes		% outcrossing	
Studied	Segregated	% segregation of progenies	Chlorina	Green	Range	Mean
PLANT TO ROW PROGENIES						
Mixed seed:						
53	52	98.1	197.0+01.4	4.9+0.6	0.0–09.8	2.7+0.3
25	23	92.0	100.8+06.6	4.0+0.8	0.0–13.8	4.0+0.6
Alternate rows:						
56	55	98.2	226.7+14.9	4.5+0.6	0.0–07.1	2.0+0.2
30	29	96.7	125.3+15.5	4.0+0.5	0.0–12.3	4.1+0.6
CAPSULE TO ROW PROGENIES						
Mixed seed:						
40	26	65.0	23.9+01.4	1.6+0.3	0.0–46.7	7.4+1.6
25	14	56.0	42.7+03.2	1.5+0.4	0.0–18.8	3.4+1.0
Alternate rows:						
40	20	41.7	28.6+03.7	0.9+0.2	0.0–25.0	3.5+0.9
25	08	32.0	43.2+02.2	0.9+0.4	0.0–19.6	1.8+0.9

The present results also did not show very high outcrossing when natural outcrossing took place under summer conditions. Thus, although sesame appears to be predominantly self pollinated crop, the present results confirm that a certain degree of natural outcrossing takes place. The outcrossing percentage could possibly be enhanced for hybrid seed production under controlled conditions by growing the plants in cages with the help of honeybees. The present results indicate that mutation breeding continues to be a powerful tool to develop heterotic hybrids using induced mutants and also to induce male sterile mutations.

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STUDIES ON INDUCED MUTATION OF SESAME MALE STERILITY

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Abstract

The dry seeds of the high yielding cultivar, Yuzhi-4, were irradiated with 300, 500 and 700 Gy of ^{60}Co-gamma rays. 3277 M_1 plants were harvested separately as single plants and also in bulk, by doses. In M_2, the single plant seeds were grown in progeny rows and the bulked seeds were grown as bulks. 25 male sterile plants were screened from M_2. 10 of the 25 male sterile plants were from the progenies of the single plant seeds and 15 were from the progenies of the bulked seeds. In further genetic research of the 25 male sterile plants in M_3 and M_4, 6 separate genic male sterile (GMS) lines were identified. Their male sterility was stable and was controlled by a pair of alleles, male fertility being dominant to sterility.

1. INTRODUCTION

Sesame is an oil crop which can show a high degree of heterosis. Its hybrids' yields can increase by 20–30%, and in the best a 60% increase can be obtained. Sesame heterosis breeding research is progressing slowly because male sterile breeding material is scarce and not ideal. Cytoplasmic-genic male sterile (CGMS) material has not been found in the world so far. The existing genic male sterile (GMS) materials are not good. Their male sterility rates are low (less than 50%) and their agronomic characters are not ideal. Induction of mutation is an efficient method for creating new breeding materials, so research was carried out to create new male sterile breeding material that would be ideal and be used for heterosis breeding directly.

2. MATERIALS AND METHODS

In M_1, the dry seeds of the high yielding cultivar,'Yuzhi-4', were irradiated with 300, 500 and 700 Gy of ^{60}Co-gamma rays. All M_1 plants were selfed and harvested individually by treatment. The number of the harvested capsules from the single plant varied: 5–10 when the capsules were large, 10–15 if medium and 15–20 if they were small. In M_2, the seeds from the single plants were grown in progeny rows and the mixed seeds of each dose treatment were grown in a bulk. The anthers of each M_2 plant were observed carefully. The male sterile plants whose anthers did not contain any pollen or contained only a little pollen were labeled at early flowering stage. All male sterile plants were observed every day during the whole flowering period. Their male sterile expression was recorded. All male sterile plants were crossed with their sib-plants at 5 a.m., before the bees started work. Wheat straw pieces were used to cover the stigmas of the male sterile plants after pollination to prevent out-crossing. The capsules of each male sterile plant were harvested separately at maturity. In M_3, the seeds from the single capsules of the male sterile plants were grown separately. The male sterility of M_3 plants was recorded. The segregation ratio of the male sterile and fertile plants in the progenies of the single capsule seeds were counted. The heterozygous fertile (*Ms/ms*) plants (sib-plants of the male sterile plants) which segregated among the progenies of the single capsule seeds were selfed, and the male sterile plants which segregated from them were crossed with the heterozygous male fertile plants (sib-plants) which segregated from the progenies of the same capsules and with the homozygous fertile (*Ms/Ms*) plants (non-irradiated parent plants). In M_4, the seeds from the selfed *Ms/ms* plants and from the male sterile plants which were crossed with the *Ms/ms* plants and with the *Ms/Ms* plants were grown separately. The male sterile expression of all M_4 male sterile plants was checked further. The frequencies of male sterile and fertile plants in the progenies of the three combinations were recorded.

3. RESULTS AND DISCUSSION

3.1. Development of M_1 plants

The single plant seeds of 3277 M_1 plants and the mixed seeds of all M_1 plants of each dose treatment were harvested. 1147 of 3277 M_1 plants were from 300 Gy treatment, 1125 from 500 Gy treatment and 1005 from 700 Gy treatment.

3.2. Screening for male sterile plants in M_2

In M_2, the seeds from each plant of 3277 M_1 plants were grown in progeny rows and the mixed seeds of all M_1 plants of each dose treatment were grown in a bulk; 25 male sterile plants were recovered. They were numbered as 95ms-1, 95ms-2, 95ms-3, 95ms-4, 95ms-5, 95ms-6, 95ms-7, 95ms-8, 95ms-9, 95ms-10, 95ms-11, 95ms-12, 95ms-13, 95ms-14, 95ms-15, 95ms-16, 95ms-17, 95ms-18, 95ms-19, 95ms-20, 95ms-21, 95ms-22, 95ms-23, 95ms-24, 95ms-25. 9 of the 25 male sterile plants came from 500 Gy treatment, 16 from 700 Gy treatment, and none from the 300 Gy treatment. Ten male sterile plants, 95ms-1, 95ms-2, 95ms-3, 95ms-4, 95ms-5, 95ms-6, 95ms-7, 95ms-8, 95ms-9 and 95ms-10 were found among the single plant progenies and the other 15 male sterile plants were screened from the bulk progenies from each dose treatment. During the whole flowering period, the 10 male sterile plants had different male sterile expressions. They are described below.

95ms-2 and 95ms-19 gave completely male sterile plants. During the whole flowering period their anthers had no pollen. They were completely male sterile when they were selfed and could bear seeds when they were crossed with their sib-plants. The anthers of 95ms-2 were brown, while those of 95ms-19 were green. The anthers of both were flat and a little smaller than normal.

In 95ms-1, 95ms-8, 95ms-9 and 95ms-10 the male sterility could be environmentally affected. Their anthers contained a little pollen but showed self-sterility when the temperature was high late in the flowering period. The anthers were normal and showed self-fertility when temperatures were low at the early flowering stage. Their anther color and shape were different, i.e. greenish and flat when they were sterile, and normal when they were fertile.

95ms-3, 95ms-4, 95ms-5, 95ms-6, 95ms-7, 95ms-12, 95ms-13, 95ms-20, 95ms-21 and 95ms-23 were unstable sterile plants. Their anthers sometimes contained a little pollen, sometimes contained no pollen. At times, all anthers in a flower contained a little pollen, sometimes only one or two where the others contained no pollen. Their anther color was special; one half was greenish and the other half was white. Their anther shape varied; some were small and flat, and some were long and flat. They expressed fertility when anthers contained pollen, and sterility when anthers contained no pollen.

95ms-11, 95ms-14, 95ms-15, 95ms-16 and 95ms-17 gave male sterile plants whose anthers were malformed. Their anthers were triangular and very small, being about one fifth or one tenth of the normal anther size. The anther color was yellow. They were male sterile during the whole flowering period.

95ms-18 and 95ms-25 were the male sterile plants whose anther color and shape were unstable; their anther color was sometimes green, and sometimes yellow or white-green. Their anthers were sometimes big, sometimes small and sometimes crescent-shaped.

95ms-22 and 95ms-24 were false male sterile plants. They expressed male sterility during 3–5 days when the male sterile plants were being counted, but they always expressed male fertility later.

3.3. Identification and preliminary genetic research of male sterile mutants in M_3

3.3.1. Identification of 6 male sterile mutants

In M_3, 25 male sterile mutants behaved as follows: i) two mutants (95ms-1 and 95ms-25) did not have any progeny because their seeds were unfilled; ii) 6 male sterile mutants (95ms-2, 95ms-3, 95ms-4, 95ms-5, 95ms-6 and 95ms-7) segregated for male sterile and -fertile plants continued; iii) the other 17 male sterile mutants did not produce any male sterile plants.

The male sterility of the M_3 male sterile plants which segregated among the progenies of the 6 male sterile mutants, was stable. During the whole flowering period their anthers did not contain any pollen; they were completely sterile when they were selfed. The anther color of the male sterile plants from 95ms-2 was brown and all anthers of all the male plants from the other sterile mutants were green. The anther shape of all male sterile plants was flat and a little shorter than the normal anthers.

3.3.2. Genetic research of the 6 male sterile mutants

Segregation was observed for male sterile and fertile plants in the progenies of each single capsule seeds of each male sterile mutant. The progenies of some single capsule seeds produced male sterile and -fertile plants, some only produced male fertile plants, and none produced only male sterile plants. The result showed that the 6 male sterile mutants that gave male sterile and -fertile segregation in M_3 were genic male sterile (GMS) mutants. Progenies of the single capsule seeds segregated male sterile and -fertile when the capsules resulted from crosses with heterozygous fertile (*Ms/ms*) plants in M_2, and produced only male fertile plants when the cross was with homozygous fertile (*Ms/Ms*) plants in M_2.

Segregation ratio was observed in M_3 for male fertile vs. -sterile plants in all the progenies that were raised from each different male sterile mutant and that segregated. The segregation ratio of male fertile and -sterile plants was 38:30 for 95ms-2, 41:38 for 95ms-3, 57:52 for 95ms-4, 88:75 for 95ms-5, 74:71 for 95ms-6 and 37:34 for 95ms-7. The result showed that the observed frequencies did not deviate significantly from the expected monogenic segregation (1:1) ratio (Table I). The findings showed a good fit to monogenic control of male sterility, with the fertility allele being dominant.

TABLE I. SEGREGATION FOR MALE -STERILE AND -FERTILE PLANTS IN ALL THE PROGENIES THAT WERE RAISED FROM THE SINGLE CAPSULES OF THE SIX MALE STERILE MUTANTS

Male sterile mutants	Observed ratio F:S	Expected ratio F:S	X^2 value	P value
95ms-2	38:31	1:1	0.523	0.5-0.25
95ms-3	41:38	1:1	0.051	0.9-0.75
95ms-4	57:52	1:1	0.147	0.75-0,5
95ms-5	88:75	1:1	0.883	0.5-0.25
95ms-6	74:71	1:1	0,028	0,9-0.75
95ms-7	37:34	1:1	0.056	0.9-0.75

3.4. Further genetic research of 6 male sterile mutants in M_4

In M_4, segregation was observed for male -sterile and -fertile plants in the progenies of the selfed heterozygous fertile (*Ms/ms*) plants, the male sterile (*ms/ms*) plants crossed with heterozygous fertile (*Ms/ms*) plants and the male sterile (ms/ms) plants crossed with homozygous fertile (*Ms/Ms*) plants. The segregation ratios of male sterile and fertile plants in the progenies of 3 combinations are listed in Table II. The observed frequencies in the three combinations did not deviate significantly from the expected values. The high probability values showed good fit to the 1:1, 1:0 and 3:1 ratios, further confirming a monogenic control of the male sterility with male fertility completely dominant over male sterility.

TABLE II. SEGREGATION FOR MALE -STERILE VS. -FERTILE PLANTS IN THE PROGENIES OF *ms/ms* x *Ms/ms*, *ms/ms* x *Ms/Ms* AND THE SELFED *Ms/ms*

Cross/self	Observed ratio F:S	Expected value F:S	X^2 value	P value
95ms-2xMs/ms	621 : 603	1:1	0.236	0.750–0.500
95ms-2xMs/Ms	163 : 0	1:0	–	–
Selfed Ms/ms	225 : 69	3:1	0.290	0,750–0.500
95ms-3xMs/ms	716 : 660	1:1	2.198	0.250–0.100
95ms-3xMs/Ms	157 : 0	1:0	–	–
Selfed Ms/ms	219 : 72	3:1	0.0014	>0.995
95ms-4xMs/ms	1167:1086	1:1	2.842	0.100–0.050
95ms-4xMs/Ms	125 : 0	1:0	–	–
Selfed Ms/ms	243 : 75	3:1	0.2683	0.750–0.500
95ms-5xMs/ms	843 : 819	1:1	0.318	0.750–0.500
95ms-5xMs/Ms	184 : 0	1:0	–	–
Selfed Ms/ms	234 : 72	3:1	0.2788	0.750–0.500
95ms-6xMs/ms	1109:1026	1:1	3.149	0.100–0.050
95ms-6xMs/Ms	198 : 0	1:0	–	–
Selfed Ms/ms	254 : 76	3:1	0.5818	0.500–0.250
95ms-7xMs/ms	1126:1053	1:1	2.306	0.250–0.100
95ms-7xMs/Ms	175 : 0	1:0	–	–
Selfed Ms/ms	213 : 65	3:1	0.3069	0.750–0.500

4. CONCLUSION

Induced mutation is an efficient method of creating new breeding material. The 6 GMS lines induced by ^{60}Co gamma rays possessed good economic characters and resistance to disease. They were similar to their parent (a good cultivar, Yuzhi-4) in all ways except their male sterility. They have been used for heterosis breeding.

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DEVELOPMENT OF AN IDEAL PLANT TYPE AND MALE STERILITY SYSTEM IN SESAME SUITABLE FOR SUMMER RICE FALLOW IN THE COASTAL REGIONS OF TAMIL NADU

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Abstract

In Tamil Nadu, sesame growing on available residual soil moisture after the rice harvest is expanding. In order to achieve higher and more reliable yields under these conditions, a more suitable plant type is needed; with shorter stature and growing period, moderate basal branching and higher productivity. Seeds of 6 varieties were treated with gamma rays, diethyl sulphate (DES) and ethyl methane sulphonate (EMS). The M_1–M_4 generations were studied and several promising mutants were selected. Among them were also male sterile mutants; it is thought that such mutants will assist in producing hybrid varieties which will give the desired yield breakthrough.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is regarded as "Queen of oil seeds" by the users because of its oil quality and multiple domestic and religious applications. Sesame is believed to have originated in India where much genetic diversity occurs in the cultivated forms. India is the largest producer of sesame in the world (40% of the area and 30% of the production). Though sesame is an energy rich crop, it is mostly raised under low input conditions. Consequently, it has become well adapted to varying agro-climatic conditions. Although the crop's yield potential is around 1000 kg/ha, the current level of productivity in India is only 325 kg/ha.

1.1. Ideal plant type

Tamil Nadu is one of major sesame growing states in India. The scope for increasing the production in the traditional area in Tamil Nadu is very much limited. Oilseed Technology Mission (1986) paved the way to increase the area and production in the state. Sesame cultivation using the available residual soil moisture after rice harvest in the delta regions of Tamil Nadu during February–May has gained momentum. The productivity under such an ecosystem is considerably higher. However, improved varieties available in Tamil Nadu are mostly tall growing with longer duration, which are not suitable for the rice fallow ecosystem. An attempt was made to develop an ideal plant type with following characters suitable for rice fallow situation:

- Short stature
- Short duration
- Moderate basal branching
- Profuse fruit set
- High seed set
- High productivity

1.2. Male sterility system

Hybrid breeding is one of the most effective methods to achieve a quantum jump in seed yields, up to 200 per cent or more. Sesame is one of the self pollinated crops best suited for heterosis breeding because of the following added advantages:

- Fruit set is very high
- Honey bee activities help easy pollen transfer
- A high number of seeds per fruit
- Significant degree of heterosis
- Scope for the development of male sterile line.

Therefore an attempt was made also to develop genic male sterile lines among the locally well adapted genotypes with nicking ability for the expression of heterosis for seed yield.

2. MATERIALS AND METHODS

2.1. Selection of genotypes

The selection of desirable genotypes is definitely the most decisive factor for any mutation breeding programme. It requires a thorough knowledge of the morpho-physiological traits of the genotypes to be used for the study. Based on the said objectives, the following points were considered while selecting the genotypes for the mutagenic treatments in the present study:

- Genetically divergent
- Recently developed/released
- Locally well adapted
- Good combining ability
- Significant level of heterosis [1,2]

2.2. Genotypes selected

– Annamalai	– BS 6-1-1
– CO 1	– BS 49
– Paiyur 1	– TMV 4

2.3. Selection of mutagens

Both physical and chemical mutagens were used in the present study:
Physical mutagen – Gamma rays
Chemical mutagens– DES, EMS

2.4. LD_{50} vlues

LD_{50} values for gamma rays, DES and EMS were determined by seed germination and seedling survival methods for all the genotypes studied. The following were established:

Gamma rays	–	500 Gy
DES	–	0.1 % for 2 hr + 2 hr post treatment washing
EMS	–	1.0 % for 2 hr + 2 hr post treatment washing

2.5. Observations mde

- Seed germination
- Seedling survival
- Days to flowering
- Plant height
- Number of branches per plant
- Number of capsules per plant
- Number of seeds per capsule
- Seed yield per plant
- Pollen fertility per cent

2.6. Populations studied

- M_1 generation
- M_2 generation

- M_3 Families
- M_4 Families

3. EXPERIMENTAL RESULTS

3.1. Evaluation of mutagens

Among the mutagens and doses studied, the chemical mutagens were superior to gamma rays in the induction of viable mutations. More EMS-induced desirable mutants bred true in the later generations, as compared to the DES-induced mutants.

3.2. Evaluation of genotypes

Induction of desirable mutants was at random in respect to both the genotypes and the mutagens.

3.3. M_1 generation

In general, M_1 generation showed a reduction in all growth characters in all genotypes, when compared to the control populations in all the treatments (Table I).

TABLE I. MEAN PERFORMANCE OF ECONOMIC CHARACTERS IN M_1 GENERATION

Genotype/ treatment	Days to flowering	Plant height (cm)	No. branches per plant	No. capsules per plant	Seed yield / plant (g)
Annamalai					
Control	42.20	97.70	3.00	67.90	8.99
Gamma	39.24	86.60	3.88	48.68	8.06
EMS	39.96	87.12	3.60	43.60	7.82
CO 1					
Control	41.00	90.00	3.80	60.00	8.53
Gamma	38.88	89.64	4.40	46.12	6.92
EMS	40.00	86.36	3.88	44.30	6.00
Paiyur 1					
Control	42.80	85.10	4.70	71.10	7.52
Gamma	40.84	76.20	4.60	60.74	4.91
EMS	40.56	78.15	4.10	62.14	6.42
BS 6-1-1					
Control	42.80	85.10	3.20	56.60	5.20
Gamma	40.86	76.20	3.76	46.00	4.10
EMS	40.56	78.15	3.88	46.52	4.62
BS 49					
Control	41.30	91.00	3.50	42.90	6.73
Gamma	39.92	86.90	3.68	44.44	4.96
EMS	38.72	84.00	4.24	47.62	4.77
TMV 4					
Control	41.70	105.80	3.89	68.60	6.63
Gamma	39.92	90.40	3.84	47.52	4.44
EMS	40.96	87.20	4.20	56.66	4.06

3.4. M_2 generation

The M_2 generation showed a wide range of variation in all the characters studied. However the mean performance showed general reduction in number of days to flowering, plant height, number of capsules per plant and seed yield per plant. However, there was a slight increase in the number of branches per plant and number of seeds per capsule (Table II). The M_2 generation produced a few male sterile plants.

TABLE II. MEAN PERFORMANCE OF ECONOMIC CHARACTERS IN M_2 GENERATION

Genotype/ Treatment	Days to flowering	Plant height (cm)	No. branches/ plant	No. capsules/ plant	Seeds/ capsule	Seed yield/ plant (g)
Annamalai						
Control	42.20	97.70	3.00	67.90	48.00	8.99
Gamma	40.26	70.10	3.90	49.70	53.56	4.01
EMS	40.76	67.12	3.58	50.90	56.56	4.25
CO 1						
Control	41.00	90.00	3.80	60.00	40.40	7.82
Gamma	40.01	71.43	4.40	48.12	47.88	4.20
EMS	40.36	69.64	3.80	52.98	57.44	4.41
Paiyur 1						
Control	42.80	85.10	4.70	71.10	42.10	7.52
Gamma	42.60	66.09	4.10	46.92	46.80	4.18
EMS	40.54	62.56	4.02	55.42	67.20	4.82
BS 6-1-1						
Control	42.80	85.10	3.20	56.60	42.00	5.20
Gamma	42.12	60.20	3.80	47.52	50.20	4.10
EMS	39.98	59.44	3.72	43.18	46.16	3.88
BS 49						
Control	41.30	91.00	3.50	42.90	46.00	6.73
Gamma	41.80	74.48	4.18	48.68	49.10	4.12
EMS	41.30	66.92	3.68	55.82	59.76	4.66
TMV 4						
Control	41.70	105.80	3.89	68.60	41.20	6.63
Gamma	42.80	60.10	4.22	44.60	47.16	4.30
EMS	41.10	60.40	5.02	64.02	68.08	6.78

3.5. M_3 and M_4 families

Selection pressure for plants with the ideal plant type was applied in the M_2 generation. Selected M_2 plants were selfed and advanced to M_3 families.

M_3 families again showed a wide range of variation for all characters, particularly for seed yield per plant, number of capsules per plant and number of seeds per capsule (Table III). This increased variability, caused by induction of mutations, helped us to select high yielding lines. Nine selected superior individuals from the M_3 families were advanced to the M_4 generation and studied family wise (Table IV). It was interesting to note that selection pressure on the characters like number of branches per plant, number of capsules per plant and number of seeds per capsule significantly contributed to higher seed yield. Based on the ideal plant type, the following four mutant families have been recommended for preliminary yield trial:

Mutant	Seed yield/plant (g)
AUS 933 - 46	16.76
AUS 1138 - 31	16.75
AUS 1198 - 15	19.36
AUS 1207 - 30	21.31

TABLE III. MEAN PERFORMANCE OF ECONOMIC CHARACTERS IN M_3 FAMILIES

Select. No.	Mutants	Days to flowering	Plant height (cm)	No. branches/ plant	No. capsules/ plant	No. seeds/ capsule	Seed yield/ plant (g)
1.	AUS 280	41.74	69.86	4.08	60.42	67.08	6.22
2.	AUS 802	40.94	83.63	4.98	78.92	71.80	7.45
3.	AUS 826	41.10	84.90	5.12	79.44	74.00	7.50
4.	AUS 993	38.66	66.58	4.30	55.60	65.50	7.11
5.	AUS 1138	39.04	61.76	4.10	56.24	60.32	5.42
6.	AUS 1198	37.14	60.42	4.32	59.32	66.36	6.06
7.	AUS 1207	37.10	62.42	4.24	57.22	64.28	6.01
8.	AUS 1272	38.72	65.88	4.12	86.82	62.32	5.66
9.	AUS 1373	43.96	78.52	4.14	60.32	72.04	5.44

TABLE IV. MEAN PERFORMANCE OF ECONOMIC CHARACTERS IN M_4 FAMILIES

Select. No.	Mutants	Days to flowering	Plant height (cm)	No. branches/ plant	No. capsules/ plant	No. seeds/ capsule	Seed yield/ plant (g)
1.	AUS 280-10	43.94	82.90	5.96	99.18	83.00	12.11
2.	AUS 802-17	43.32	86.30	7.58	117.78	88.16	12.16
3.	AUS 826-110	43.36	89.58	8.48	153.58	85.80	14.21
4.	AUS 993-46	43.46	87.98	7.23	161.00	75.36	16.76
5.	AUS 1138-31	41.52	86.18	7.58	156.32	71.44	16.75
6.	AUS 1198-15	37.56	75.90	7.78	177.40	86.44	19.36
7.	AUS 1207-30	39.46	79.96	8.08	173.50	99.68	21.31
8.	AUS 1272-120	40.06	94.52	5.86	120.78	67.84	13.60
9.	AUS 1373-104	44.42	95.50	5.92	88.70	71.72	13.50

3.6. Male sterility system

The M_2 generation was studied in detail to locate male sterile plants in the population. Flowers of all the M_2 plants were tested for pollen sterility with 1% acetocarmine staining. Out of 15,200 plants tested only two plants were found to be completely male sterile. The two male sterile plants were sib-mated and few capsules from each plant were harvested. The male sterile plants were mostly unbranched, produced few small flowers and on sib pollination, they produced few capsules (Table V).

TABLE V. ATTRIBUTES OF THE MALE STERILE PLANTS (OPEN POLLINATED)

Plant height, cm	78
Number of branches/plant	3–4
Number of capsules/plant	20–24
Number of seeds/capsule	15–20
Seed yield / plant, g	1.50
Pollen sterility, %	100

However on open pollination they produced more capsules, with a few seeds in each capsule. The sib-mated progenies failed to produce equal number of male sterile and male fertile plants. There was no regular Mendelian segregation in the F_2 or other generations. The frequencies of male sterile plants were always lower than expected. Further standardisation of the maintenance of male sterile plants is in progress.

4. DEVELOPED ECONOMIC AND USEFUL MUTANTS

In this project several interesting and useful mutants were found in advanced mutant families. Most of these can and will be further used in breeding programmes. These mutants are:

- *Mono-stem (uniculm) mutant*
  A mono-stem mutant was identified in the M_3 families and selfed to obtain homozygosity for this economic trait. The stem colour is pale green, capsules long and white seeded.
- *Hairy mutant*
  Few plants with low branching habit possessed more hairs on the stems, petioles and capsules. Their selfed seeds are to be sown to study the genetics of this character.
- *Male sterile mutants*
  The progenies of two male sterile lines are under further study.
- *Other mutants* (these mutants have no economic value but could serve as markers)
  – Tiny leaf mutant
  – Chlorophyll mutant
  – Dichotomous branching mutant

5. FUTURE PLAN OF WORK

The sesame breeding efforts will continue and emphasis will be made on the development of cytoplasmic male sterile lines to be used in cross breeding programmes. The following plans are made to proceed in this manner:

– Male sterile plants will be crossed with wild species *S. malabaricum* to develop cytoplasmic male sterile lines through the backcross method.
– Wide hybridization with two wild forms, namely *S. indicum* var. *senkottaienises* and *S. indicum* 0var. *yanamalaiensis,* will also be attempted in order to develop CMS lines.

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MUTATION INDUCTION IN SESAME IN UGANDA

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Abstract

Seeds of five sesame cultivars: T-85, Serra, EM-14, Anyana and S were irradiated with 0, 200, 300, 400, 600 and 800 Gy doses of gamma rays. Irradiated seeds together with their controls were planted in 1995 to produce M_1 plants. Records were taken on germination percentage after four days and three weeks, and vigour also after three weeks of germination. Much decline in growth was recorded from the doses of 600 and 800 Gy. Five capsules/plant from each variety per dose were harvested to grow M_2 progenies. 276 single plants were selected out of 2,636 plants from all the treated varieties. Out of 276 plants selected and planted, 30 progeny rows of those single plants were further selected to be tested in a preliminary yield trial. From five varieties about 7,000 seeds per dose per variety have again been irradiated with 300, 400, 500, and 600 Gy gamma rays.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is a crop grown for its seeds, which contain 45–55% high quality oil [1]. In Uganda, it is mainly grown in the north and north-eastern part of the country which is relatively drier and sparsely populated. Seed yield of sesame in Uganda are low due to lack of better varieties, poor agronomic practices and severe environmental conditions like drought, water logging, pests and diseases. This has also been realised in some other countries [2]. Sesame breeding as a traditional oil crop was neglected for a long time until the recent past. Farmers still grow their local cultivars that are low yielding but adapted to the local condition. The breeding programme lacks genetic resources of wide and useful variations.

Table I shows the annual area cultivated, its production and yield. Whereas the area has expanded, the yield still fluctuates between 350–500 kg/ha. Table II shows the seasonal yields of some of the breeding lines at the Institute.

TABLE I. AREA HARVESTED, PRODUCTION AND YIELD OF SESAME IN UGANDA 1981–1989*

Year	1981	1982	1983	1984	1985	1986	1987	1988	1989
Area (x 1000 ha)	70.01	79.97	94.56	86.29	75	80.44	73.99	80.82	133.6
Production (x 1000 MT)	25.42	35.42	41.98	38.78	26	34.61	32.97	36.21	66.8
Yield (kg/ha)	363	443	444	402	347	430	446	448	500

*Source: Ministry of Agriculture and Forestry, Uganda.

Introductions of germplasm from other countries have not been sufficiently promising to be released directly as varieties. They either succumb to pests and diseases or do not withstand the climatic condition of the area. They are normally used in the hybridisation programme. To supplement hybridisation, a mutation induction programme was initiated in 1995 to develop mutants that can either be selected directly or used in the crossing programme. The induced mutation technique in sesame has proved successful and good results have been attained [3–5].

TABLE II. YIELD (kg/ha) OF SOME OF THE LOCAL CULTIVARS UNDER MULTILOCATION TESTS IN UGANDA*

Cultivar	Serere 1995	Serere 1996	Serere 1997	Ngetta 1997
EM-15-3-4	361.9 (7)	168.0 (9)	285.1 (5)	381.9 (1)
Ad-1-1-1	342.5 (10)	212.3 (5)	243.4 (8)	366.0 (2)
1851	271.8 (13)	188.8 (7)	253.1 (7)	281.2 (3)
Adong 4-4	370.8 (6)	469.8 (1)	376 (1)	257.0 (4)
U1-f-2-1	343.6 (9)	164.4 (10)	133.7 (14)	246.5 (5)
EM-15-3-2	401.7 (5)	145.0 (12)	333.1 (2)	194.5 (8)
EM-15-1-5	322.8 (11)	229.0 (3)	256.0 (6)	173.6 (11)
EM-14	480.6 (1)	162.0 (11)	238.6 (9)	166.7 (12)
Arut	349.9 (8)	120.1 (14)	223.6 (11)	86.8 (14)
S	423.8 (3)	134. 1 (13)	200.3 (13)	208.3 (7)
Serra	316.8 (12)	195.5 (6)	223.1 (12)	184.1 (10)
U1-f-1	403.7 (4)	244.8 (2)	304.3 (4)	211.8 (6)
Local 158	193.1 (14)	228.2 (4)	232.3 (10)	125.0 (13)
U1-f-7	456.1 (2)	171.3 (8)	319.7 (3)	187.5 (9)

* Figures in parenthesis ( ) show the rankings of the cultivars.

Objectives

Since most of the varieties grown in Uganda are low yielding, late maturing with first capsule placed high on the stem and wider internodes, the objectives of the project were:

i) To improve yield and harvest index.
ii) To reduce the height of the first capsule on the main stem and increase the length of capsule zone.
iii) To reduce the internode length and to maximize the number of capsules on the main stem and branches.
iv) To reduce the length of the growing period from about 110 days to 80–90 days.
v) To induce resistance to diseases and other environmental stresses, e.g. drought and water logging.
vi) To breed for stable high yielding varieties across seasons and locations.

Constraints

The potential yield of sesame in Uganda has been low mainly because of the following:

a) Lack of high yielding varieties with good stability across seasons and locations.
b) Long growing periods of the local varieties that do not match with the unpredictable rainfall pattern.
c) Damage by pests especially the sesame webworm (*Antigastra catalaunalis*) and gall midge (*Asphondylia sesami*).
d) Damage by diseases like *Fusarium* wilt, leaf spots and powdery mildew.
e) Uneven maturity of capsule due to uneven flowering.
f) The indeterminate growth habit.
g) Shattering of capsules.

2. MATERIALS AND METHODS

In June 1995, five sesame varieties: 'T-85', 'Serra', 'EM-14', 'Anyena', and 'S' were irradiated with 4 doses of ^{60}Co gamma rays at 200, 400, 600 and 800 Gy. A germination test was made in petri dishes (Table III). A field experiment, including unirradiated controls, was planted in October 1995 and the germination percentage (Table IV) together with vigour (Table V) were recorded after three weeks.

TABLE III. SEED GERMINATION TEST OF THE IRRADIATED SEEDS IN PETRI-DISH (%)

	Dose (Gy)				
Variety	0	200	400	600	800
T-85	100	100	90	65	95
Serra	100	100	100	100	90
EM-14	75	85	85	80	95
Anyena	95	95	80	90	90
S	90	100	95	80	95
X	92	96	90	83	93

TABLE IV. GERMINATION % AFTER THREE WEEKS

	Dose (Gy)				
Variety	0	200	400	600	800
T-85	92.3	89.7	88.3	16.0	14.7
Serra	96.0	84.7	86.0	38.7	4.7
EM-14	94.0	96.0	87.0	10.9	6.0
Anyena	95.3	96.7	88.0	14.7	3.3
S	95.3	88.0	87.7	39.0	7.0
X	94.6	91	87.6	24.4	7.1

TABLE V. VIGOUR AFTER THREE WEEKS OF GERMINATION*

	Dose (Gy)				
Variety	0	200	400	600	800
T-85	3.3	3.3	4.3	8.0	8.0
Serra	2.7	3.3	4.7	6.7	8.0
EM-14	3.0	2.7	4.7	8.0	8.0
Anyena	2.7	3.0	3.3	8.0	9.0
S	3.0	3.0	4.3	6.7	8.3
X	2.9	3.1	4.3	7.5	8.3

*Scored on a 1–9 scale: 1 = Very vigorous, 9 = Stunted growth.

The five varieties with five doses including the controls formed 25 treatment combinations that were randomized for each replication using RCBD with 4 replications. Each plot was 3m x 0.9m with 4 rows. The recommended spacing of 30 x 10cm was followed. At maturity, 5 capsules/plant for each plot and treatment were harvested and dried separately. At the same time, seeds from all the plants from the same dose and variety were bulked together.

In September 1996, a plant to row approach was followed to obtain the M_2 progenies. 344 individual M_1 plant progeny rows were planted to produce the M_2 generation.

In April 1997, seeds of single M_2 plants and bulk per variety per dose were planted as M_3 progenies.

In June 1997, more seeds of varieties: EM-14, EM-15-3-4, Local 158, Arut and U1-f-7 were irradiated with 5 doses of ^{60}Co gamma rays at 300, 400, 500, 600, 700 Gy; they were planted in October 1997 together with the controls for each variety.

3. RESULTS

3.1. Germination test

Germination test was done to find out the effect of the radiation dose effects on the seeds of the various varieties. Ten seeds were soaked in petri dishes and number of germinated seeds counted daily for three days after soaking. There was no consistency in seed germination according to a dose. Some varieties germinated better at higher dose while others germinated well at low dose. The lack of consistency could be due to varietal rather than irradiation effect.

After three weeks growth was retarded depending on the dose but there was less difference between controls and doses of 200 Gy and 400 Gy. Much decline was recorded from doses of 600 Gy and 800 Gy. There was high vigour in the controls and the of 200 Gy dose. Plants from seeds treated with of 600 Gy and 800 Gy showed loss of vigour and stunted growth.

3.2. Selection of mutants in M_2

During maturity and harvest time in January 1997, selection was done on M_2 progenies for individual plants resistant to drought and *Fusarium* wilt as part of the objectives listed above and these two factors were prominent during harvest. 276 single plants were selected out of the 2,636 plants from all the treated varieties (Table VI) to obtain M_3 plant progenies.

3.3. Selection of lines in M_3

Seeds of the selected 276 single M_2 plants were used as plant progenies in M_3 where further selections of lines was done. Out of those 276 single plant progeny rows, 30 progeny rows were further selected in terms of yield assessment (Table VII).

3.4. Preliminary yield trial of M_4 generation

The 30 selected M_3 lines were planted in October 1997 for preliminary yield assessment. Unfortunately, there was again too much rain, therefore the capsules failed to produce seeds. All the seeds were shrunken and the experiment has to be repeated using the remnant seed.

TABLE VI. STAND COUNTS OF M_2 PLANTS DURING HARVEST

Variety	Dose	Selected Stands	Unselected Stands	Total
T-85	200	18	363	381
T-85	400	28	293	321
T-85	600	3	39	42
Serra	200	59	567	526
Serra	400	17	234	251
Serra	600	0	4	4
EM-14	200	15	95	110
EM-14	400	12	69	81
EM-14	600	0	19	19
Anyena	200	42	274	316
Anyena	400	7	77	84
S	200	66	314	380
S	400	9	12	21
Total		**276**	**2360**	**2636**

TABLE VII. NUMBER OF M_2 LINES SELECTED PER VARIETY PER DOSE

Variety	Dose (Gy)			
	200	400	600	Total
T-85	3	5	2	10
Serra	3	0	0	3
EM-14	7	5	0	12
S	5	0	0	5
Anyone	0	0	0	0
Total	18	10	2	30

3.5. Crossing the promising local cultivars with dt-45

Dt-45, a determinate mutant induced by Ashri through treating dry seeds of the local sesame cultivar No. 45 with gamma-rays, 500 Gy [6] is now being used in our hybridization programme. Dt-45 itself does not perform well under our climatic condition and so it is being used to incorporate the determinate gene into the local promising, adapted cultivars as suggested by Ashri [6].

4. CONCLUSIONS

Although few mutants were selected which showed resistance to drought and wilt, desirable mutants for yield components were few. This could have been due to low population size of M_1 generation and therefore more seeds of 5 varieties have been sent to the FAO/IAEA Agriculture and Biotechnology Laboratory in Seibersdorf for another irradiation using ^{60}Co gamma ray doses of 300, 400, 500, 600 Gy. 7,000 seeds are to be irradiated per variety per dose.

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YIELD IMPROVEMENT OF KENYAN SESAME VARIETIES

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Abstract

In an effort to improve the yield of Kenyan sesame cultivars the seeds of three cultivars, SPS SIK6, SIK 096 and SPS SIK 50/1 were subjected to 300Gy, 400Gy and 600Gy of gamma rays. A first batch of seeds were subjected to these treatments in March 1994 (Experiment I) while the second batch was treated in March 1995 (Experiment II). The M_1, M_2, M_3 and M_4 generations of experiment I and M_1 generation of Experiment II were raised at the University of Nairobi Dryland Research Field Station, Kibwezi from 1994 to 1996. The M_6 and M_7 generations of Experiment I and M_2 of Experiment II were raised at Siaya Farmer's Training Centre in 1997. The effects of radiation in M_1 generation were expressed in reduced and delayed seedling emergence, reduced plant height, sectorial deformed plants, delayed flowering and extremely low yield. There was increased variation in M_2 for most evaluated traits. Plants in M_2 and subsequent generations were scored for a number of yield related morphological traits and days to flowering. Selection was done in the early generations for increased capsule number and earliness. As a result of selection, a total of 88 lines from M_4 generation were used to derive M_5 generation. Further selection in M_6 generation lead to 35 lines being retained for preliminary yield trials in M_7 generations.

1. INTRODUCTION

Use of artificial mutagenesis in breeding programmes leads to increased variation. This is a phenomenon that has been observed in many crop plants. For example increased variation in soybean oil and protein contents has been reported [1]. The study reported by IAEA [1] also revealed a disruption of negative correlation between these two traits. Increase in variability has also been reported in mung bean phenology and yield related traits following treatment by EMS and gamma rays [2].

In sesame increased variation has been reported following artificial mutagenesis [3,4]. In these studies substantial variation was reported for yield related traits and other agronomic traits. Rahman and Das [4] observed the occurrence of mutants with long capsules, three capsules per axil, short internodes and increased seed number per capsule as compared to the parental cultivars. In a study by Li [5] mutants were obtained that had longer capsules, taller and higher yielding than the parental cultivars. Maneekao et al. [6] reported improvement in sesame seed yield and 1000 seed weight as a result of induced mutations, and in a mutation breeding programme Hoballah [7] obtained sesame mutants that were shorter, earlier, higher yielding, had more capsules per plant, reduced first capsules height and reduced internode length.

The study presented here summarises a sesame mutation breeding work initiated in 1994 with the aim of improving yield of Kenyan sesame cultivars.

2. MATERIALS AND METHODS

2.1. Experiment I

2.1.1. M_1 to M_4 generations

Three Kenyan sesame cultivars SPS SIK 6, SIK 096 and SPS SIK 50/1 were subjected to gamma rays treatment at IAEA/FAO Agriculture and Biotechnology Laboratory in Seibersdorf, Austria, in March 1994. The seeds of the three cultivars were treated with 300, 400 and 600 Gy of gamma rays, giving a total of nine treatments. The M_1 generation was raised at the University of Nairobi Dryland Research Field Station, Kibwezi and used to obtain M_2 and subsequent generations which were also planted at Kibwezi as follows:

Generation	Season	Planted as
M_2	November '94 to March '95	Plots of progenies of individual M_1 plants
M_3	May to September '95	Plots of progenies of individual M_2 plants
M_4	November '95 to March '96	Plots of progenies of individual M_3 plants or M_3 families

Selection of individual plants and families was conducted for increased capsule number and earliness. The product of this selection was 88 lines used to raise M_5 generations as described below.

2.1.2. M_5 generation

Eighty eight lines selected in M_4 generation were planted as M_5 lines in the field at Kibwezi during May–September 1996. These lines which comprised of six lines derived from SPS SIK 6, twenty from SIK 096 and sixty two from SPS SIK 50/1 had been selected for earliness, capsule number per plant and absence of disease infestation. The lines were planted in a two-replicate randomised complete block design. Each plot had two rows spaced 50 cm apart. Spacing within the rows was 20 cm. The experiment was rainfed with supplemental irrigation. No data were taken and, therefore, no selection was done due to a serious nematode attack. However, seed was harvested from each for use in the next generation.

2.1.3. M_6 generation

The eighty eight lines in M_5 (as described above) were harvested and the seed used to derive M_6 at Siaya Farmers Training Centre (FTC) in western Kenya during April to August 1997. The experiment was moved to Siaya FTC because of the serious nematode infestation of the fields at Kibwezi. The M_6 planted at Siaya was planted in a two replicate randomised complete block design with between row spacing of 50cm and within row spacing of 20cm. Each row was 4m long. The M_6 lines were scored for days to flowering. At maturity data were taken for plant height, height to first capsule, stem length from first capsules on the main stem per plant, mean length and mean width of lowest three capsules on the main stem and seed yield per plant.

2.1.4. M_7 generation

The 35 M_7 generation lines were planted at Siaya FTC for preliminary yield tests in October 1997. They were planted in a three replicate randomized complete block design. Each line had a plot of two rows and each plot was 4m long. The spacing was 50 cm by 20 cm. The excessive rains during the season spoilt the first planting. A second planting was done in December 1997 and will be harvested in late April 1998.

2.2. Experiment II

2.2.1. M_1 generation

Seeds of the same varieties as above were subjected to 300, 400 and 600 Gy of gamma rays at the IAEA/FAO Agriculture and Biotechnology Laboratory in Seibersdorf, Austria, in March 1995. The seeds obtained from the nine treatments were planted at Kibwezi in June 1995 to obtain M_2 seed as described in our report of 1995 [8].

2.2.2. M_2 generation

The seed previously harvested from M_1 at Kibwezi was planted out at Siaya FTC during April–August 1997 to give the M_2 generation. The M_2 for each treatment was planted as bulk in a plot with 20 rows measuring 15m long. Between row spacing was 50 cm while within row spacing was 2 cm. The aim of such close spacing was to maximise plant population within the plots. Bulking approach was adopted for M_2 due to limited resources.

3. RESULTS AND DISCUSSION

3.1. M_1 to M_4 generation

The effects of radiation were manifested in the M_1 generation in the form of low and delayed emergence, delayed flowering and maturity, reduced height to first capsule and to first branch, diminutive plants, various forms of sectorial deformation and highly reduced seed production. However, there was substantial recovery in M_2. A number of variant plants were observed in M_2 as compared to the parental cultivars. These were mainly related to morphological traits; such observations were made in M_3 and M_4 as well. As compared to the parental cultivars there were variants which were branched with three capsules/axil, lower first capsule height, more capsules/plant, early and late flowering, reduced plant height and changed locule number. The details of our observations are summarised in our previous reports [8,9,10]. Selection was conducted as from M_2 generation and by M_4 generation there were 88 lines selected to give M_5 generation.

3.2. M_5 generation

The M_5 generation at Kibwezi performed so poorly that no data were taken on the crop. The crop was seriously attacked by nematodes and only a little seed was harvested from each plant. The stand was poor because of limited rainfall which led to poor emergence. The seed harvested from M_5 was merely used to derive M_6 generation at Siaya FTC. It was the nematode infestation of the fields at Kibwezi that made it necessary to move the research site from Kibwezi to Siaya FTC.

3.3. M_6 Generation

The M_6 generation at Siaya FTC had an average of 43 days to flowering with earliest lines being 128/1, 119/2/1, and 108 which were derived from cultivar SPS SIK 50/1 (Table I). Plant height had a small negative correlation to days to flowering (Table II), an observation similarly reported by Khan *et al*. [11]. Mean plant height at flowering was 83.8 cm. Apart from lines obtained from SIK 096 the lines evaluated were slightly taller than the control (Table I).

TABLE I. OVERALL MEAN PERFORMANCE OF M_6 LINES AND CONTROL PARENTAL CULTIVARS TESTED AT SIAYA (APRIL–AUGUST, 1997)

Parent cultivars	No. of lines	Days to flowering	Plant height (cm)	Stem length from first capsule to tip (cm)	No. of branches bearing capsules	Height to first capsule on main stem	Total No of capsules on main stem	Total No. of capsules per plant	Length of 3 lowest capsules on main stem (cm)	Width of 3 lowest capsules on main stem (cm)	Mean seed yield per plant (g)
SPS SIK 006	6	41	82.3	45.3	2	34.9	10	17	2.90	0.94	1.95
	Control	42	81.1	23.8	2	57.3	11	12	2.82	0.91	1.80
SIK 096	20	43	83.0	42.1	2	36.5	10	16	2.70	0.92	2.35
	Control	50	94.9	41.2	3	5.7	11	19	2.90	0.99	2.00
SPS SIK 50/1	62	44	86.0	47.8	2	40.0	12	19	2.92	0.95	2.28
	Control	49	80.4	27.9	0	52.7	16	20	2.91	0.94	2.10

The tallest line was derived from SPS SIK 50/1 and was 52/1. On the other hand the shortest line tested, 95/2/1, was also derived from SPS SIK 50/1 and had a height of 61.8 cm. Most of the lines were branched with at least two branches. Even some lines with three capsules per axil namely 291/2/3 which was derived from SIK 096, 25/1 and 148 which were derived from SPS SIK 50/1, and 353/6/1 from SPS SIK 6 had at least 1 branch bearing capsules. Branching habit was positively related to days to flowering and plant height (Table II). Usually the sesame cultivars with three capsules/axil tend to be unbranched.

The parental cultivars used in this study were branched with 1 capsule per axil except for SPS SIK 50/1 which was unbranched with 3 capsules per axil. The appearance of a few branched lines with 3 capsules per axil suggests a novel characteristic which may be capitalised on through selection. A combination of 3 capsules per axil and moderate branching were observed on 36/1, 128/3, 55/1/1, 63/1, 109/2/2 which were derived from SPS SIK 50/1, 287/1 which was derived form SIK 096 and 353 which was derived from SPS SIK 006. The lines with this characteristic tended to have high capsule number per plant. However, the degree of branching in such lines was moderate with branches bearing capsules rarely exceeding three. Most of them had only two capsule bearing branches. Height to the first capsule ranged from 60.1 to 23.0 cm. The lines with the lowest first capsule height were derived from SIK 096, namely lines 291/2/3, 303/1, and 303/2/4 which had first capsule heights of 23.0 cm, 23.4 cm, 28.8 cm respectively. This trait was positively correlated to days to flowering and plant height (Table II). Such a relationship was reported by Reddy *et al.* [12] and Padmarathi [13].

On the average, half of the stem length in the lines tested had capsules as reflected by mean lengths from first capsule to stem tip (Table I). The lines with the longest stretches were 218/1 and 108 derived from SPS SIK 50/1. There were strong relationships between this trait and other traits except branch number, capsule length, capsule width and seed yield (Table II).

TABLE II. PHENOTYPIC CORRELATIONS AMONG THE TRAITS STUDIED IN M_6

	Days to flower-ing	Plant height (cm)	Height to first capsule (cm)	Stem length from 1st capsule to tip (cm)	No. of branches bearing capsule	Total No. capsules on main stem	Total No. capsules/ plant	Mean seed yield/ plant (g)	Length of 3 lowest capsules on main stem (cm)	Width of 3 lowest capsules on main stem (cm)
Days to flowering	1	–0.53	0.33 ***	–0.31 ***	0.15 *	–0.31 ***	–0.17 ***	0.07	–0.01	–0.15 *
Plant height (cm)		1	0.53 ***	0.56 ***	0.22 ***	0.43 ***	0.49 ***	0.02	0.02	0.05
Height to 1st capsule (cm)			1	–0.32 ***	0.25 ***	–0.26 ***	–0.08	–0.35	–0.05	0.05
Stem height from 1st capsule to tip (cm)				1	–0.02	0.73 ***	0.65 ***	0.06	0.10	0.06
Branches bearing capsules					1	0.12	0.48 ***	0.05	0.01	0.01
Capsules on main stem						1	0.81	–0.08	0.12	0.06
Capsules per plant							1	–0.03	0.11	0.05
Mean seed yield/plant (g)								1	–0.19	–0.02
Length of 3 lowest capsules on main stem (cm)									1	0.16
Width of 3 lowest capsules on main stem (cm)										1

* Indicates level of significance at P = 0.05.

TABLE III. M_6 LINES SELECTED FOR FURTHER EVALUATIONS

Variety	Line	Days to flowering	Plant height (cm)	Stem length from 1st capsule to tip	No. of branches bearing capsules	Height to 1st capsule (cm)	No. of capsules on main stem	No. of capsules/ plant	Length 3 lowest capsules on main stem (cm)	Width of 3 lowest capsules on main stem (cm)	Mean seed yield/ plant (g)
SPS SIK 006	353/6	41	80.6	38.9	2	41.6	8	15	2.7	0.93	2.47
	335	41	80.2	36.4	3	40.8	8	15	2.7	0.92	2.47
	353/6/1	42	84.1	39.1	2	43.7	9	17	2.8	0.96	2.70
SIK 096	291/2	52	97.7	55.1	4	55.5	14	25	3.0	1.02	4.32
	303/2/1	37	76.0	36.5	1	29.3	8	12	2.5	0.89	2.61
	303/1	37	67.0	32.9	2	23.4	7	9	2.5	0.88	2.52
	303/2/4	37	75.8	35.4	1	28.8	8	12	2.5	0.87	2.58
	291/2/3	33	61.8	31.1	1	23.0	5	8	2.2	0.84	2.25
	296/2	50	88.5	43.8	3	50.1	11	19	2.9	0.98	3.08
	269	51	91.1	45.5	3	50.1	10	20	2.9	0.98	3.40
	311	48	87.3	41.5	3	46.3	11	18	2.9	0.97	2.95
	291/3	48	86.2	40.5	3	45.0	9	18	2.9	0.97	2.93
	K7/2/2	49	88.5	40.4	3	47.2	10	19	2.9	0.97	3.05
	291/1/2/2	48	85.8	43.5	3	44.7	10	18	2.9	0.97	2.90
	303/2/2	51	90.9	40.2	3	49.6	11	19	2.9	0.98	3.20
	296/1	52	93.2	45.0	3	51.1	11	22	2.9	0.99	3.72
	287/1	52	91.7	48.1	3	50.3	11	20	2.9	0.99	3.53
	286/5	51	89.8	46.7	3	49.6	11	19	2.9	0.98	3.20
	299	50	88.8	45.0	3	47.7	10	19	2.9	0.98	3.14
	303/2/3	50	88.8	44.1	3	49.2	10	19	2.9	0.98	3.20
	311	48	87.3	44.7	3	46.3	10	18	2.9	0.97	2.95
SPS SIK 50/1	55/1/1	41	82.5	45.5	2	35.6	11	17	2.9	0.95	2.90
	63/1	39	80.0	43.3	2	32.5	10	16	2.8	0.93	2.88
	165/3	40	80.5	44.1	2	32.4	10	16	2.8	0.93	2.89
	25/1	47	89.1	49.6	2	43.4	13	20	2.9	0.96	2.82
	108	48	91.6	50.9	3	46.6	14	22	2.9	0.97	2.96
	36/1	48	90.4	49.9	2	45.3	14	21	2.8	0.97	2.96
	96/3	39	78.4	43.2	2	31.8	9	15	2.9	0.92	2.82
	109/2/2	50	96.0	54.8	3	51.5	15	20	2.9	0.98	2.97
	95/2/1	47	88.6	49.0	2	43.4	13	20	2.8	0.96	2.96
	218/1	45	86.3	48.3	2	41.0	12	19	2.9	0.96	2.28
	100/2	42	84.9	46.9	2	30.0	11	17	2.9	0.95	2.14
	128/1	42	84.3	46.6	2	37.3	11	17	2.9	0.95	2.10
	119/2/1	44	85.9	48.1	2	39.4	12	18	2.9	0.96	2.21

Lines 291/2 derived from SIK 096, and 108 and 36/1 derived from SPS SIK 50/1 were among those lines that produced the highest number of capsules per plant (25, 22 and 21 respectively). Generally tall lines with high number of capsule bearing branches and high number of capsules on the main stem had the highest capsule number per plant (Table II). Similar observations for some of these traits were reported by Padmarathi *et al*. [13]. The branched lines with the highest capsule number also had three capsules per axil. Thus to maximise capsule number it would be necessary to select for these traits which were positively related to capsule number. Capsule number per axil on the main stem had significant (P = 0.05) correlations of 0.46 and 0.224 to capsules on the main stem and capsules per plant respectively. Unfortunately none of these traits had positive correlation to seed yield in this study. However, selecting for any of them would not have adverse effects on seed yield. The highest seed yield/plant was observed for 287/1, 269, 296/1 and 291/2 derived from SIK 096.

Capsule length as measured by length of the three lowest capsules had an overall mean value of 2.84 cm for all the lines tested. The longest capsules were obtained from lines 291/2 derived from SIK 096, 165/2, 218/3 and 108 which were derived from SPS SIK 50/1. On the other hand the shortest capsules were born on line 94 derived from SPS SIK 50/1. Another line with short capsules was line 122/2 derived from SPS SIK 50/1. This trait had no relationship to any trait except seed yield and capsule width (Table II). While Reddy *et al.* [12] reported positive relationship between capsule length and seed yield the data in this study suggested negative correlation between these two traits. Capsule width had an overall mean of 0.94 cm for the lines tested. The widest capsules were observed on SPS SIK 50/1 derived lines like 123/5, 133/2/1 and SIK 096 derived line 303/4. The values for capsule length varied form 2.26 cm to 3.03 cm while those for capsule width ranged from 0.69 cm to 1.05 cm. In this study capsule width had no strong relationship to any of the traits except days to flowering and capsule length.

Based on the tests conducted and reported here 35 lines were selected for preliminary trials in M_7. Among these selections 3 had SPS SIK 6 as the original parental cultivar 15 lines were of SIK 096 origin while 17 had the parental cultivar as SPS SIK 50/1. The selected lines are listed in Table III.

3.4. M_7 generation

The lines listed in Table III were planted to raise the M_7 generation for preliminary trials. This was seriously affected by excessive rains from October 1997 to February 1998. The second planting which was done in December 1997 was harvested in late April 1998. Though yield data have not been taken observations that were made on other yield related traits and freedom from disease attack in the field lead to conclusions that lines 96/3, 218/3, 55/1/1, 353/6/1, 291/2, 287/1, 269, and 296/1 would be promising lines 96/3, 218/3, 55/1/1 and 36/1 were derived from the unbranched SPS SIK 50/1 having 3 capsules per axil. A novel character that these four lines have in common is that they are branched. Line 96/3 has an additional character in that its plants develop purple pigmentation at maturity. Line 218/3 is also pubescent, a character that is absent in the parental SPS SIK 50/1. Plants from line 353/6/1 develop purplish coloration at maturity and have 3 capsules per axil. These two characteristics are absent in the parental SPS SIK 6. The lines obtained from the branched SIK 096 were 291/1, 287/1 and 303/2/3. These lines were branched and had 3 capsules/axil. The parental cultivar had only one capsule/axil. Once the yield data have been obtained from the M_7 generation about half of the lines will be advanced for a second season of preliminary yield trials.

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SELECTION AND AGRONOMIC EVALUATION OF INDUCED MUTANT LINES OF SESAME

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Abstract

Station yield trial: Three high yielding mutants (8, 48, and EFM 92) with better and stable performance were developed in our breeding programme and submitted for registration to the Agricultural Research Center (ARC), Egyptian Ministry of Agriculture and Land Reclamation. Multi-location yield trials indicated that mutant line EFM92 ranked first in all locations; significant yield increases recorded for it ranged from 14.7 to 74.0% over the check variety. Moreover, it was 15–20 days earlier than the check and/or other mutants. Mutant lines 8 and 48 produced higher seed yields than the check at two different locations. These mutants can probably be grown and produce more yield than the check variety at the low yielding environments.

Seed quality assay: During 1996 and 1997, 15 promising lines of sesame including mutants and hybrid populations as well as the local variety were evaluated for seed protein, oil content and fatty acid composition. The protein content varied from 20.6 to 26.7%; hybrid population EXM90 gave the highest value. About 85% of the total fatty acids in the oil are unsaturated (oleic and linoleic) and 15% saturated, mainly palmitic and stearic. Linoleic acid ranged from 41.8 to 47.9%. Mutant lines 6, 9, and EFM92, which gave high oil content (54–55.5%) together with high linoleic acid values (45.2–47.8%), are recommended for breeding for seed oil quality.

Heterosis, combining ability and type of gene action in sesame: A half diallel set of crosses involving seven parents was used to study heterosis and combining ability in the F_1 generation as well as the nature of gene action controlling seed yield and its contributing traits in both F_1 and F_2 in order to identify the most efficient breeding methods leading to rapid genetic improvement. The expressions of heterosis varied with the crosses and characters investigated. The maximal significant positive useful heterosis was observed for branches/plant (52.9%) followed by seed yield/plant (38%), capsules/plant (33.6%), capsule length (19.0%), 100-seed weight (18.6%) and plant height (12.1%). Analysis of variance for combining ability indicated that general (GCA) and specific (SCA) combining ability variances were highly significant for all studied traits. Estimates of GCA effects showed that EXM90, EFM92 and Mutant 8 were the best general combiners for earliness; the variety Giza 32 and Mutant 48 the best for seed yield and number of capsules per plant. Both parents and their derived crosses could be utilized for hybrid sesame production and varietal improvement in terms of the probability of selecting desirable segregants for yield and yield components. Estimates of the type of gene action confirmed the importance of both additive and non-additive (dominant) gene effects in the inheritance of the studied characters in both F_1 and F_2 generations. However the dominance components were larger than the additive ones for most investigated traits in the F_1 and vice versa in the F_2. Overdominance was also noted. Heritability in narrow sense (H_n) was low for most characters in the F_1. On the other hand, high values of heritability (H_n) were recorded for all the investigated traits in the F_2, indicating that the genetic variance associated with those traits was mostly due to additive effects of genes, and therefore, it could be concluded that selection based on the accumulation of additive effects would be very successful in improving such traits.

1. INTRODUCTION

The main objectives of our breeding programme at Cairo University, Egypt are to develop new varieties with high yield potential, wide adaptability, early maturity, tolerance to wilt disease and high seed quality. Towards these objectives, the most promising genotypes were identified through the use of induced mutations, cross breeding and selection as well as the screening of exotic germplasm. Success has been achieved in this regard with the release of three high yielding mutants which were submitted to the Egyptian Ministry of Agriculture and Land Reclamation in 1997 for registration as new varieties. Moreover, the high yielding mutants and other promising lines were evaluated for seed quality and fatty acid composition as an advanced step of the breeding work.

Further improvement in certain characters of the promising genotypes depends upon basic information on the nature of the inheritance of growth and yield components as well as identification

of parental materials showing superior expression in the most important traits, and combine genes for these traits into a superior genotype. In this respect, knowledge of heterosis, combining ability and type of gene action helps in identifying parents and their derived crosses to be used for genetic improvement.

2. MATERIALS AND METHODS

2.1. Station yield trials

Three high yielding mutant lines from our breeding programme which showed better and stable performance during the last five years were submitted to the Agricultural Research Center (ARC), Egyptian Ministry of Agriculture and Land Reclamation for registration. Station yield trials were conducted under supervision of the Oil Crop Research Section, ARC, in 1997 summer season in five experimental research stations, namely Giza, Inshas, Malawi, Shandweel and Komombo which represented the different ecological zones of Egypt. The three high yielding mutants (8, 48 and EFM92) alongwith a check variety Giza 32 were planted in a randomized complete block design (RCBD) with four replications. The plots consisted of six 4 m long rows, 60 cm apart. The spacing between hills within the rows was 20 cm for mutants 8 and 48 (branched types) and 10 cm for mutant EFM92 (non-branched type) and the check variety (few branched type). Sowing was carried out in the last week of May, 1997 for all the locations. Thinning was done when the seedlings attained 10–15 cm in height, retaining two plants per hill. Other recommended agronomic practices for sesame production were followed at all locations from sowing to harvest. Data were statistically analysed using the regular analysis of variance method of RCBD.

2.2. Seed quality assay

The seed quality in relation to protein and oil content as well as the fatty acid composition of our promising genotypes including mutants and hybrid populations were determined during my postdoctoral fellowship at the Institute of Plant Production and Plant Breeding, Giessen Univ., Germany in 1997. The analytical methods selected for seed quality assay were as follows: 1) Nuclear Magnetic Resonance (NMR) for total oil content determination, as described by Robertson and Marrison [1]. 2) Modified technique proposed by Marquard [2] using nitrogen analyzer type: ANA 1500, Carlo Erba instruments for total protein content determination. 3) Gas chromatography for total fatty acid composition according to Thies [3] with modified technique described by Marquard [2].

2.3. Heterosis, combining ability and type of gene action

In 1995, seven diverse genotypes of sesame, viz. four homozygous mutants, one F_5 hybrid population and one exotic line as well as the local variety Giza 32 were crossed in all possible combinations excluding reciprocals, to obtain a total of 21 F_1 hybrids using a half diallel mating system. In 1996 the parent genotypes alongwith their F_1's were sown in a RCBD with three replications at the Experimental Station of the Faculty of Agric., Cairo Univ., Giza, Egypt. Each F_1 plot consisted of 2 rows, 3m long with a spacing of 60cm between rows and 20 cm between plants. In the same season, crosses were made among the parental genotypes to obtain additional F_1 seeds, while F_1 plants were grown to produce the F_2 seeds.

Data on ten randomly selected plants from each plot were recorded for number of days to maturity, plant height, height to first capsule, capsule length, number of branches number of capsules per plant, 1000-seed weight and seed yield per plant. The data were tested for significance on the basis of the analysis of variance. Heterosis and heterobeltiosis in F_1 were estimated as percentages over mid-parents and better parents, respectively. Combining ability analysis was performed according to Griffing's [4] method 2 model 2. General and specific combining ability effects were also estimated.

In 1997, the parents, F_1 hybrids and F_2 populations were evaluated in a RCBD with three replications. Each plot consisted of 10 rows, i.e. 2 rows for each parent, 2 rows for F_1's and 4 rows for F_2's. Row length and spacing between and within rows were as in the F_1. At maturity, 10 random competitive plants per each entry were sampled to study the same characters mentioned before. Recommended agronomic practices were applied at the proper time in both generations.

To study the inheritance of the mentioned characters, genetic parameters were computed according to diallel cross analysis proposed by Hayman [5,6] for each trait in both the F_1 and F_2 generations. These parameters and their ratios were as follows:

D: The component of variation due to additive effect.
H_1: The component of variation due to dominance effect.
H_2: The component of variation due to dominance effect, correlated for gene distribution to positive and negative genes in the parents, when they are equal, then $H_1 = H_2$.
F: An indicator of relative frequencies of dominant vs. recessive genes in the parents.
h^2: Dominance effect as algebraic sum over all loci in heterozygous phase in all crosses.
E: Environmental or non-heritable component of variation.
$(H_1/D)^{0.5}$: Mean degree of dominance.
$H_2/4H_1$: Proportion of positive and negative gene effects in the parents.
K_D/K_R: Proportion of dominant and recessive genes in the parents
where; $K_D/K_R = (4DH_1)^{0.5}+F/(4DH_1)^{0.5}-F$.

Narrow sense heritability (Hn) was estimated as proposed by Mather and Jinks [7] in the F_1 and by Verhalen and Murray [8] in the F_2 generation. The validity of diallel analysis assumptions made by Hayman [5,6] was tested by t^2 as suggested by Singh and Chaudhary [9].

3. RESULTS AND DISCUSSION

3.1. Station yield trials

Data on seed yield per hectare of the three promising mutant lines and the check commercial variety growing at five experimental research stations in 1997 summer season are given in Table I. Significant differences in seed yield among the tested mutants and the check were recorded at all five locations.

TABLE I. YIELDS OF PROMISING SESAME MUTANTS GROWING AT FIVE EXPERIMENTAL RESEARCH STATIONS IN 1997 SUMMER SEASON

Mutants	Yield and rank	Experimental research stations					Mean (combined)
		Giza	Inshas	Shandweel	Malawi	Komombo	
EFM 92	Mean[#]	2559.2	2368.8	2829.1	2316.5	1165.7	2247.9
	lncrease(%)[@]	14.7*	35.0*	18.7*	33.6*	74.0*	35.2
	Rank	1	1	1	1	1	
Mutant 8	Mean	2241.2	2258.4	2073.4	1803.6	954.3	1866.2
	Increase(%)	0.4	28.7*	–13.0	4.0	42.4*	12.5
	Rank	3	2	4	2	3	
Mutant 48	Mean	2403.0	1952.1	2195.5	1625.2	1137.9	1862.8
	Increase(%)	7.7*	11.3	–7.9	–6.3	69.8*	14~9
	Rank	2	3	3	4	2	
Giza 32	Mean	2231.5	1754.2	2384.2	1733.6	670.0	1754.7
	Rank	4	4	2	3	4	

[#] kg/ha.
[@] Rate of seed yield increase (%) over the check variety (Giza 32).
* Significant at 5% level.

Mutant line EFM92 produced the highest seed yield/ha and ranked first at all locations with mean values ranging from 1165.7 to 2829.1 kg/ha and grand mean of 2247.9 kg/ha over all locations. Significant seed yield increase recorded for this mutant ranged from 14.7 to 74.0 % over the commercial variety, Giza 32, with a mean of 35.2 % over all locations. Moreover, the same mutant was also 15–20 days earlier in flowering and maturity than the check variety and/or other mutants (data not presented). Thus, it was clearly evident that such a mutant is very promising for commercial production across a range of different environments.

Mutant 8 mean seed yield varied from 954.3 to 2258.4 kg/ha with an average of 1866.2 kg/ha and yield increase of 12.5% over all locations. This mutant outyielded the check variety at two locations; Inshas and Komombo, with significant increases of 28.7 and 42.4%, respectively. Insignificant increase and/or decrease of seed yield were observed for the mutant in the other three locations compared to the check.

Mutant 48 mean seed yield ranged from 1137.9 to 2403.0 kg/ha with an average of 1862.8 kg/ha and a yield increase of 14.9% over all locations. This mutant showed also higher seed yield than the check at two locations; Giza and Komombo, with significant increases of 7.7 and 69.8%, respectively. The data showed insignificant differences between the mutant and the check variety in the other three locations.

From the above results it can be stated that the three tested mutants recorded the highest rate of seed yield increase at the low yielding location (Komombo) as compared to the other four favourable or high yielding locations. It means that these mutants could also be grown successfully and produce higher seed yields than the check variety at the low yielding environments. However, to confirm these findings, station further yield trials will be conducted for one more season in the same locations, as well as on farm trials.

3.2. Seed quality assay of the promising genotypes

Data obtained on sesame seed quality in relation to protein, oil and fatty acid composition for the promising genotypes growing at Giza, Egypt in 1996 and 1997 summer seasons are presented in Tables II and III.

Protein content ranged from 20.6 to 26.5% with an average of 23.7% in 1996, and from 21.8 to 26.7% with an average of 23.5% in the 1997 season. The highest protein content (>26.5%) was recorded for the hybrid population EXM90 in both seasons.

Seed oil content varied from 51.7 to 55.0% in 1996, and from 52.8 to 55.5% in the 1997 season, with a grand mean of 53.7% in both seasons. The highest oil content was recorded for mutant 8 in the first season, and for mutants 9 and EFM92 in the second season.

Concerning oil quality, sesame oil has few fatty acids, about 85% are unsaturated (oleic and linoleic) and 15% are saturated acids mainly palmitic and stearic. The range of unsaturated oleic acid was 37.0–41.1% and 36.3–41.7% with means of 38.9 and 39.0% for the 1996 and 1997 seasons, respectively. The range of linoleic acid was 41.8–47.9% and 44.0–47.8% with means of 46.0 and 45.7%, in the first and second seasons, respectively.

Regarding the saturated acids, the range of palmitic and stearic acids in the first season was 9.4–11.6% and 3.5–5.5%, with an average of 10.2% and 4.9%, respectively. In the second season, the range was from 9.4–11.3% and 4.4–5.5% with means of 10.2% and 5.1% for palmitic and stearic acids, respectively.

As evident in Tables II and III, mutant lines 6, 9 and EFM92 which gave high oil content of between 54.0 and 55.5% together with high linoleic acid values (45.2–47.8%) are recommended for breeding sesame for seed oil quality.

TABLE II. PROTEIN AND OIL CONTENT OF THE SEED AND FATTY ACID COMPOSITION OF THE OIL OF PROMISING MUTANTS AND HYBRID LINES IN 1996

Mutants and hybrids	Protein %	Oil %	Fatty acid composition C 16:0 Palmitic	C18:0 Stearic	C18:1 Oleic	C18:2 Linoleic	Total[+] saturated acids	Total[@] unsaturated acids
Mut. 5	22.9	53.7	10.0	2.5	39.6	47.9	12.5	87.5
Mut. 6	22.5	54.4	9.4	4.9	38.9	46.7	14.3	85.6
Mut. 7	22.9	54.4	10.0	5.1	38.6	46.3	15.1	84.9
Mut. 8	20.6	55.0	9.8	4.8	41.1	44.3	14.6	85.4
Mut. 9	22.5	53.8	11.6	5.3	39.0	44.1	16.9	83.1
Mut. 12	22.5	53.8	10.4	5.1	38.7	45.8	15.5	84.5
Mut. 14	22.6	53.6	9.6	5.3	38.1	47.0	14.9	85.1
Mut. 15	24.0	53.6	9.8	5.5	38.6	46.0	15.3	84.7
Mut. 48	22.5	54.7	9.9	5.2	38.4	46.5	15.1	84.9
EFM 92	26.0	54.4	10.2	4.9	39.8	45.2	15.1	85.0
EXM 90	26.5	53.3	10.3	4.8	38.2	46.6	15.1	84.8
H 7	24.5	51.8	9.4	5.2	38.8	46.7	14.6	85.5
H 17	25.9	52.5	10.8	5.2	37.0	46.9	16.0	83.9
H 25	23.1	53.8	10.1	4.9	37.3	47.7	15.0	85.0
H 52	24.0	52.9	11.0	5.0	40.5	43.4	16.0	83.9
Giza 32*	26.1	52.8	10.5	4.5	40.5	44.5	15.0	85.0
Mean	23.7	53.7	10.2	4.9	38.9	46.0	15.1	84.9

[+] = Palmitic & Stearic.
[@] = Oleic & Linoleic.
[*] = Check Variety.

TABLE III. PROTEIN AND OIL CONTENT OF THE SEED AND FATTY ACID COMPOSITION OF THE OIL FOR PROMISING MUTANT AND HYBRID LINES IN 1997 SEASON

Mutants and hybrids	Protein %	Oil %	Fatty acid composition C16:0 Palmitic	C 18:0 Stearic	C18:1 Oleic	C18:2 Linoleic	Total[+] saturated acids	Total[@] unsaturated acids
Mut. 5	23.7	53.4	9.4	4.6	38.3	47.7	14.0	86.0
Mut. 6	22.6	54.9	9.7	5.5	37.1	47.8	15.2	84.9
Mut. 7	23.8	53.4	10.3	5.2	39.8	44.8	15.5	84.6
Mut. 8	23.6	54.6	9.5	5.3	39.6	45.6	14.8	85.2
Mut. 9	21.8	55.5	10.3	5.1	37.5	47.2	15.4	84.7
Mut. 12	23.9	53.4	9.9	5.2	39.3	45.6	15.1	84.9
Mut. 14	23.6	53.9	10.5	5.1	37.7	46.7	15.6	84.4
Mut. 15	23.5	53.5	10.1	5.2	40.3	44.4	15.3	84.7
Mut. 48	22.6	53.3	10.0	5.1	39.8	45.1	15.1	84.9
EFM 92	23.7	55.5	10.3	5.0	37.7	47.0	15.3	84.7
EXM 90	26.7	51.7	10.3	4.9	38.8	45.9	15.2	84.7
H 7	22.7	53.5	10.3	5.3	39.9	44.5	15.6	84.4
H 17	24.1	54.0	10.8	5.1	36.3	47.8	15.9	84.1
H 25	22.5	52.8	10.4	5.2	40.4	44.0	15.6	84.4
H 52	23.8	53.3	11.3	5.2	41.7	41.8	16.5	83.5
Giza 32[*]	24.0	53.1	9.8	4.4	40.4	45.3	14.2	85.7
Mean	23.5	53.7	10.2	5.1	39.0	45.7	15.3	84.7

[+] = Palmitic & Stearic.
[@] = Oleic & Linoleic.
[*] = Check Variety.

3.3. Heterosis, combining ability and types of gene action

3.3.1. Heterotic effects

The heterosis effects expressed as the percentage deviation of F_1 mean performance from the mid-parents (heterosis) and better parents (heterobeltiosis) are shown in Table IV. The direction and magnitude of the heterotic effects differed with the crosses and characters investigated.

For days to maturity, eight crosses showed significant heterosis and four out of them recorded highly significant heterobeltiosis. The values of significant negative heterosis ranged from –2.2 to –13.4%, while the range was from –5.3 to –9.9% for heterobeltiosis. It was also noted that the crosses which exhibited significant negative heterobeltiosis were derived from the local variety Giza 32 (Pl) as a female parent. Significant negative heterosis for this trait was also reported by others [10, 11,12,13].

Estimates of heterosis for plant height showed significant positive values in 7 crosses ranging from 6.5% (P2 x P5) to 22.2% (P1 x P2). However, significant positive heterobeltiosis was observed in 5 crosses, it varied between 6.4% (P1 x P3) to 12.1% (P2 x P4). The rest of crosses possessed negative heterosis or heterobeltiosis in such character. These results are in harmony with those obtained by Shivprakash, [14]; Singh *et al*. [15] and Yadav & Mishra, [11] who reported positive and negative heterosis for plant height.

Concerning the height to first capsule, as a plant character of great importance to sesame breeders, the data in Table IV shows that most crosses recorded undesirable positive heterosis and none of them showed significant negative heterosis for this character. Similar results were found by Mahdy and Bakheit [16]. However, Ibrahim *et al.* [17] and EI-Shazly *et al.* [18] reported favourable negative heterosis for this character.

With regard to capsule length, significant positive heterosis was recorded in six crosses with values ranging from 6.1% (PI x P5) to 21.0% (P2 x P7), whereas significant positive heterobeltiosis was indicated in three crosses ranging between 8.7% (P3 x P6) and 19.0% (P2 x P7). Similar results were reported by El-Shazly *et al.* [18] and Padmavathi *et al.* [19].

The maximum values of heterosis and heterobeltiosis were observed in number of fruiting branches. Significant positive heterosis was recorded in six crosses with values ranging from 86.7% (P5 x P7) to 203.7% (PI x P4), while only one cross (PI x P4) exhibited significant positive heterobeltiosis of 52.9%. Positive heterosis for number of branches has also been reported by Sodani & Bhatnagar [20] and Mishra & Yadav [13]. On the other hand, significant negative heterobeltiosis of –54.2, –52.0 and –79.8% was recorded for (PI x P6), (P2 x P3) and (P5 x P6), respectively. Ibrahim *et al., (*1983) found also significant negative heterosis for number of fruiting branches/plant.

The most important yield component, number of capsules per plant, exhibited significant positive heterosis and heterobeltiosis in 4 crosses viz. (P1 x P2), (P1 x P4), (P1 x P7) and (P3 x P5) with values ranging from 25.9 to 47.4% for heterosis and from 21.7 to 33.6% for heterobeltiosis. Significantly positive heterobeltiosis has been reported by Atta [2l], Sodani & Bhatnagar [20] and Mishra & Yadav [13].

For seed index (1000 seed weight), results obtained indicated that 6 crosses namely, (P1 x P4), (P1 x P5), (P2 x P4), (P4 x P6), (P5 x P7) and (P6 x P7) gave significant heterosis of 15.5, 25.8, 14.5, 18.5, 16.7 and 29.5%, respectively. However, significant heterobeltiosis of 18.6% was recorded for one cross (P6 x P7). The remaining crosses showed insignificant values with the exception of (P1 x P2) which gave negative heterosis. These results are in agreement with that obtained by Singh *et al.* [15], Ding *et al*. [22] and Mishra & Yadav [13].

TABLE IV. HETEROSIS AS % OF MID-PARENTS (UPPER VALUES) AND BETTER PARENT (LOWER VALUES) IN HALF DIALLEL CROSSES OF SESAME IN THE F_1 GENERATION

Crosses	Days to maturity	Plant height (cm)	Height to first capsule (cm)	Capsule length (cm)	Branches/ plant, No.	Capsules/ plant, No.	1000 seed weight (g)	Seed yield/ plant (g)
P1 x P2	–9.1**	22.2**	27.8	2.1	31.6	26.2*	–16.6	9.9
	–5.4	3.1	48.7	–0.1	18.3	23.2*	–24.3	2.2
P1 x P3	–8.2**	21.5**	26.3	3.3	–12.6	2.4	–1.8	16.1
	–5.3 .*	6.4*	45.7	–5.3	–25.8	–7.6	–11.9	2.9
P1 x P4	–1.4	13.0**	54.9	0.0	203.7	25.9*	15.5*	41.9
	10.3**	–4.5	157.4	–5.3	52.9*	22.3*	0.7	38.0
P1 x P5	–10.1**	4.8	13.6	6. l**	68.4*	20.7	25.8	41.4
	0.0	–10.2**	59.7	–7.6	–15.3	9.3	9.7	28.3*
P1 x P6	–13.4**	–21.5**	–1.4	–5.9*	–44.1	–41.1**	–5.3	–23.7
	–9.9	–26.8**	2.3	–16.1	–54.2*	–44.9**	–11.9	–24.7
P1 x P7	–6.0	4.8	10.5	11.9**	3.5	43.9**	10.8	38.8
	–3.5**	–6.4*	26.5	1.7	–6.6	33.6*	–5.2	3 1.0*
P2 x P3	–1.8	–9.0	–3.8	–4.0	–48.8	–25.4*	–7.3	–25.9
	–0.9	–13.0**	–3.2	–4.6	–52.0*	–31.2*	–8.6	–29.7
P2 x P4	–6.7 **	12.4**	42.2	–0.6	109.0**	7.6	14.5	1.2
	0.0	12. 1 **	95.7	–3.4	5.1	7.1	9.7	–8.2
P2 x P5	–6.2"	6.5*	18.2	–5.3	21.2	13.0	3.8	14.9
	0.0	4.5	40.0	–22.8*	–39.0	0.1	–0.8	–2.3
P2 x P6	0.9	–6.4	9.2	–0.3	1.4	–28.7*	7.5	–23.2
	0.9	–16.0**	21.9	–3.9	–8.9	–31.8*	4.7	–27.6
P2 x P7	2.2*	16.3**	24. 1	21.0**	15.8	2.1	11.8	–7.4
	3.6	9.0 **	25.8	19.0**	15.2	–7.3	5.0	–18.1
P3 x P4	9.5	15.0**	55.8	–2.6	23.9	1.2	13.8	–4.1
	18.6**	10.2**	16.2	–5.9	–37.8	–6.3	10.5	–17.0
P3 x P5	4.3**	14.0**	25.9**	–6.9**	134.5**	47.4**	6.8	45.9**
	12.2**	11.0**	50.3**	–24.7**	17.8	21.7*	3.4	18.9
P3 x P6	0.9	8.9 *.	13.6**	11.6**	37.7	2.1	0.0	12.6
	1.8	1.8	26.0**	8.7**	31.6	–1.8	–3.9	1.0
P3 x P7	1.3	–16.4**	6.9	–4.0	26.5	9.0	–9.9	–0.4
	1.8	–18.2**	7.7	–5.0	18.7	–8.0	–14.2	–16.0
P4 x P5	10.8**	0.0	–2.0	1.2	0.00	–5.9	2.1	–4.8
	11.3**	–1.6	11.9	–15.6	0.00	–16.7	2.1	–11.4
P4 x P6	9.6**	–13.6**	–10.3	3.0	50.8	–28.4*	18.5**	–0.6
	17.5**	–22.3**	41.8**	–3.4	–24.3	–31.2'	10.8	–4.6
P4 x P7	8.1 **	–14.4**	27.5**	6.8*	146.9**	–25.5	2.8	2.0
	17.5'*	–19.6**	78.6"'	2.2	23.5	–32.7*	0.6	–1.1
P5 x P6	0.5	–17.5**	11.5	–3.1	–59.7	37.6**	12.7	–10.6
	7.1**	–24.7**	49.7**	–23.3**	–79.8**	46.8**	5.0	–19.8
P5 x P7	–0.9	–12.5**	22.4	5.1*	86.7	–15.4	16.7*	15.5
	7.1*'	–16.5**	47. 1	–15.6**	–6.6	–17.6	14.6	10.8
P6 x P7	–2.2*	–19.8**	9.1	12.5**	–28.8	40.2**	29.5**	–29.0*
	–0.9	–23.5**	20.0**	10.5**	–36.0	47.8**	18 6*	–33.9*

P1=Giza32, P2=Mut 8, P3=Mut 48, P4=EFM 92, P5=EXM 90, P6=EXL 139, P7=TM90.
* and ** indicate significance at the 5% and 1% levels, respectively.

Regarding seed yield per plant, three crosses namely; (P1 x P4), (P1 x P5) and (P1 x P7), which derived from the local variety Giza 32 as a female parent, recorded significant heterobeltiosis. Whereas, (P3 x P5) exhibited only significant heterosis. The range of significant heterosis was from 38.8 to 45.9%, and from 28.3 to 38.0% for heterobeltiosis. The remaining crosses showed

insignificant heterosis in both directions with the exception of cross (P6 x P7) that exhibited negative heterosis. Many investigators [11, 13, 19, 23] reported significant positive heterosis and heterobeltiosis for seed yield in other crosses.

From the above results it was clear that the expression of heterosis varied with the crosses and also with the characters. The maximum significant heterobeltiosis (useful heterosis) was observed for the number of fruiting branches (52.9%) followed by seed yield per plant (38.0%), number of capsules (33.6%), capsule length (19.0), 1000 seed weight (18.6%) and plant height (12.1%).

3.3.2. Combining ability

Analysis of variance for combining ability was employed for all investigated characters in the F_1 generation (Table V). The mean squares (variance) of the general – (GCA) and specific (SCA) – combining abilities were highly significant for all studied traits, suggesting the involvement of both additive and non-additive (dominance) gene effects in the expression of these traits. Several investigations revealed the importance of both additive and dominant gene effects in the genetic control of seed yield and its contributing characters [17, 18, 24, 25].

However, non-additive gene action was found to be more important for days to maturity, plant height, number of branches, number of capsules, 1000-seed weight and seed yield per plant as indicated by the additive/dominance ratio being smaller than one. Conversely, the ratio exceeded 1.0 for height to first capsule and capsule length, indicating that the additive component was more important in controlling such characters.

TABLE V. ESTIMATES OF VARIANCE (MEAN SQUARE) FOR GENERAL – (GCA) AND SPECIFIC - (SCA) COMBINING ABILITY FROM A HALF DIALLEL CROSS OF SESAME IN F_1 GENERATION

Source of variation	df	Days to maturity	Plant height	Height to first capsule	Capsule length	Branches per plant	Capsules per plant	1000 seed weight	Seed yield/ plant
G.C.A.	6	82.05**	2932.30**	889.40**	0.996**	1.416**	1561.35**	0.384**	49.05**
S.C.A.	21	30.25**	648.93**	159.06**	0.041**	0.491**	796.31**	0. 15 8**	22.35**
Error	54	0.71	22.35	10.59	0.004	0.173	184.21	0.039	6.39
	Variance components								
Additive		11.51	507.42	162.30	0.21	0.21	170.01	0.05	5.93
Dominant		29.54	626.58	148.48	0.04	0.32	612.09	0.12	15.97
Add./Dom		0.39	0.81	1.9	5.25	0.66	0.28	0.42	0.37

** significance at 1%.

TABLE VI. ESTIMATES OF GENERAL COMBINING ABILITY EFFECTS FOR EACH PARENT IN F_1 GENERATION

Parents	Day to maturity	Plant height	Height to first capsule	Capsule length	Branches per plant	Capsules per plant	1000 seed weight	Seed yield/ plant
P1 (Giza 32)	0.090	39.252**	16.354**	0. 145**	0.017	10.913**	0.375**	2.294
P2 (Mut. 8)	–0.873**	–3.966**	1.336	–0. 166**	0.159	2.247	–0.115	–0.076
P3 (Mut.48)	3.275**	3.523*	2.158*	–0.245**	0.390**	21.484**	–0.204**	3.875
P4 (EFM 92)	–1.947**	–10.35 1**	–12.883**	–0.087**	–0.394**	1.035	–0.048	–0.769
P5 (EXM 90)	–5.132**	–11.274**	–11.73 1**	0.689**	–0.687**	–7.916	–0.049	–0.584
P6 (EXL 139)	1. 164*'	–7.166**	3.817**	–0.262**	–0.202	–15.624**	0. 187**	–2.726
P7 (TM 90)	3.423**	–10.018**	0.947	0.073**	0.313*	–12.139**	–0. 145*	–2.013
SE (Gi)	0.260	1.459	1.004	0.020	0.129	4.189	0.061	0.780
SE (Gi –G)	0.398	2.229	1.534	0.031	0.196	6.398	0.093	1.191

* and ** indicate significant at 5 % and 1 % levels of probability, respectively.

3.3.2.1. General combining ability effects

Estimates of general combining ability (GCA) effects of individual parents for each character in the F_1 are illustrated in Table VI. General combining ability effects were found to be either significant or highly significant in some cases. Highly positive values would be of interest for all studied traits except days to maturity and height to first capsule where the reverse situation is desirable, i.e. high negative values may be useful from the breeder point of view. In this respect, P2 (Mut. 8), P4 (EFM92) and P5 (EXM90) appeared to be good general combiners for earliness.

Estimates of GCA effects for seed yield and its components indicated that the P1 (local variety Giza 32) and P3 (Mut. 48) were the best general combiner parents for seed yield per plant due to their highly significant positive values of GCA effects. Such parents also exhibited significant or highly significant positive GCA effects for two or more yield components especially number of capsules per plant. These findings are in harmony with those previously reported by El-Shazly *et al.* [12]. Another parent, viz. P5 (EXM90), appeared to be good a combiner for capsule length. P6 (EXL 139) was a good combiner for seed weight, while P7 (TM90) proved to be a good combiner for number of branches. However, the three latter parents (P5, P6 and P7) were poor general combiners for seed yield itself.

Thus, it is worth noting that the parental genotypes which showed high GCA effects in seed yield might be also good combiners in two or more of the traits contributing to yield. Therefore, it is suggested to use these genotypes in a multiple crossing programme for isolating high yielding varieties. On the other hand, the genotypes containing high GCA effects for particular yield components may not be good combiners for seed yield, but they may be utilized for improving a particular yield components.

3.3.2.2. Specific combining ability effects

Specific combining ability effects calculated for the investigated characters for F_1 crosses are presented in Table VII. Significant positive and negative SCA effects were noted for each character.

Highly significant negative SCA effects towards earliness were observed for eight cross combinations viz. (P1 x P2), (P1 x P3), (P1 x P5), (P1 x P6), (P1 x P7), (P2 x P4), (P2 x P5) and (P6 x P7), while (P5 x P7) exhibited significant negative SCA effects for this trait.

Concerning seed yield per plant, five crosses namely; (P1 x P4), (P1 x P5), (P1 x P7), (P3 x P5) and (P3 x P6) recorded highly significant positive SCA effects. These crosses possessed also highly significant or significant SCA effects for two or more characters contributing to seed yield. Also, none of these favourable crosses gave significant negative SCA effects for any of the yield components. Therefore, such cross combinations are considered promising for varietal improvement purposes as they showed high SCA effects and involved one of the parents as a good general combiner (Tables VI and VII).

In general, it is of interest to mention that the local variety Giza 32 (P1) and Mutant 48 (P3) showed highly significant positive GCA effects for seed yield and two or more of its components (Table VI). Moreover, the favourable cross combinations, that performed highly significant positive SCA effects of seed yield and some of its main components (Table VII), were derived from these two parents. Therefore, such parents and their derived crosses could be utilized for both hybrid sesame production and varietal improvement purpose in terms of probability of isolating desirable transgressive segregants for yield and some of its components.

TABLE VII. ESTIMATES OF SPECIFIC COMBINING ABILITY EFFECTS FROM HALF DIALLEL CROSSES OF SESAME IN F_1 GENERATION

Crosses	Days to maturity	Plant height	Height to first capsule	Capsule length	Branches per plant	Capsule per plant	1000 seed weight	Seed yield/ plant
1. P1 x P2	–2.491**	29.918**	11.233**	0.003	0.445	23.843*	–0.680**	1.096
2. P1 x P3	–4.639**	31.463**	9.544**	0.105*	–0.452	–13.761	–0.044	0.745
3. P1 x P4	0.583	16.037**	24.119**	–0.052	1.065**	25.587*	0.366*	6.622**
4. P1 x P5	–5.231**	1.626	– 0.433	0.235**	0.291	8.306	0.764**	4.005*
5. P1 x P6	–9.528**	–46.748"	– 8.781	–0.271**	–0.798*	–42.887**	–0.429**	–6.621**
6. P1 xP7	–1.787**	10.704**	– 2.911	0. 183**	–0.208	43.761**	0.203	6.100**
7. P2 x P3	–0.676	–34.885**	–14.937"	–0.097	–1. 179**	–42.728**	–0.161	–7.484**
8. P2 x P4	–8.454**	10.922**	11.737**	–0.045	0.589	13.487	0.342*	1.126
9. P2 x P5	–4.269**	4.178	3.385	–0. 187**	0.015	11.672	–0.036	2.675
10. P2 x P6	3.435**	– 5.063	3.037	–0.057	0.176	–14.754	0.141	–2.584
11. P2 x P7	4.176**	32.589**	8.841**	0.454**	0.082	5.928	0.267	–0.496
12. P3 x P4	5.065**	18.300**	19.981**	–0.046	–0.308	–1.783	0.351*	–2.625
13. P3 x P5	3.583**	20.756**	8.296**	–0.205**	1.234**	51.968**	0.106	8.817**
14. P3 x P6	0.287	28.715**	6.615**	0.352**	0.945**	22.009*	–0.103	5.165**
15. P3 x P7	0.028	–31.933**	– 4.915**	–0.251**	0.251	8.624	–0.424**	–1.081
16. P4 x P5	6.806**	–1.004	–12.463**	0.081	–0.631*	–8.583	–0.317*	–4.099*
17. P4 x P6	6.509**	–13.144**	–14.678**	0.051	0.347	–12.809	0.303*	1.642
18. P4 x P7	4.250**	–21.059**	4.459	0.039	0.786*	–26.16 1 *	–0.268	–0.237
19. P5 x P6	0.694	–17.922**	6.337*	–0.112*	–0.728*	–26.924**	0.082	–2.475
20. P5 x P7	–1.565*	–13.604**	7.707**	0.066	0.495	–18.309	0.187	0.779
21. P6 x P7	–2.861**	–16.244"	4.359	0.166**	–0.644*	–24.135*	0.695**	–4.680*
0.644	3.611	2.485	0.050	0.318	10.366	0.150	1.930	
SE (Sij – Sik)	1.124	6.303	4.338	0.088	0.555	18.097	0.262	3.370
SE (Sij – Ski)	1.052	5.896	4.058	0.082	0.519	16.928	0.245	3.152

P1=Giza 32, P2=Mut.8, P4=EFM 92, P5=EXM 90, P6=EXL 139, P7=TM 90.

3.3.3. Types of gene action and heritability

The analysis of variance revealed significant differences between entries for all the characters in both the F_1 and F_2 generations. The genetic components of variance and their standard errors estimated from the diallel analysis together with the ratios of the genetic parameters, heritability and "t^2" values are given in Table VIII. The values of t^2 were found to be non-significant for all studied characters in both generations, indicating that the additive dominance model was adequate to explain the present variation.

The results of Table VIII showed that the estimates of additive genetic component (D) were significant for days to maturity, plant height, height to first capsule, capsule length, branches/plant, and 1000 seed weight in both F_1 and F_2 generations, and for capsules/plant in the F_2 only; suggesting the importance of D component in the inheritance of such characters.

The presence of dominance effects was substantiated by the significant values of H_1 which were higher in magnitude as compared to the D components for all traits (except for capsule length) in the F_1 and vice versa for all studied characters in the F_2 generation. These results suggested that since the non-additive gene action was predominant in the F_1, heterosis breeding in sesame could be used.

However, the additive gene effect was the main component of the total genetic variance for most traits in the F_2 generation, and consequently facilitates improvement of such traits by means of selection.

TABLE VIII. ESTIMATES OF GENETIC AND ENVIRONMENTAL VARIANCE COMPONENTS AND THEIR DERIVED RATIOS OF F_1'S FROM HALF DIALLEL CROSSES OF SESAME FOR SEED YIELD AND ITS ATTRIBUTES

Parameter		Days to maturity	Plant height (cm)	Height to 1st capsule (cm)	Capsule length (cm)	Branches/ plant, No.	Capsule/ plant, No.	1000-seed weight (g)	Seed yield/ plant (g)
D	F_1	71.82	896.06	409.30*'	0.495**	0.901**	204.30	0.51*	10.63
		+10.35	+193.36	+87.08	+0.016	+0.074	+208.16	+0.062	+6.86
	F_2	103.02	805.48	1180.77	0.228**	2.443**	524.06	0.211**	4.62
		+2.72	+81.85	+96.74	+0.035	+0.098	+73.94	+0.024	+3.09
H_1	F_1	149.89**	2946.55**	567.81**	0.164**	1.594**	3178.84	0.546	85.50
		+24.93	+465.52	+209.65	+0.038	+0.178	+501.14	+0.148	+16.52
	F_2	29.53**	578.65**	667.15	0.177*	0.820**	422.46**	0.219**	29.22
		+6.56	+197.05	+232.89	+0.084	+0.236	+178.0	+0.057	+7.44
H_2	F_1	93,97	2209.12	509.04	0.137**	1.471**	2422.28	0.489**	65.46
		+21.97	+410.19	+184.73	+0.034	+0.157	+441.58	+0.131	+14.55
	F_2	27.40**	535.51**	605.18	0.147*	0.625**	281.50	0.190**	22.09**
		+5.78	+173.62	+205.21	+0.074	+0.208	156.85	+0.051	+6.56
F	F_1	89.23**	60.46	67.93	0.090*	0.514**	34.06	0.035	3.79
		+24.84	+463.52	+208.91	+0.038	+0.178	+499.37	+0.148	+16.46
	F_2	3.03	265.48	450.99	0.009	0.988**	105.55	0.104	7.39
		+6.54	+196.35	+232.07	+0.083	+0.236	+177.38	+0.057	+7.42
h^2	F_1	3.61	–11.01	525.43	0.016	0.254*	–55.94	0. 174*	1.31
		+14.75	+275.5	+124.07	+0.023	+0.106	+296.58	+0.088	+9.77
	F_2	3.07	811.30	108.57	0.041	–0.068	2.33	–0.003	30.45**
		+3.88	+116.61	+137.83	+0.049	+0.140	+105.35	+0.034	+4.41
E	F_1	0.69	25.30	10.24	0.004	0.168**	182.03*	0.039	6.22
		+3.66	+68.36	+30.79	+0.006	+0.026	+73.60	+0.022	+2.43
	F_2	0.93	74.68	35.68	0.015	0.149**	72.32**	0.013	1.81
		+0.96	+28.94	+34.20	+0.012	+0.035	+26.14	+0.008	+1.09
$(H_1/D)^{0.5}$	F_1	1.44	1.81	1.18	0.58	1.33	3.94	1.90	2.84
	F_2	0.27	0.42	0.38	0.44	0.29	0.45	0.51	1.26
$H_2/4H_1$	F_1	0.16	0.19	0.22	0.21	0.23	0.19	0.22	0.19
	F_2	0.23	0.23	0.23	0.21	0.19	0.17	0.22	0.19
K_D/K_R	F_1	2.51	1.04	1.15	1.38	1.55	1.04	1.13	1.13
	F_2	1.06	1.48	1.68	1.05	2.07	1.25	1.63	1.93
Hn %+	F_1	44.33	57.66	59.27	84.80	32.24	37.04	34.93	37.31
	F_2	91.50	72.16	93.30	69.70	88.80	60.50	78.90	29.90
t^2	F_1	0.702 ns	0.454 ns	1.229 ns	0.446 ns	0.369 ns	0.376 ns	0.520 ns	0.207 ns
	F_2	1.614 ns	0.518 ns	0.694 ns	1850 ns	0 826 ns	0.701 ns	0.394 ns	2.510 ns

*, ** Significant at 0.05 and 0.01 levels, respectively; ns = not significant
+ Heritability in narrow sense

Estimates of the dominance component (H_2) were smaller than H_1 for all studied characters in both generations, indicating that the frequencies of positive and negative genes at the loci covering these characters were not equal in proportion in the parents.

The distribution of dominant versus recessive genes (F) was positive and significant for days to maturity, capsule length in the F_1 and for branches/plant in both the F_1 and F_2 generations, indicating an excess of dominant genes in the parents for these traits.

The overall dominance effects of heterozygous loci (h^2) were found to positive and significant for height to first capsule, branches/plant and 1000 seed weight in the F_1 and for plant height and seed yield/plant in the F_2 generation, stressing that dominant gene effects were mainly attributed to heterozygosity and dominance seeming to be acting in positive direction (unidirectional) for such traits. The remaining characters showed insignificant values of h^2, indicating that dominance effect for the character was bi-directional in nature; i.e. both dominant and recessive alleles were involved at various loci.

The environmental component of variation (E) was significant only for plant height in the F_2 and for branches/plant and capsules/plant in both generations, reflecting the large effect of environmental factors on these traits.

The mean degree of dominance over all loci, as estimated by the ratio $(H_1/D)^{0.5}$ was found to be more than unity for all traits in the F_1 generation, indicating, the role of overdominance gene effects in the inheritance of the traits. However, the ratio was less than unity for all traits in the F_2 generation (with two exceptions), suggesting the presence of partial dominance in the control of such traits.

The ratio of $H_2/4H_1$, which measures the mean frequency of negative vs. positive genes in the parents, was below its maximum theoretical value (0.25) in both generations, confirming that genes having positive and negative effects were not equally distributed in the parents.

The ratio of dominant to recessive genes (K_D/K_R) in the parents was greater than one for all traits in both F_1 and F_2 generations, suggesting an excess of dominant genes in the parents for each trait.

Narrow sense heritability (Hn) as estimated from F_1 data was found to be low for the studied characters (except for capsule length) with values ranging from 32.24 to 59.27%, indicating that the genetic variance associated with those characters was mostly due to dominance gene effects. However, heritability (Hn) on the basis of the F_2 data recorded high estimates for all characters (except for seed yield/plant) with values ranging between 60.5 and 93.3%, confirming that the additive gene effects were more prevalent.

From the above results it was evident that the estimates of genetic variance and its ratios indicated the importance of both additive and non-additive (dominance) gene effects in the investigated characters in both the F_1 and F_2 generations. But the predominant role of non-additive components for most traits in the F_1 generation which were confirmed by the genetic parameters; H_1, $(H_1/D)^{0.5}$ and Hn, suggested the possible use of heterosis breeding. However, the predominance of additive genetic variance for most of the investigated characters in the F_2 generation that was confirmed by the significant and high magnitude of parameters; D and Hn can be exploited by selection based on progeny performance.

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DEVELOPMENT AND RELEASE OF GAMMA RAY INDUCED SESAME MUTANT ANK-S2 IN SRI LANKA

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Abstract

Epiphytotic conditions and lack of resistant germplasm in sesame (*Sesamum indicum* L.) prompted the use of mutation induction techniques to develop a variety resistant to *Phytophthora* blight caused by *Phytophthora nicotianae* var. *parasitica.* Dry seeds of three varieties were irradiated with six doses of ^{60}Co gamma rays in the range 100–700 Gy. The mutant line 182/3 of variety MI-3 selected from 200 Gy dose treatment in M_2 showed tolerance to the disease in subsequent testing at Angunakolapelessa in the disease nursery. The mutant line was tested in the major yield trial, National Co-ordinated Variety Trials and in the National Co-ordinated Variety Adaptability Trials. It was superior to MI-3 in yield and plant survival during the seasons favouring development of the disease and was similar to MI-3 and other recommended varieties in other seasons. The mutant has cream colour seeds, branched stem, and recorded 1890 kg/ha at Girandurukotte, 1593 kg ha^{-1} at Maha Illuppallama and 1151 kg/ha at Angunakolapelessa under rainfed conditions. The mutant was released as ANK-S2 in 1993 and may be used to increase the declining sesame area due to low yield of existing varieties and their susceptibility to disease. It should serve as a valuable parent material in cross-breeding programmes too.

1. INTRODUCTION

Ease of cultivation, drought resistance and the high quality of its oil have made sesame (*Sesamum indicum* L.) an important oil seed crop in many countries with arid climates. Of the 6.95 million ha harvested in 1995 worldwide, India (2.5 million ha) Sudan (1.1 million ha), China (0.9 million ha) and Myanmar (0.8 million ha) constitute 75% [1]. The relatively large area of production recorded in Sri Lanka in the 1970s and 1980s, which ranged annually from 30,000 ha–40,000 ha, has declined in recent years, with only 9000 ha in 1992 (FAO 1970–1992). Diseases and poor yields resulting in low income to the farmers have caused this decline in production.

The main disease affecting sesame in the southern dry zone of Sri Lanka is caused by *Phytophthora nicotianae* var. *parasitica* [2]. Due to lack of resistant germplasm, a mutation breeding programme was initiated to develop cultivars tolerant to this disease. Mutation induction and selection in early generations under epiphytotic conditions have been reported earlier [2]. This paper describes the performance of the mutant line 182/3 derived from the recommended variety MI-3 in the varietal testing programme of the Department of Agriculture, Sri Lanka.

2. MATERIALS AND METHODS

The standard procedures used in the co-ordinated variety testing programmes of the Department of Agriculture [3] were adopted. When the plots were affected by the disease, plant survival percentage was assessed by counting the total number of plants in the plot and those that survived to give at least one capsule with filled seeds.

3. RESULTS AND DISCUSSION

The mutant line 182/3 was tested with three recommended varieties MI-1, MI-2 and MI-3 in the major yield trial at the Agricultural Research Station, Angunakilopalessa during the south west monsoon (Yala) 1984 and north east monsoon (Maha) 1984/85. Both seasons were conducive to the

development and spread of *Phytophthora* disease and the mutant line recorded significantly higher yields than the best of the recommended varieties of that season (Table I and Table II). MI-3 variety, the parent cultivar of 182/3 line was the most affected by the disease and the mutant line was the least affected.

TABLE I. YIELD PERFORMANCE AND INCIDENCE OF *PHYTOPHTHORA* IN THE MAJOR YIELD TRIAL AT ANGUNAKOLAPELESSA, 1984 (SOUTH WEST MONSOON SEASON)

Variety	Seed yield, kg/ha	Yield, %	Incidence of *Phytophthora,* %
ANK–S2	675	151.7	10.8
MI-3	421	94.6	58.8
MI-1	385	86.5	52.1
MI-2	445	100.0	49.6
LSD 5%	142		18.8
LSD 1%	268		38.3

TABLE II. YIELD PERFORMANCE AND INCIDENCE OF PHYTOPHTHORA IN THE MAJOR YIELD TRIAL AT ANGUNAKOLAPELESSA, 1984/85 (NORTH EAST MONSOON SEASON)

Variety	Seed yield, kg/ha	Seed yield, %	Incidence of *Phytophthora,*%
ANK-S2	569	120.8	12.1
MI-3	356	75.6	65.2
MI-1	471	100	66.7
MI-2	418	88.8	57.8
LSD 5%	151	20.8	
LSD 1%	288	42.6	

The mutant line was tested in the sesame National Co-ordinated Variety Trials (NCVT) from 1987 Yala season. The parent variety MI-3 was used as the control in these experiments. During the Yala 1987 season, the mutant significantly out-yielded MI-3 variety at Aralaganwila in the Polonnaruwa District. However its yield was significantly lower than the parent at Wariyapola in Kurunegala District. The yield differences at Maha Illuppallama and Angunakolapelessa were not high and statistically not significant (Table III). The yields were not affected by the disease during that season.

In the Maha 1987/88 season, the disease incidence was relatively high and the mutant recorded a significant yield increase at Angunakolapelessa (Table IV). When averaged over the three locations where the NCVT was conducted, the mutant out-yielded its parent by 13.5%. Due to disturbances during the field trials only the yield data for Girandurukotte could be collected in Yala 1989. During this season, the mutant recorded the highest yield of 1898 kg/ha at Girandurukotte (Table V). The yield was very low in all varieties in Yala 1990 season, and ANOVA was not significant (Table V). In the subsequent northeast monsoon season (1990/91) the variety MI-3 was tested with its mutant at two locations. The yield of the mutant was comparable to its parent's in these two locations (Table VI). Due to the already recorded tolerance of the mutant to phytophthora blight and its superior or equal performance during several seasons of testing in the National Co-ordinated Variety Trials, it was promoted to the National Coordinated Variety Adaptability Trials prior to release. Thus it was tested along with MI-3 cultivar in three regions during Maha 1990/91 season. At all the regions and in all locations of different regions the mutant recorded higher yield compared to the parent cultivar (Table VII). The National Co-ordinated Variety Adaptability Trials were conducted at five locations in Yala 1991 season. Again the mutant recorded higher yields than the parent cultivar at all locations, giving a mean yield increase of 14.7% (Table VIII).

TABLE III. COMPARISON OF YIELD (kg/ha) IN THE NATIONAL COORDINATED VARIETY TRIALS, SOUTH WEST MONSOON SEASON 1987

Variety/line	Angunakolapelessa	Maha Illuppallama	Aralaganwila	Wariyapola	Mean
182/3	1151	986.5	652.7	682.1	868.1
MI-3	1013	1112.1	416.5	1327.7	967.3
Mean	959.5	855.4	447.8	924.8	
LSD 5%			166.9	551.7	
LSD 1%			225.5	753.1	

TABLE IV. COMPARISON OF YIELD (kg/ha) OF MUTANT WITH PARENT CULTIVAR IN THE NATIONAL COORDINATED VARIETY TRIALS, NORTHEAST MONSOON SEASON 1987/88

Variety/line	Angunakolapelessa	Aralaganwila	Wariyapola	Mean
182/3	756	174	434	400.0
MI-3	279	215	706	400.0
Mean	331	240	697	
CV %		62.4	47.3	13.3
LSD 5%			434	

TABLE V. COMPARISON OF YIELD (kg/ha) IN THE NATIONAL COORDINATED VARIETY TRIALS DURING 1989 AND 1990 (SOUTH WEST MONSOON SEASON)

Variety	Girandurukotte 1989	Girandurukotte 1990	Aralaganwila	Weerawila
182/3	1898	246	220	428
MI-3	1436	189	446	336
Mean	1489	–		
LSD 5%	994			
LSD 1%	1363			

TABLE VI. THE YIELD PERFORMANCE (kg/ha) OF MUTANT LINE 183/3 AND ITS PARENT AT TWO SITES DURING NORTH EAST MONSOON SEASON, 1990/91

Variety	A`pelessa	Weerawila
182/3	540	853
180/52	700	956
MI-3	484	865
F	NS	NS

TABLE VII. YIELD PERFORMANCE (kg/ha) OF MUTANT 182/3 IN NATIONAL CO-ORDINATED VARIETAL ADAPTABILITY TRIALS, NORTH WEST MONSOON SEASON 1990/91

Variety	Location1	Location 2	Location 3	Location 4	Mean
Angunakolapelessa region					
ANK–S2	518	584	321	608	507
MI-3	368	412	293	425	375
Maha Illuppallama region					
ANK–S2	658	412	701	753	631
MI-3	508	315	451	541	454
Wariyapola region					
ANK-S2	521	542	482		515
MI-3	394	381	401		392

TABLE VIII. YIELD PERFORMANCE (kg/ha) OF MUTANT 182/3 IN NATIONAL COORDINATED VARIETY ADAPTABILITY TRIALS, AT MI REGION SOUTH WEST MONSOON SEASON 1991

Variety	L1	L2	L3	L4	Mean
AK–S2	628	614	501	562	576
MI-3	495	508	493	512	502

TABLE IX. CHARACTERISTICS OF NEW MUTANT VARIETY ANK-S2

Name of the variety	– ANK–S2
Source	– RARC/Angunakolapelessa
Pedigree	– A mutant variety derived from variety MI-3 irradiated with ^{60}Co gamma rays at 200 Gy
Age group	– 2 ½ months
Photoperiod sensitivity	– Insensitive
Leaf colour	– Pale green
Plant height	– 80 cm
Stem height of the yielding part	– 30 cm
Branching or not	– Branched
Number of branches per plant	– 5
Flower colour	– Light purple
Number of days from planting to harvesting	– 78–80 days
Plant height to 1st capsule	– 31 cm
Number of nodes to the 1st capsule	– 6
Capsule length	– 3.4 cm
Number of locules per capsule	– 4
Number of capsules in a bunch	– 1
Number of capsules per plant	– 46
Seed colour	– Cream
1000 seed weight	– 3.8 g
Reaction to diseases	– Tolerant to *Phytophhora* blight disease
Potential yield	– 1890 kg/ha (G`kotte) – 1593 kg/ha (MI) – 1151 kg/ha (A`pelessa)

ANK-S2 (Mutant line 182/3)

Variety ANK–S2 is a mutant derived from variety MI-3 irradiated at 200 Gy with ^{60}Co gamma rays. It is a cream seeded variety and it matures in about 78–80 days It is tolerant to *Phytophthora* blight disease and is superior over the recommended white seeded variety MI-3 and black seeded varieties MI-1 and MI-2 for yielding ability and for *Phytophthora* disease tolerance. The highest yield potentials recorded are 1890 kg/ha at Maha Illuppallama and 1151 kg/ha at Angunakolapelessa under rainfed conditions. This variety is more suitable for the southern dry region of Sri Lanka where the occurrence of *Phytophthora* blight disease is predominant.

The mutant line 182/3 was officially released by the Department of Agriculture, Sri Lanka in 1993 under the name ANK-S2. The characteristics of the new variety are given in Table IX.

Although disease resistance is a major concern in sesame breeding [4] very few efforts have been made to develop disease resistant sesame cultivars [5]. This may be due to lack of easy methods for screening and also absence of resistant material in germplasm collections for cross breeding [6, 7].

In Korea, X ray irradiation with 200 Gy of early Russian variety has led to the development and release of a disease resistant variety. This variety has later served as initial material for development of several disease resistant cultivars [8]. Therefore the disease tolerant qualities of mutant variety ANK-S2 should be exploited not only to expand the declining sesame production area in the country, but also in cross breeding to develop new cultivars with improved traits.

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EVOLUTION OF IMPROVED VARIETIES OF SESAME THROUGH INDUCED MUTATIONS

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Abstract

Sesame varieties/genotypes showed a good response to radiation with gamma rays and treatments with EMS. In M_1 both gamma rays and EMS influenced germination, seedling height, survival of plants and pollen fertility/sterility, producing deleterious effects on these characters. Compared to black seeded genotypes, white seeded ones are more susceptible to radiation. Both gamma rays and EMS produced various types of morphological variations in M_2 generation. These were dwarf plant mutants, mottled and fleshy leaved mutants (sterile), fasciated stem, flower colour, altered phyllotaxy, early, uniculm, capsule size variations, multiple capsule/leaf axil, seed coat colour variations, indehiscent and semi-indehiscent type mutants. Moreover, studies on quantitative characters including seed yield revealed the induction of mutants in both positive and negative directions for such traits which made a good scope of selection of desirable mutants in M_2 generation. Mutants selected in M_2 were raised in M_3 in plant to progeny rows and further selection was made. Compared to the M_2 generation, the range of family means became narrower in M_3 which indicated the effectiveness of selection in the M_2. True breeding lines isolated in M_3 generation have given potentially higher seed and oil yield in a preliminary yield trial in M_4 compared to source. Six promising mutant lines were evaluated in M_4, M_5, M_6, M_7 and M_8 generations for seed yield and other agronomic parameters at various locations of Bangladesh under variable environments. Mutants SM5, SM7 have produced significantly higher seed yields at all locations with 50–52% oil content compared to 40–44% oil content in the source varieties. Some mutants were tolerant to stem rot and sesame mosaic in most of the locations. The increased yield was due to higher number of capsules/leaf axil, longer capsules with continuous bearing and increased number of seeds/capsule. It was also observed that white seeded mutants have 6–10% more oil in the seed as compared to black seeded ones. Combined analysis of variances for seed yield over locations revealed significant differences in the performance of the mutants over their source material. Mutants SM5 and SM7 proved superior in respect to seed and oil yield and other agronomic characters. The mutants were given on farm trials at various locations with two management practices, viz., research management with higher inputs and farmers' management practices with low or no inputs. In both management practices the mutants produced significantly higher yield compared to the source. Significant differences were found in seed yield in mutants/check (G), locations (L), management practices (M) and interaction between (G x L) while the interaction between management and location (M x L) was insignificant. Mutants SM5 and SM7 would be submitted to National Seed Board for registration as commercial high yielding mutant varieties. Some of the promising mutants will be utilized in cross-breeding programmes. The present report discusses the effect of mutagen on sesame genotypes, results obtained in different mutant generation and overall mutation breeding studies carried out throughout the project period starting from 1993 to 1997.

1. INTRODUCTION

In Bangladesh sesame occupies the second position in oilseed crops with respect to area under cultivation and total production next to mustard/rapeseed. Only one variety (T-6) is cultivated throughout the country. The variety is low in yield potential (598 kg/ha) [1], black seeded with 40–42% oil in the seed. Improvement with respect to seed and oil yield in sesame is important. This is because the crop is well adapted under traditional to advanced technologies and there is a high deficit of oilseed in Bangladesh. The production of oilseed in Bangladesh can cover only one third of the total requirement. Huge import thus costs more than Tk. 10,000 million annually. The low yield of the present variety/land races is mostly due to smaller capsule, poor and alternate capsule bearing/leaf axil, fewer seeds/capsule, shattering of seeds before harvest, susceptibility to water logged condition, and diseases. In order to improve yield and yield related characteristics induced mutation breeding programmes through gamma rays and EMS were undertaken for creation of variability and selection for improved mutant lines.

2. MATERIALS AND METHODS

Description of research carried out : The programme of work was as follows :

- On-farm trial with two promising mutants at farmers' field in different agro-ecological zones under two management practices during kharif-II of 1996 and kharif-I 1997.
- Regional yield trials with the promising mutants during kharif-II of 1996 and kharif-I of 1997.
- Advanced Yield Trial with 12 M_5 promising mutants to evaluate yield and other attributes.
- Evaluation of local and exotic germplasm for selection of suitable lines for irradiation.
- Raising M_3 plant progeny for selection of desirable true breeding mutants among segregating population.
- Growing of M_2 progeny for preliminary selection of desirable mutants.
- Cross breeding with promising mutants x local variety (T-6) and S-30 x T-6 genotypes.
- Screening of mutants under different generations against stem rot and sesame mosaic.
- Effect of water-logging on the growth and yield of the promising sesame mutant SM7.

2.1. On-farm trial with two promising mutants at farmers' field in two different agro-ecological zones under two management practices during kharif-II of 1996 and kharif-I 1997

Four experiments were conducted with mutants SM5 and SM7 in farmers fields of Comilla and Barisal during kharif-II of 1996 and kharif-I 1997. T-6 and S-30 were included in the trials as check. The experiments were laid out in split plot design (dispersed) with unit plot size of 5m x 5m (25 m^2). Performance of the mutants were evaluated under two management practices, i.e., research management and farmers' management. The research management consisted of high fertilizer doses (NPK, 80:60:40 kg/ha), one weeding 25 days after sowing, one irrigation, the farmers' management had low fertilizer doses (NPK 40:20:20 kg /ha) only. Data on days to maturity, seed yield and oil content were taken and analyzed for statistical interpretation.

2.2.1. Regional yield trials with the promising mutants during kharif-II of 1996

To evaluate the performance of the selected mutants in various locations of country Regional Yield Trials (RYT) were conducted with six promising mutants along with two checks (T-6 and S-30) in three locations, i.e., BINA farms at Magura, Ishurdi and Comilla during kharif II (September–December) of 1996. The mutants were SM-1, SM-2, SM-4, SM-5, SM-7 and SM-9. The trials were laid out in a randomized complete block design with four replications. Unit plot size was 5m x 5m. Row to row and plant to plant distances were 25 and 5–6cm, respectively. NPK fertilizers were applied at 80:65:40 kg/ha. Sowing was on 17.9.1996 at Magura, 15.9.1996 at Ishurdi and 22.9.1996 at Comilla. Operations, such as weeding, mulching, spraying of insecticide, etc. were done to ensure normal growth of plants. Data on days to maturity, plant height, number of capsules/plant, number of seeds/capsule, 1000-seed weight and seed yield were taken and subjected to statistical analysis. Oil content was determined by NMR technique.

2.2.2. Regional yield trials with the promising mutants during kharif-I of 1997

The above trials were carried out in kharif I (February–May) of 1997 in five locations. These were BINA farms at Ishurdi, Rangpur and Comilla and BARI farms at Dinajpur and Barisal. The experimental details were same as described in the previous trials.

2.3. Advanced yield trial with 12 M_5 promising mutants during kharif- I, 1997

An experiment was conducted with 12 mutants and two checks (T-6 and S-30) at BINA farm, Ishurdi and Magura during kharif I, 1997 to select the most promising mutants having high yielding potential in a wide range of environments. The experiment was laid out in randomized complete block design with three replications. Unit plot size was 3m x 4m with 25cm. spacing between the rows. Sowing was done on 15.2.1997 at Ishurdi and 5.3.1997 at Magura. NPK fertilizers were applied at 80:65:40 kg/ha. Operations, such as weeding, mulching, spraying of insecticide, etc. were done to

ensure normal growth of plants. Data on days to maturity, plant height, number of capsules/plant, number of seeds/capsule, seed yield and oil content were taken and subjected to statistical analysis.

2.4. Evaluation of local and exotic germplasm of sesame during kharif- I, 1997

The experiment was carried out at BINA farm, Ishurdi with 14 accessions (9 local and 5 exotic collections) during kharif I, 1997 for evaluation of their performance in respect of seed yield potential and other characters. The experiment was laid out in randomized complete block design with two replications. Unit plot size was 2 m × 3 m with row to row spacing of 25cm. Seeding was done on 16.2.1997. NPK fertilizers were applied at 80:60:40 kg/ha. Recommended operations were done to ensure normal growth of plants. Data were taken on days to maturity, plant height, number of capsules/plant, number of seeds/capsule and seed yield (kg/ha). Statistical analysis was done using the mean values of different characters.

2.5. Raising M_3 plant progeny to study true breeding behaviour and selection from among segregating population during kharif- II, 1996

A total of 475 variants/mutants of S-30 and T-6 isolated in M_2 generation were grown in plant progeny rows in M_3 generation to study segregation patterns and true breeding behaviour of the mutants, and further selection was made from among the segregating population. The experiment was conducted at BINA farm, Mymensingh during September–December of 1996. Seeds of each mutant/variant were sown in 5m long rows with 25cm spacing. Plant to plant distance was 5–6 cm. Seeds of source varieties were sown after every 10 rows of the treated populations. Recommended cultural practices were followed to ensure normal growth and development of the plants.

2.6. Growing of M_2 progeny for preliminary selection of desirable mutants during kharif II, 1996

M_2 progeny of S-30 and T-6 were grown in plant progeny rows, each 5m long under different doses and concentrations of gamma rays and EMS, respectively with plant to plant distance 5–6 cm in the row for selection of mutants with higher seed yield, resistance to water-logging and stem rot disease. Details of the experiment are similar to the above experiment.

2.7. Cross breeding of promising mutants x local variety (T-6) and S-30 x T-6 genotypes

F_3 generation was raised from the selected plants in plant progeny rows. Each row was 5 m long. Recommended cultural practices as described before were followed also in this experiment.

Further crosses were made between the locally adapted variety T-6 and 8 promising mutants. F_1 seeds from different crosses have been collected to raise F_2 progeny in the coming season. In another programme, non-segregating populations (P_1, P_2 and F_1) and segregating ones (F_2, F_3, B_1 and B_2) of a single cross of S-30 (P_1) and T-6 (P_2) were raised and inheritance studies on seed yield and six yield contributing characters were made.

2.8. Screening of mutants under different generations against stem rot and sesame mosaic

Six advanced generation induced mutants, their source, S-30 and a check, T-6, were evaluated against stem rot (*Macrophomina phaseolina* L.) and sesame mosaic under field conditions during February–March, 1997. The experiment was conducted in a randomized complete block design with three replications at BINA sub-station farm, Ishurdi and Rangpur in collaboration with the Plant Pathology Division. The unit plot size was 5m x 5m and row to row and plant to plant distances were 30 and 8–10cm, respectively. Recommended cultural practices were followed to ensure normal growth and development of plants in the field. The incidence (% infected plants) of stem rot and the

incidence and severity of sesame mosaic were recorded at the maximum capsule ripening stage of plant growth.

Another experiment having the same objectives was conducted with fourteen accessions during September–December 1996 and February–May 1997 at BINA sub-station farm, Ishurdi. Unit plot size, spacing and cultural practices were as mentioned before.

Field evaluation was also made with 12 advanced mutants along with two checks against stem rot and sesame mosaic during September–December 1996 at Ishurdi and February–May 1997 at Magura. The unit plot size was 3m x 2m. Spacing and cultural operations were similar as described above.

2.9. Effect of water-logging on the growth and yield of a promising sesame mutant SM7

This experiment was conducted at BINA sub-station farm, Ishurdi to study the effect of water-logging on the growth and seed yield of a promising mutant SM7. The experiment was laid out in randomized complete block design having 3 m × 2 m plot size. The water-logging treatments having 3cm standing water in each plot were as follows:

D_0 = Control (No waterlogging)
D_1 = 48 hours water-logging at 25 days after sowing
D_2 = 48 hours water-logging at vegetative stage
D_3 = 48 hours water-logging at flowering stage
D_4 = 48 hours water-logging at seed filling stage

Records on plant height, number of capsules/plant, seed and straw yield were taken and analyzed statistically.

3. RESULTS

3.1. On-farm trial with two promising mutants at farmers' field in two different agro-ecological zones under two management practices during kharif-II, 1996 and kharif-I, 1997

The results presented in Table I show significant differences in seed yield in mutants/check (G), locations (L), management practices (M) and interaction between G x L while the interaction between management and location (M x L) was not significant during kharif-II of 1996 and significant in kharif-I of 1997.

Overall mean performances in respect of days to maturity, seed yield and oil content (%) of the mutants and check are presented in Table II. The result of kharif-II of 1996 showed that both mutants matured between 86–93 days while the check, S-30 and T-6 took 97–98 days to mature in recommended management practice. It was also found that the mutants and check in farmers' management took 2–5 days less to mature compared to research management. Seed yield in both locations was higher under the recommended management practices than under the farmers' management. The differences in seed yield of the mutants and check were statistically significant. Mutant SM7 produced the highest seed yield of 1230kg/ha at Comilla and 1465kg/ha at Barisal followed by SM5 which gave 1110 and 1280kg/ha at Comilla and Barisal, respectively in recommended management. S-30 and check variety T-6 produced 980 and 965kg seed/ha at Comilla and 1120 and 1100kg/ha at Barisal, respectively. Mutant SM7 had the highest oil content of about 52% followed by SM5 (about 50%) while the check had 6–7% less oil in the seed. The result of kharif-I of 1997 was almost similar as desired above for kharif-II of 1996. All the genotypes matured earlier compared to kharif-II of 1996. Seed yield was also higher in kharif-I of 1997.

TABLE I. COMBINED ANALYSIS OF VARIANCE FOR SEED YIELD OF TWO PROMISING MUTANTS ALONG WITH CHECK OVER TWO LOCATIONS AND TWO MANAGEMENT PRACTICES IN FARMERS' FIELDS

Source of variation	Degrees of freedom	Mean squares	
Kharif-II (1996)			
Mutants/check (G)	3	124323	**
Locations (L)	1	5418365	**
G x L	3	82584	**
Management (M)	1	135942	**
M x L	1	19082	
Error	36	11857	
Kharif-I (1997)			
Mutants/check (G)	3	130753	**
Locations (L)	1	4917052	**
G x L	3	103211	**
Management (M)	1	141630	**
M x L	1	28739	**
Error	36	7391	

**Significant at 1% level.

TABLE II. MEAN PERFORMANCE OF TWO MUTANTS COMPARED TO CHECK VARIETIES UNDER TWO MANAGEMENT PRACTICES AT FARMERS' FIELDS IN TWO LOCATIONS

Location with mutant/variety	Research management		Farmers' management		Oil content (%)
	Days to maturity	Seed yield (kg/ha)	Days to maturity	Seed yield (kg/ha)	
Kharif-II (1996)					
Comilla (Location-1)					
SM5	92b	1110ab	90b	1020a	49.8
SM7	87c	1230a	85c	1095a	52.0
S-30	97a	980c	97a	900b	43.5
T-6	98a	965c	97a	880b	42.3
Barisal (Location-2)					
SM5	93b	1280b	90b	1200b	49.7
SM7	86c	1465a	84c	1290a	51.9
S-30	98a	1120c	96a	975c	44.0
T-6	98a	1100c	97a	970c	43.2
Kharif- I (1997)					
Comilla (Location-1)					
SM5	84b	1250a	83b	1155a	50.2
SM7	82b	1300a	82b	1170a	51.8
S-30	89a	1010b	87a	975b	43.0
T-6	91a	980b	90a	900b	42.7
Barisal (Location-2)					
SM5	85b	1405b	85b	1290a	50.0
SM7	84b	1575a	83b	1395a	52.2
S-30	91a	1030c	90a	980b	43.7
T-6	91a	1000c	91a	945b	43.0

Values having same letter/s in a column of each location do not differ significantly at 5% level.

3.2. Regional yield trial with the promising mutants during kharif-II of 1996

Combined analysis of variance for days to maturity, number of capsules/plant and seed yield over three locations is presented in Table III. Significant mean square values in these characters indicated that there existed differences in performance of the mutants, i.e., they responded differently in different locations for all the characters except days to maturity which did not show significant difference between locations. Table IV shows the mean performance of different characters in three different locations. Mutant. SM7 took 86, 88 and 86 days to mature at Magura, Ishurdi and Comilla, respectively, while the other mutants took 3–5 days more to mature. The maturity period of S-30 and T-6 ranged between 95 and 103 days in these three locations. In respect of seed yield mutant. SM7 gave the highest yield of 1163kg/ha at Magura and 1393 at Ishurdi while at Comilla mutant. SM4 produced the highest yield of 1228kg/ha followed by SM5 (1150) and SM7 (1125). The other three mutants also produced higher yield than the check, i. e., S-30 produced 806, 916 and 784kg/ha seeds at Magura, Ishurdi and Comilla and variety T-6 gave 668, 789 and 765kg/ha seeds, respectively. Mutant SM7 had the highest oil content of 52% followed by SM4 (50%) and SM5 (50%) in the seed at all the 3 locations. Other mutants had more than 45% oil in the seed while the check, S-30 and T-6 had about 43–44% oil.

Further trials will be given in kharif-1 (February–May) of 1998 involving more locations. Then an application will be made to the National Seed Board of Bangladesh for recommendation of at least one or two mutants as high yielding varieties for commercial cultivation in the country.

TABLE III. COMBINED ANALYSIS OF VARIANCE OVER LOCATIONS FOR DAYS TO MATURITY, NUMBER OF CAPSULES/PLANT AND SEED YIELD OF PROMISING MUTANTS AND CHECKS OF SESAME (KHARIF-II OF 1996)

Source of variation	Degrees of freedom	Days to maturity	No. of capsules/plant	Seed yield (kg/ha)
Location (L)	2	3.1	167.1 *	255434 **
Error	9	3.0	35.5	5431
Mutants (G)	7	264.5 **	238.1 **	408757 **
G x L	14	12.1 **	10.7 *	8745 **
Error	63	3.1	2.2	1265
CV (%)	-	1.9	3.7	3.5

* and ** Significant at 5 and 1% level.

3.3. Regional yield trial with the promising mutants during kharif-I of 1997

The result of combined analysis of variance (mean squares) and mean of characters of the mutants and check are presented in Tables V and VI. All the items showed significant mean squares for all the characters under study except seed yield under the item G x L interaction. The mean seed yield over all the locations showed that the mutant SM7 produced the highest seed yield of 1214kg/ha. mutant SM5 and SM-4 produced 1167 and 1155kg seeds/ha. The yields of these three mutants were statistically similar but were significantly different from all other mutants and check. Mutant SM1 produced 1080kg/ha. The check variety T-6 and S-30 produced 834 and 839kg/ha, respectively. Regarding oil content mutant SM7 maintained its superiority over all other mutants and check. An application will be made to the National Seed Board for release of SM7, SM5/SM4 as commercial varieties.

3.4. Advanced yield trial with 12 M_5 promising mutants

The result of combined analysis of variance showed significant mean square values in the items location (L) and mutant (G) for days to maturity, number of capsules/plant and seed yield (Table VII). The G x L interaction was not significant for days to maturity and seed yield and significant for number of capsules/plant. Mean values of different characters of mutants and check over two locations are shown in Table VIII. The mutants were found to mature 2–11 days earlier compared to the check T-6 and S-30 which

took 97 days to mature. Mutant SM13 produced the highest seed yield of 1132 kg/ha followed by SM18 (1110 kg) and SM-12 (1040 kg). The check T-6 and S-30 gave 835 and 803 kg/ha, respectively. Oil content ranged from 44.5% in mutant SM13 to 51.2% in SM6. T-6 and S-30 had 43.0 and 43.5% oil, respectively. A zonal yield trial will be given with five of the most promising mutants involving more locations to see their seed yield potential.

TABLE IV. MEAN VALUES OF DIFFERENT CHARACTERS OF PROMISING MUTANTS AND CHECKS GROWN IN THREE LOCATIONS DURING KHARIF II OF 1996

Location and mutants/check	Days to maturity	Plant height (cm)	No. of capsules/ plant	No. of seeds/ capsule	1000-seed wt. (g)	Seed yield (kg/ha)	Oil content (%)
Magura (Location-1)							
SM-1	92b	84f	39c	50b	2.98bcd	965c	48.2
SM-2	89f	95c	41b	53b	2.88d	973c	47.8
SM-4	94d	101ab	41bc	56a	3.03abc	1105b	49.9
SM-5	96c	82f	45a	44c	2.93cd	1095b	50.3
SM-7	86g	103a	44a	56a	3.10a	1163a	52.1
SM-9	93d	93d	36d	50b	3.10ab	889d	47.0
S-30	98b	88e	36d	43c	2.90d	806e	43.6
T-6	103a	99b	33e	39d	2.90d	668f	43.1
Ishurdi (Location-2)							
SM-1	93de	88ef	41cd	53c	3.05abc	1055e	48.0
SM-2	89f	93de	43c	55bc	2.98cd	1121d	47.6
SM-4	93e	102bc	43c	61a	2.90d	1309b	49.7
SM-5	96c	84f	49b	51d	3.10ab	1253c	50.0
SM-7	88g	104b	53a	60a	3.15a	1393a	51.7
SM-9	94d	98cd	38d	56b	3.13a	1085de	47.2
S-30	99b	97d	40d	49d	3.00bcd	916f	43.3
T-6	101a	100a	39d	43e	2.95cd	789g	43.5
Comilla (Location-3)							
SM-1	94c	95b	37c	48de	3.00bc	860e	48.4
SM-2	87d	90c	39c	48d	3.03ab	925d	47.5
SM-4	94c	103a	42b	58a	3.13a	1228a	49.0
SM-5	95bc	90c	47a	46e	3.00bc	1150b	50.0
SM-7	86d	91c	43b	55b	3.03ab	1125b	51.7
SM-9	98a	102a	38c	52c	3.03ab	982c	46.9
S-30	95b	84d	33d	41f	2.90c	784f	43.5
T-6	100a	104a	36c	38f	2.92c	765f	43.2

Values having same letter(s) in a column of each location do not differ significantly at 5% level.

TABLE V. COMBINED ANALYSIS OF VARIANCE FOR DIFFERENT CHARACTERS OF MUTANTS AND CHECK, KHARIF-I, 1997

Source of variation	df	Days to maturity	Plant height	Capsules/plant	Seeds/capsule	Seed yield
Location (L)	4	674.4 **	5106 **	613.3 **	475.8 **	36779 *
Error	15	3.65	56.7	34.2	8.29	16352
Mutant (G)	7	273.3 **	269.9 **	304.1 **	133.9 **	496187**
G x L	28	11.48 **	104.1 **	74.9 **	85.4 **	4633 ^{NS}
Error	105	2.80	49.09	20.3	18.4	8315
CV (%)		1.93	6.16	9.17	6.54	8.96

* and ** Significant at 5 and 1% level, respectively.

TABLE VI. MEANS OF DIFFERENT CHARACTERS OF THE PROMISING MUTANTS AND CHECKS GROWN IN 5 LOCATIONS, KHARIF-I, 1997

Location and mutants / check	Days to maturity	Plant height (cm)	Capsules /plant, No.	No. of seeds/capsule	Seed yield (kg/ha)	Oil content (%)
Ishurdi (Location-1)						
T-6	97a	121b	50bc	67cd	883c	43.3
S-30	96a	122ab	62a	75abc	877c	43.9
SM-1	87d	113bc	48bc	71abc	1185ab	47.5
SM-2	89c	105c	52b	68bcd	1055bc	47.0
SM-4	91bc	129a	61a	79a	1140ab	49.6
SM-5	92b	113bc	60a	76ab	1222ab	50.2
SM-7	85d	114b	54ab	61d	1275a	51.3
SM-9	91bc	120b	43c	68bcd	925c	46.8
Dinajpur (Location-2)						
T-6	98a	104	47ab	59abc	840b	43.0
S-30	96a	106	52a	60abc	847d	43.5
SM-1	87c	101	45ab	64ab	1060bc	46.9
SM-2	87c	103	47ab	57bc	975c	47.1
SM-4	92b	103	53a	60abc	1085ab	49.0
SM-5	92b	97	50ab	56c	1105ab	50.0
SM-7	86c	104	51a	65a	1187a	50.5
SM-9	93d	104	42b	60abc	865d	46.2
Rangpur (Location-3)						
T-6	94a	131bcd	46b	61	838c	43.4
S-30	92a	120e	40c	67	823c	44.0
SM-1	85bc	129cde	48b	63	1025d	47.0
SM-2	83cd	123de	45bc	64	970b	47.3
SM-4	84bcd	137abc	44bc	68	1138a	49.2
SM-5	91a	122de	46b	68	1168a	50.2
SM-7	82b	139ab	57a	70	1205a	51.3
SM-9	86b	142a	45bc	65	823c	46.2
Comilla (Location-4)						
T-6	85a	109c	41bc	62d	763c	43.6
S-30	84a	116abc	49c	70ab	793c	43.3
SM-1	77bc	123a	45d	66bcd	1040b	47.4
SM-2	74b	121ab	44bc	67bc	945b	47.3
SM-4	85a	125a	42bc	64cd	1233a	48.2
SM-5	82a	114bc	45b	70ab	1160a	49.7
SM-7	77b	124a	54a	72a	1183a	50.3
SM-9	83a	125a	43bc	64cd	810c	46.1
Barisal (Location-5)						
T-6	87a	100	50bc	58de	845c	44.1
S-30	87a	102	51bc	53e	853c	43.4
SM-1	81bc	100	48c	68bc	1088ab	47.2
SM-2	83b	102	49c	64cd	1003bc	47.2
SM-4	83bc	102	59ab	74a	1178a	48.7
SM-5	86a	94	62a	63cd	1180a	49.6
SM-7	80c	97	65a	73ab	1220a	50.1
SM-9	83b	101	48c	61d	900c	45.7
Mean over 5 locations						
T-6	92a	113b	47de	61c	834d	-
S-30	91a	113b	49cd	65b	839d	-
SM-1	83d	113b	47de	66ab	1080b	-
SM-2	83d	111bc	47de	64bc	990c	-
SM-4	87c	119a	51bc	69a	1155a	-
SM-5	89b	108c	52b	67ab	1167a	-
SM-7	82e	115ab	56a	68a	1214a	-
SM-9	87c	118a	44e	64bc	865d	-
Locations						
(Location-1)	91a	117b	53a	71a	1070a	-
(Location-2)	91a	103c	48b	60d	996b	-
(Location-3)	87b	130a	46bc	66b	998b	-
(Location-4)	81d	119b	44c	67b	991b	-
(Location-5)	84c	100c	54a	64c	1033ab	-

Values having same letter(s) in a column of each location do not differ significantly at 5% level.

TABLE VII. COMBINED ANALYSIS OF VARIANCE OVER TWO LOCATIONS FOR DAYS TO MATURITY, NUMBER OF CAPSULES/PLANT AND SEED YIELD OF 14 MUTANTS/CHECK, AYT OF KHARIF I, 1997

Source of variation	Degrees of freedom	Days to maturity	Number of capsules/plant	Seed yield
Location (L)	1	1885.8 **	1991.4 **	163858 *
Error	4	0.46	14.6	9347
Mutants (G)	13	58.47 **	148.0 **	134487 **
G x L	13	1.20 NS	45.9 **	1833 NS
Error	52	2.90	13.64	6929

* and ** Significant at 5 and 1% level, respectively.

TABLE VIII. MEANS OF TWO LOCATIONS OF DIFFERENT PARAMETERS OF PROMISING MUTANTS AND CHECK, AYT OF KHARIF I, 1997

Mutants/check	Days to maturity	Plant height (cm)	Capsules/plant No.	No. of seeds/capsule	Seed yield (kg/ha)	Oil content (%)
SM-3	90	111	57	75	967	46.6
SM-6	93	110	51	73	640	51.2
SM-8	92	115	52	77	552	47.4
SM-10	90	104	43	69	732	46.2
SM-12	86	111	45	70	1040	46.1
SM-11	90	113	51	72	982	45.2
SM-13	96	110	53	74	1132	44.5
SM-14	92	109	53	71	910	45.0
SM-15	95	118	43	97	763	45.4
SM-16	89	104	53	70	960	46.0
SM-17	91	110	46	68	910	45.5
SM-18	93	110	43	68	1110	45.5
T-6	97	111	45	65	835	43.0
S-30	97	103	42	72	803	43.5
CD at 5%	1.96	7.80	4.28	5.14	96.44	-
CV (%)	1.84	6.12	7.65	6.10	9.24	-

3.5. Evaluation of local and exotic germplasm of sesame

The result showed that six of the local collections matured between 86 and 90 days while all the exotic and three local collections took 92 to 98 days to mature (Table IX). The exotic collections, M-2-21, M-7-9, B. Black and P. White produced 1035, 1350, 1290 and 1250kg/ha, respectively while all local collections gave significantly lower yields (586–957 kg/ha). These four exotic genotypes will be given further trial in the next season. Oil content (%) was higher in the exotic collections which ranged from 45.0 to 48.5% while the local collections had a narrow range of about 42.5 to 43.6%.

3.6. Raising M_3 plant progeny to study true breeding behaviour and selection of mutants from among segregating populations

Segregation was found in the different M_3 populations The results showed 59% segregation at 500 Gy, 48% at 600 Gy and 52% at 700 Gy for various important characters in the treated population of S-30 (Table X). Similarly, 53% segregation was estimated at 500 Gy, 46% at 600 Gy and 39% at 700 Gy for different characters of T-6 (Table XI). Altogether 227 mutants were selected in the M_3 generation for desirable true breeding characteristics. They will be grown in the coming season for further agronomic evaluation.

TABLE IX. MEANS OF SEED YIELD AND OTHER PARAMETERS OF LOCAL AND EXOTIC GERMPLASM

Genotypes	Days to maturity	Plant height (cm)	No. of capsules/ plant	No. of seeds/capsule	Seed yield (kg/ha)	Oil content (%)
Local collections						
S-6	95	117	60	68	793	43.0
S-12	86	106	56	72	749	43.4
S-29	86	114	41	69	638	43.6
S-31	95	113	49	65	590	43.2
S-40	96	112	48	69	957	42.8
S-53	86	115	48	71	757	43.0
S-54	90	113	46	72	586	42.9
S-59	86	121	52	71	606	42.5
S-61	87	114	55	69	708	43.0
Exotic collections						
M-2-21	97	96	58	71	1035	46.7
B. White	98	116	56	68	736	48.5
M-7-9	98	102	61	71	1350	47.0
B. Black	92	109	51	67	1290	45.0
P. White	93	117	67	100	1250	48.5
CD at 5%	3.36	11.86	9.76	6.71	111.0	-
CV (%)	2.18	6.33	10.88	5.58	7.69	-

TABLE X. SEGREGATION PATTERN OF SELECTED M_2 PLANTS OF S-30 GROWN IN M_3 GENERATION

Characters	500 Gy	600 Gy	700 Gy	Total plants
Plants selected in M_2	39	177	81	297
Selection made in M_3:				
Early	04	11	05	20
Uniculm	–	09	03	12
Branching	14	13	11	38
Short stature	–	07	01	08
Longer capsule	–	05	04	09
Compact plant	–	03	–	03
Continuous bearing	–	04	–	04
Indehiscent capsule	–	02	–	02
Semi-indehiscent capsule	–	13	07	20
WLT*	–	05	02	07
HYT**	–	06	04	10
SRT***	05	07	05	17
Total No. of mutants selected in:				
M_3 generation	23	85	42	150
Segregation in percent	59	48	52	–

*WLT = Water-logging tolerance; **HYT = High yielding type; ***SRT = Stem rot tolerance.

TABLE XI. SEGREGATION PATTERN OF SELECTED M_2 PLANTS OF T-6 GROWN IN M_3 GENERATION

Characters	500 Gy	600 Gy	700 Gy	Total plants
Plants selected in M_2	15	83	80	178
Selection made in M_3 :				
Early	–	03	03	06
Uniculm	–	–	–	–
Branching	07	13	05	25
Short stature	–	03	02	05
Longer capsule	–	–	–	–
Compact plant	–	03	–	03
Continuous bearing	01	04	03	08
Indehiscent capsule	–	–	–	–
Semi-indehiscent capsule	–	05	04	09
WLT*	–	04	04	08
HYT**	–	–	03	03
SRT***	–	03	07	10
Total No. of mutants selected in: M_3 generation	08	38	31	77
Segregation in percent	53	46	39	–

*WLT = water-logging tolerance, **HYT = High yielding type, ***SRT = Stem rot tolerance.

3.7. Growing of M_2 progeny for preliminary selection of desirable mutants

One hundred and eleven mutants from S-30 and 87 mutants from T-6 were isolated on the basis of good agronomic performance. All these mutants will be grown next season to assess their true breeding behaviour. Emphasis was given to the selection of indehiscent types in most of the cases.

3.8. Cross breeding of promising mutants x local variety (T-6) and S-30 x T-6

The range of variation in F_3 in respect to different characters was lower than in F_2. A few true breeding lines with desirable characters were isolated for further evaluation in the F_4 generation.

All the F_1 seeds were collected from the crosses between T-6 and promising mutants. They will be grown in F_2 generation for selection of better plants from the segregating populations. Studies on inheritance of yield and yield contributing characters of segregating (F_2, F_3, B_1 and B_2) and non-segregating (P_1, P_2 F_1) generations of cross S-30 x T-6 revealed that the number of capsule/plant and 1000-seed weight were controlled by single genes; whereas plant height, capsule length, number of seeds/capsule, days to maturity and seed yield/plant were controlled by polygenes.

3.9. Screening of mutants of different generations against stem rot and sesame mosaic virus

The differences of the mean incidence of stem rot and both the mean incidence and severity of sesame mosaic were not significant among the tested material (Table XII). The average mean incidence of stem rot ranged from 32.9 to 62.5%. The lowest incidence (32.9%) of stem rot was recorded in T-6 (check) and the highest incidence (62.5%) in mutant, SM1.

The mean incidence of sesame mosaic ranged from 23.0 to 53.3%. The lowest incidence (23.0%) was recorded in SM1 and the highest (53.3%) in SM5. All the materials showed moderately resistant reaction to sesame mosaic in the field.

The mean incidence of stem rot ranged from 19.1 to 74.5% (Table XIII). The lowest incidence (19.1%) was recorded in an exotic line, B.Black and the highest in a local collection, S-31.

TABLE XII. MEAN STEM ROT INCIDENCE (%) AND THE SEVERITY OF SESAME MOSAIC IN MUTANTS, SOURCE AND CHECK DURING FEBRUARY–MAY, 1997

Mutants/others	Mean incidence or severity				
	Stem rot incidence			Sesame mosaic	
	Ishurdi	Rangpur	Average	Incidence (%)	Severity (0–9)
T-6 (Check)	37.2	28.6	32.9	41.6	1.1
S-30 (Source)	29.7	70.8	50.3	25.0	1.3
SM1	73.4	51.6	62.5	23.0	1.3
SM2	64.8	37.0	50.5	23.3	1.6
SM4	10.4	62.5	36.5	30.0	1.5
SM5	37.7	30.6	34.2	53.3	1.5
SM7	46.1	71.8	59.0	43.3	1.9
SM9	46.1	56.3	51.2	30.0	1.6

TABLE XIII. MEAN STEM ROT INCIDENCE IN LOCAL AND EXOTIC GERMPLASM DURING WINTER (SEPTEMBER–DECEMBER) 1996 AND SUMMER (FEBRUARY–MAY) 1997

Accession	Mean stem rot incidence		
	Summer	Winter	Mean
B. Black	29.5	8.6	19.1
Magwe-2-21	28.3	10.5	19.4
Magwe-7-9	44.5	1.6	23.1
P.White	41.9	14.4	28.2
S-40	45.9	22.9	34.4
B.White	43.0	29.3	36.2
S-6	41.7	41.4	41.6
S-59	44.2	51.5	47.9
S-12	40.5	61.3	50.7
S-61	37.8	63.8	50.8
S-54	42.9	75.7	59.3
S-53	61.5	58.1	59.8
S-29	47.2	91.0	69.1
S-31	47.8	91.2	74.5
LSD at 5% level	–	56.85	–

The mean incidence of stem rot during the winter and summer seasons did not differ significantly (Table XIV). Average incidence of the disease ranged from 34.3 to 50.1%. The highest incidence (50.1%) of stem rot was recorded in T-6 and the lowest in mutant SM3. All the materials tested under field conditions will be screened under in the greenhouse next season.

3.10. Effect of waterlogging on growth and yield of the promising mutant SM7

The results of this test are presented in Table XV. It showed that the plot having no waterlogging (D_0 treatment) produced the highest seed yield of 860 kg/ha followed by D_4 and D_3 treatments which gave 760 and 755kg/ha, respectively. The lowest seed yield was obtained from the D_1 treatment (730 kg/ha). Waterlogging affected other characters as well. The overall yield performance was not up to the mark due to unavoidable weather condition during harvest.

TABLE XIV. MEAN STEM ROT INCIDENCE IN 12 MUTANTS AND TWO CHECKS DURING WINTER, 1996 AT ISHURDI AND SUMMER, 1997 AT MAGURA

Mutants/strain	Mean stem rot incidence (%)		
	Ishurdi (winter)	Magura (Summer)	Mean
T-6 (Check)	62.1	38.0	43.9
S-30 (Source)	57.2	30.5	50.1
SM-3	47.1	21.4	34.1
SM6	54.3	18.2	36.3
SM8	41.1	28.8	35.0
SM10	30.8	44.3	37.6
SM11	47.1	26.9	37.0
SM12	42.7	27.7	35.2
SM13	42.4	43.3	42.9
SM14	42.6	36.6	39.6
SM15	50.2	31.8	41.0
SM16	63.1	23.4	43.3
SM17	41.7	43.3	42.5
SM18	46.8	29.4	38.1

TABLE XV. MEAN EFFECT OF WATERLOGGING ON YIELD AND OTHER CHARACTERS OF SM7

Treatments	Plant height(cm)	No. capsules/plant	Seed yield (kg/ha)	Straw yield (kg/ha)
D_0	114	44	860	1550
D_1	111	34	730	1370
D_2	112	43	740	1500
D_3	109	40	755	1482
D_4	107	30	760	1634
LSD at 5%	NS	NS	NS	NS

TABLE XVI. PROJECT ACTIVITY CHART

Activity	1994	1995	1996	1997	1998	Remarks
Yield trial M_5, M_6, M_7, M_8	AYT	AYT	RYT OFT	RYT AYT OFT	RYT AYT OFT	Mutants SM5 and SM7 may be registered for commercial cultivation. Some more mutants were found promising in respect of yield and tolerance to waterlogged conditions
M_3 population	–	+	–	+	+	Repeated over times. Approx. 50% of the M_2 mutants segregated in M_3 under different doses.
M_2 population	–	+	+	+	–	Repeated over times. 111 mutants from S-30 and 87 mutants from T-6 were selected.
M_1 population	–	+	+	–	+	It is repeated over times. With increasing doses yield and agronomic parameters decreased. Compared to black seeded varieties white seeded one were more sensitive to radiation.
F_1, F_2, F_3, B_1, B_2						Inheritance studies revealed that number of capsule/plant and 1000- seed weight were controlled by single gene pairs, other characters including seed yield are polygenic.
Screening of M_4, M_5, M_6, M_7 mutants against stem rot and sesame mosaic	+	+	+	+	+	Some of the mutants were found tolerant to stem rot and SeMv at field condition in most of the locations. S0me hybrids were tolerant to WLC.
Screening against waterlogged condition	–	+	–	+	–	Mutants SM7 was found tolerant to waterlogged condition created artificially by Lysimeter. Some of the hybrid materials were also tolerant to waterlogged condition in the field.
Germplasm collection and evaluation	–	+	+	+		Four strains from Pakistan and Myanmar outyielded the existing varieties.

4. CONCLUSION

The four years project period on sesame varietal improvement has been completed with an extension of one more year, ending by November 1998. Within this period significant progress has been made with the development of some promising mutants having higher seed yield, higher oil content and having tolerance to *Macrophomina phaseolina* and to waterlogging conditions. Two of the mutants were given farmers' field trial for two years and more trials at more locations on farmers' field would be conducted this year which is a pre-requisite for submitting applications to the National Seed Board (NSB) for registration of the mutants for cultivation as commercial varieties. Some of the mutants and hybrid materials are in the pipe line and are at various stages of field evaluation. Every year new crosses are being made, new germplasm is collected and treatments with physical and chemical mutagens are made continuously as part of the programme of the Institute. The financial assistance of the IAEA accelerated the research work of the Institute, acilitating significant progress in sesame improvement. It is hoped that at least 2 mutants will be registered by the National Seed Board, in 2 years time and released as high yielding varieties throughout the country.

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