1. Sorghum

1-1. China

1-2. Indonesia

1-1. China

LI Guiying, LIU Luxiang and WANG Jing

Institute of Crop Sciences, Chinese Academy of Agricultural Sciences (CAAS)

Key Lab of Agricultural Nuclear Technology & Aerospace Breeding, Ministry of Agriculture

As per the general plan of the Multilateral Research Program (MRP-1) under the framework of FNCA Agriculture Project (Mutation Breeding), we have exchanged sorghum mutant germplasms with Indonesia, and have done multi-location evaluation for further use, popularized new mutant varieties, and used introduced germplasm in breeding program. This paper will give an outline summary on the researches during project years (2002-2006) as follows.

1 Goal of the MRP

This project aims to form an Asia regional cooperation network of drought tolerance improvement in sorghum by using mutation induction technique and related biotechnology.

(1) To collect, identify and utilize useful germplasms of drought tolerance for regional and national sorghum breeding programs in agricultural institutions and extend planting and utilization of the improved cultivars.

(2) To exchange the improvement techniques for raising efficiency of screening for drought tolerance in sorghum.

(3) To form Asia regional co-operation network of drought tolerance improvement in sorghum by holding meetings, inviting experts to scientific visits and exchange sorghum plant materials and information.

2 Project Progress

2.1 Exchange useful sorghum germplasms of drought tolerance

Totally China has provided Indonesia with 4 mutant or hybrid sorghum: Yuanza 1(Hybrid), Zhenzhu, Yuan8002, SP84002; Indonesia has provided China with 5 mutant and their initial material: ME/30/9, ET/20/477, DU/30/95B, DU/20/3E and JA/30/58 and Durra .

2.2 Observation on Sorghum mutant germplasm from Indonesia

5 sorghum mutants introduced from Indonesia were planted in IAAE's experimental farm in 2002. Experimental results are showed as in the table1.

Table 1. Performance of sorghum mutants introduced from Indonesia

	ME/30/9	ET/20/477	DU/30/95B	DU/20/3E	JA/30/58
Growth period (d)	125	>160	159	159	95
Plant height (cm)	310	350	250	250	220
Stem diameter (cm)	0.6	2.5	1.7	1.7	1.5
Number of tillers	1.0	2.3	1.0	1.5	2.0
Panicle length (cm)	23	30	20	23	38
Seed wt/panicle (g)	70	-	60	80	40
1000-seed weight(g)	36.5	-	28.0	21.0	18.0
Bx (%)	-	5.0	10.0	8.0	-
Type	Grain	Forage	Grain	Grain	Broom

Among the 5 mutants, JA/30/58 was very early mature, with short stalks and big spikes. It could be used as a good cultivar of broom sorghum. DU/30/95B has a bright red seed color, very beautiful, could be used for decoration. ME/30/9 and DU/20/3E have bright white color, shows good market quality. ET/20/447 was multi-tillering. It had thick and strong stalks (not sweet) and high biomass yield. It might be utilized as a good cultivar of forage sorghum or be used as a high biomass parent in energy crop sweet sorghum breeding. But it cannot get mature enough to propagation in Beijing.

2.3 Multi-location Evaluation of Sorghum Mutants and Parents

In 2005, a total number of seven varieties included four mutants and one parent from Indonesia (Du/30/95B, Du/20/100B, DU/20/3E, ET/20/477and Durra), one mutant and one parent from China (Yuanyu 8002 and SP4-8002) were used to do multi-location trial to evaluate their possible uses for forage or grain production in Beijing, Gansu and Heilongjiang, respectively. Randomized complete block design with 3 replications, row length 6 meters with 3 rows in one plot, row spacing 60cm and plant-to-plant space 50cm. The sowing date was 20 April 2005 in Beijing, 25 April 2005 in Gansu and 29 April 2005 in Heilongjiang.

Among the mutants and parents, Yuan8002 and SP4-8002 belong to grain sorghum but Du/30/95B, Du/20/100B, DU/20/3E, ET/20/477and Durra forage usage according to their agronomic performance.

Yuan8002 and SP4-8002 can be used as restoring lines of cytoplasmic male sterility of sorghum, with short stalks and growth period. SP4-8002 was about 5 days delay in heading date than its parent Yuan8002, which will be helpful to hybrid seed production.

Durra, DU/30/95B,Du/20/100B and ET/20/477 produced high biological yield with very high plant height but too long growth period in the above three locations.

Performance comparison of these varieties in Beijing was showed as Table2.

Table 2. Performance of sorghum mutants and parents with drought tolerance in Beijing in 2004

	1	2	3	4	5	6	7
Growth period (d)	110	115	183	182	183	159	>190
Plant height (cm)	138	122	248	251	262	250	350
Stem diameter(cm)	1.41	1.42	1.51	1.53	1.55	1.70	2.50
Number of tillers	1.20	1.10	1.65	1.80	1.75	1.50	2.30
Panicle length(cm)	25.8	27.1	23.5	23.1	23.2	23.0	30.0
Seed wt/panicle(g)	54.6	55.1	60.3	62.6	61.5	80.0	-
1000-seed weight(g)	25.0	24.8	25.8	26.3	26.1	21.0	-
Bx(%)	3.0	3.0	8.0	10.0	9.0	8.0	5.0

Note:1. Yuan8002 (P); 2. SP4-8002; 3. Dura (P); 4. DU/30/95B; 5. Du/20/100B; 6. DU/20/3E; 7. ET/20/477

2.4 Use of introduced mutant germplasm in breeding program

Among 5mutant from Indonesia, ET/20/447 is a useful germplasm with very high biomass yield, but it can’t get mature enough for reproduction. In order to use its useful genes, in 2003 we treated its seedlings after three leaves shoot in short sunlight (9 hr/d) for 32 days. It head 95day after sowing and short sunlight treatment. Then emasculated and pollinated with sweet sorghum CV Rio, Rio/BJk156-1-3-1 and Roma. Finally 26 seeds from cross [ET/20/477]/Rio, 50 seeds from [ET/20/477]/Roma and 50 seeds from [ET/20/477]/[Rio/BJK156 -1-3-1].

F_1 generation

In 2004 all these seeds were planted in the experiment field, and F_2 seeds were obtained. ET/20/477 is 350 cm, Rio/156-1-3-1 is an advanced lines, juicy and sweet (brix 16-18%), 360-380cm high. F_1 plants were 5.0-5.3m tall and 3-4wm thick (see Fig.1), showing very strong heterosis.

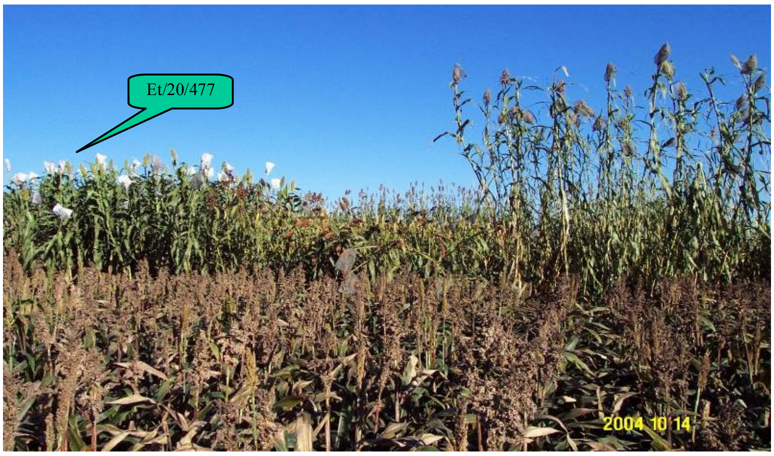

Fig1. F_1 populations of [ET/20/477]/Roma, [ET/20/477]/[Rio/156-1-3-1 and [ET/20/477]/Rio

F_2 generation

In 2005 F_2 populations (Fig2) were planted in the experimental field for selection of single plant with high biomass potential, sweet or non-sweet. From 300 F_2 population of [ET/20/477]/Roma, 35 plants were selected; from 240 F_2 of [ET/20/477]/[Rio/156-1-3-1, 46 were selected; 240 from F_2 of [ET/20/477]/Rio, 56 plants were selected. Plants with ET/20/477 characters and early mature have been recovered.

Distributions of some important characters were analyzed. Take [ET/20/477]/ [Rio/156-1-3-1] as an example, 64 F_2 plants were examined, the distributions of plant heights (Fig.3), stem types (dry or juicy)(Fig.4), Maturity (showed as mature state when frosting, i.e. waxy to full mature, milk or flowering)(Fig.5). For juicy plants, juice Brix was measured with a hand refractometer. And Brix distribution was showed as Fig 6.

Plants height

ET/20/477 is 350cm high. Rio/156-1-3-1 is an advanced line, 360-380cm high. Among 64 F_2 plants examined, 13 plants were higher than 5m, 19 were between 4.6-5m, 17 were shorter than two parents. It showed plants with ET/20/477 height character could be recovered.

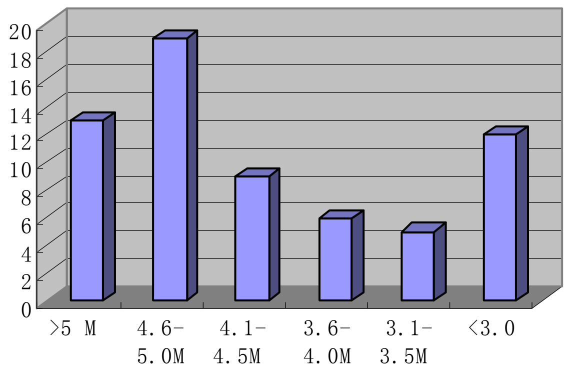

Fig2 Distribution of Plant height in F_2[ET/20/477]/ [Rio/156-1-3-1]

Stem types

ET/20/477 is a dry type, and Rio/156-1-3-1 is a juicy type, with brix 16-18%. Among 64 F_2 plants observed, there were two types of stems, 12.5% juicy and 87.5% dry, which showed juicy is controlled by recessive gene. It is easy to get a dry type with high biomass yield.

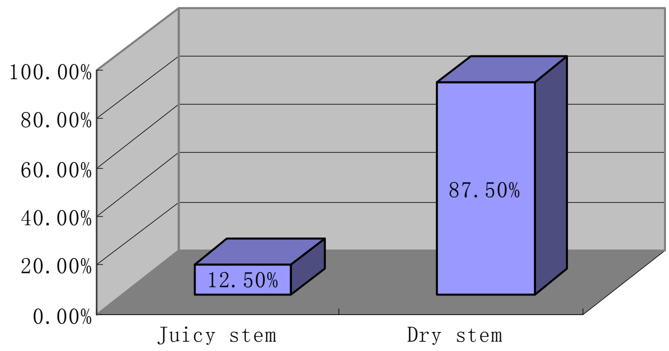

Fig3 Distribution of Plant types in F2[ET/20/477]/ [Rio/BJK156-1-3-1]

Maturity

ET/20/477 is very late mature, and could not mature enough for further reproduction. That is the key reason to treat it and cross with early varieties so as to keep its useful genes. Among 64 F_2 plants, 54.7% could develop to waxy to full ripe, enough to reproduction, 45.3% flowering to milk, difficult to reproduce.

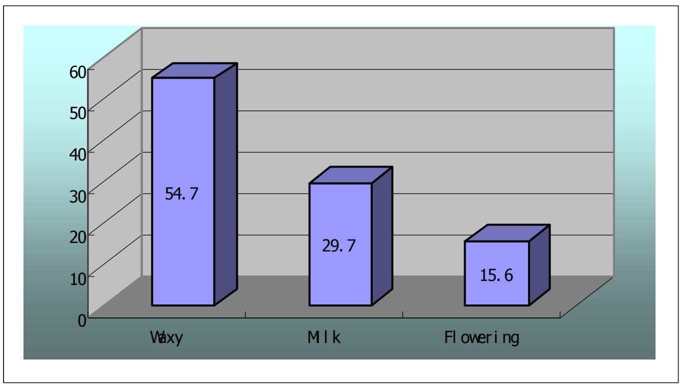

Fig4 Distribution of maturity in F_2 [ET/20/477]/ [Rio/BJK156-1-3-1]

Juice Brix

Among 64 F_2 plants, only 8 or 12.5% were sweet. Brix were from 10-18%, 3 plants between 10-13%, 4 plants 13-16%, 1 plant 18%. Generally sweet type is later mature. It needs a large population to select for a sweet type with high biomass yield.

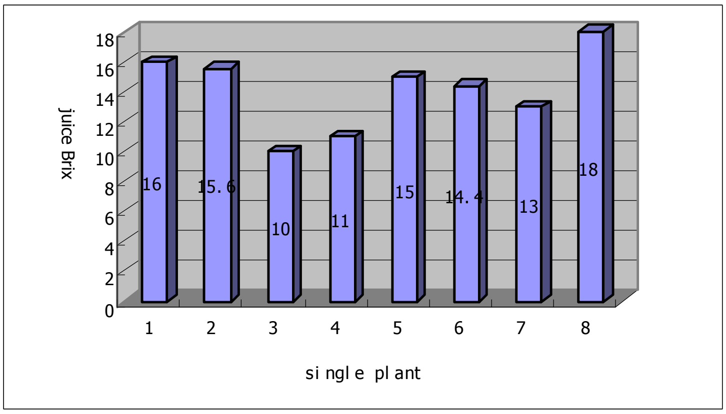

Fig5 Distribution of Brix in F_2 [ET/20/477]/ [Rio/156-1-3-1]

F_3 generation

F_3 generation is growing as Fig. 6. The result has yet to obtain.

Fig 6 F_3 generation of [ET/20/477]/ [Rio/156-1-3-1]

2.5 Mutation technology in sorghum improvement

2.5.1 Production of M_1 and M_2 population after gamma radiation

Seeds of grain sorghum variety "*Zhenzhu*" and sweet sorghum "*Sart*" were irradiated by gamma rays, 100Gy, 150Gy, 200Gy, 250Gy, 350Gy and 400Gy, respectively. The results of the germination test and the field planting showed that 200Gy～250Gy could be the appropriate radiation dose, while very lower survival plants in 350 Gy treatment and no seeds in 400 Gy in M_1 generation. M_2 seeds from 100Gy to 350Gy were obtained and will be used to laboratory test for drought tolerance by PEG6000 and field planting in next year.

2.5.2 Mutational effects of new mutagens on sorghum

Seeds of sorghum cv. *Y030* and *Yuan8002* were irradiated by proton, with the energy of 3Mev and dosage of 300Gy, and synchrotron (ultra-soft X rays, 5～20λ), respectively. The result showed that the biological effects of proton and synchrotron irradiation on the current generation of treated sorghum seeds are very similar. The sorghum seedlings in 1～3 leaflets stage from the treated seeds showed variations of stripe chlorophyll deletion, with the deletion rate near 100%. However, no such variation was found in the treatments with 200Gy gamma rays irradiation. The chlorophyll deletion was also not reported in literature.

Electron beam was used to irradiate the seeds of four sorghum cultivars, i.e.,*Wusawu, Jinwu*, *Aisi* and *Yuan2B*. The preliminary results from bioeffect analysis showed the proper doses of electron beam to treat sorghum seeds were to be 30～50 Gy for white grain and 100～150 Gy for red grain, respectively. This dose is significantly lower than that of gamma rays, indicating a high relative biological effect.

2.6 New varieties

Yuantian No 1 a sweet type showed as Fig 7, released in 2002. It was developed from Rio as initial material by induced mutation with gamma ray. It is grown ca. 1000 hectares.

Fig7 Plants, stem and spike of *Yuantian No 1*

Hybrid variety *Yuanza 502*(*Yuan2/ Sp8002*) In the variety comparison experiment, 25 new crosses made with mutants Cms lines or restorer lines were evaluated, Yuan2/ Sp8002 showed more than 20% higher in grain yield than original Yuan2/ Yuan8002. Sp8002 is a mutant developed by space breeding. The performance of this cross shows as Fig 8.

Fig.7 Field performance of new hybrid variety *Yuan2/ Sp8002*

3 Discussion

Through this project, participating countries exchange their research experience, mutant share achievement, which is conducive to all participating experts and also good for enhancing application of atomic energy in a wider research field.

Induced mutation has become a conventional breeding approach, it become less and less an opportunity to get support as an independent project. So it is suggested that the future FNCA project be combined with other related domestic project. It may be better to organize project group as end-up use, not as single crop, such could attack more experts to participate in FNCA activity.

1-2. Indonesia

Dr. Soeranto Human

Center for Application of Isotope and Radiation Technology

National Nuclear Energy Agency (BATAN)

Introduction

Sorghum (*Sorghum bicolor* L.) is a cereal crop that is usually grown under hot and dry conditions. According to House (1985) sorghum might be originated from the headwaters of the Niger River in Africa. Archaeological evidence suggested that the practice of sorghum domestication was introduced from Ethiopia to Egypt about 3000 B.C. Now about 80 % of sorghum cultivation is found in the Africa and Asian regions, however, the world sorghum production is still dominated by the USA, India, Nigeria, China, Mexico, Sudan and Argentina.

In many countries sorghum is generally used as food source, animal feed, and raw materials for industry. According to ICRISAT/FAO (1996), as global food source sorghum ranks the fifth after wheat, rice, corn, and barley. In many countries, sorghum grains and stovers are mainly used for animal feed. Sorghum grains are also used for industry such as ethanol, bear, wine, syrup, paint, glue, and modified starch. Related to energy source, countries like USA, India and China, have developed sweet sorghum as raw materials of bioethanol (biofuel) production. In the USA sorghum can produce up to 10,000 while in China 7,000 and in India 3,000-4,000 liters ethanol/ha/year. In India an improved, pressurized, multifuel (kerosene, ethanol or diesel) mantle lantern producing light output of 1,250-1,300 lumens (equivalent to that from a 100 W light bulb) called "Noorie" was developed (Reference). A pressurized alcohol stove with a heating capacity of 3 kilowatts for 85% (v/v) ethanol concentration with a thermal efficiency of 30-50% was also created (RAJVANSHI and NIMBKAR, 2004).

Sorghum has a high yield potential, comparable to those of rice, wheat, and maize. On a field basis, grain yields have exceeded 11 ton/ha (in Japan, total (seed + stems and leaves) dry yield are higher than 26t/ha), with above average yields ranging from 7-9 ton/ha where moisture is not a limiting factor in Indonesia. In those dry areas where sorghum is commonly grown, yields of 3-4 ton/ha are obtained under normal condition (Hause, 1985). Sorghum is also known to have wide adaptability, ranging from lowland, medium and highland altitude. Highest yields are usually obtained from varieties maturing in 100-120 days. Late-maturing varieties tend to be appropriate for forage crop.

Sorghum is beleived to have high tolerance to adverse conditions such as drought. Compare to maize, sorghum has a more extensive and fibrous root system. The plant roots penetrate a greater volume of soil to obtain moisture. Fertilizer, even under low rainfall conditions, encourages root development, hence the root are able to extract moisture from a greater volume of soil. Sorghum requires less moisture for growth than some other cereal crops. A study shows that sorghum requires 332 kg of water per kg of accumulated dry matter, while maize requires 368 kg of water, barley 434 kg, and wheat 514 kg. Compared to maize, sorghum is also more tolerant to water lodging, salinity, and aluminum toxicity (RANA and RAO, 2000).

Based on form of its spike and basic spikelet, sorghum is classified into 5 races namely *Bicolor*, *Guenia*, *Caudatum*, *Kafir*, and *Durra*. The characteristic of basic spikelet for each race is shown in Figure 1. Race Durra having white color of grains is the one that is commonly cultivated as grain sorghum and used as food source. Among race Durra, there is a variety having high sugar content in its stalk, a type what so called sweet sorghum. In many countries, sweet sorghum is used for syrup, sugar (*jaggery*), and/or ethanol industry (RAJVANSHI and NIMBKAR, 2004; UNDERSANDER et al., 1990).

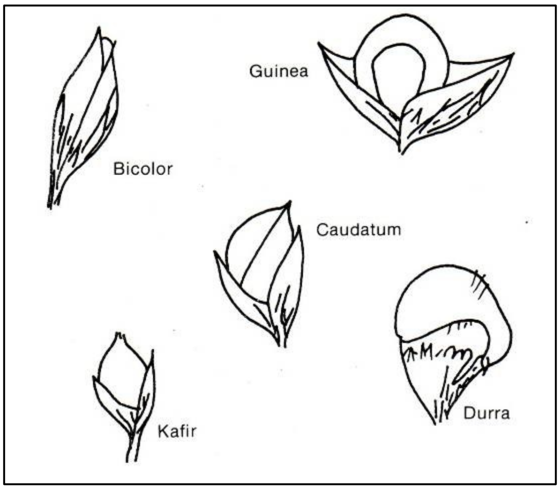

Figure 1. Classification of sorghum by basic spikelet type

Because sorghum is not Indonesian origin, so its genetic variability found in Indonesia is still limited. Some sorghum genotypes have been introduced from abroad e.g. from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in India. Through plant breeding programs, the Ministry of Agriculture has released some sorghum varieties such as *UPCA*, *Keris*, *Mandau*, *Higari*, *Badik*, *Gadam*, *Sangkur*, *Lumbu* and *Kawali*. These national varieties have a big potential to be cultivated and developed in the arable land in Indonesia especially during wet seasons. Further research on sorghum breeding is needed especially to search for genotypes that can be grown and cultivated during dry seasons.

FNCA Mutation Breeding Project

Under FNCA plant mutation breeding project, the first meeting of the sub-project entitled "Drought Tolerance in sorghum and soybean" was held in Indonesia on 25 February - 01 March 2002. The participating countries included China, Indonesia, Japan, the Philippine, and Vietnam. The goal of this sub-project is to provide a broad base of common interests and to strengthen research collaboration among participating countries in the field of mutation breeding. Two kinds of crop species i.e. sorghum and soybean have been selected as targets for indication of drought tolerant crops. China and Indonesia took part in breeding sorghum, while the Philippine and Vietnam were in soybean. Exchange of breeding materials was agreed among the participating countries, which necessarily intended only for breeding purposes. (This part will be written in the preface of the report (book).)

For sorghum, the sub-project has been implemented accordingly. Exchange of sorghum breeding materials (sorghum seeds) has been made between counterparts of Indonesia and China. The list of the exchanged materials is presented in Table 1 below.

Table 1. List of exchanged sorghum breeding materials between counterparts of Indonesia and China

From Indonesia to China	From China to Indonesia
ET/20/477	*Zhengzhu*
DU/20/100-B	*Yuan 002*
DU/20/3E	*Yuantianza*
DU/30/95-B	*Yuanyu 8002*
Durra	*SP4-8002*

Sorghum Breeding For Drought Tolerance

Drought problem is one of limiting factors in agriculture development in Indonesia especially in Java and eastern part of the country. The problem is that annual dry season in some regions sometime happens quite long i.e. for about 6 months, starting from May up to October. During dry season most arable land usually becomes fallow, so farmers harvest almost nothing from

their land. For example, in the district of Gunungkidul in Yogyakarta Province, during dry season farmers attempt to import corn leaves in a huge amount from other Districts or Provinces in order to suffice their ruminant animal feeds.
For the areas having drought problem such as that in Gunung Kidul District, selection of crop species indicating high water use efficiency would be of valuable to be introduced. Sorghum plant (*Sorghum bicolor* L.) is thought to have high tolerance to drought (ICRISAT/FAO, 1996). Sorghum breeding to improve its yield in drought prone areas can be of importance for increasing the overall agricultural production in the region. Its biomass may be used for animal feed while the grains may be used as an alternative food during dry seasons.

The Indonesian farmers have long known sorghum landraces but its improvement and development seem to be neglected if compared to the other food crops. By being able to grow sorghum during dry seasons, it is hoped that the fallow land at least can produce biomass for feeding the animals. If good quality of sorghum variety is available, it may also provide food source to the local people so that it will prevent a hunger. As a food source, sorghum has been reported to have good nutrition values (DEPKES RI. 1992). Thus, sorghum has a big potential to help farmers increase their income, stimulate economic growth in the rural areas, and its cultivation will also promote soil improvement to support sustainable agriculture development.

Sorghum is actually not Indonesian origin but it has a big potential to be grown and cultivated in this country owing to its wide adaptability. However, sorghum is not as popular as other cereal crops and it is still insignificantly grown by very limited farmers. Available genetic variability of sorghum plant is also low, thus, plant breeding program is badly required in order to support sorghum development in the country. The breeding objective is to search for superior genotypes to help improve sorghum production with good quality according to its use either as food, animal feed or material for industry. Any plant breeding method such as that of selection, introduction, hybridization, mutation and/or other related biotechnology may be of appropriate to be applied in sorghum improvement program.

With regard to drought tolerance, indirect and direct selection methods have been implemented in sorghum breeding (SOERANTO, 2003). These methods are briefly described below:

A. Indirect selection:

- **Using 25% Polyethilene Glycol (PEG Method).** This method is used in seedling stage. It can reduce water potential equivalent to natural drought condition so that water absorption by roots is affected.
- **Using 0.3 % solution of potassium iodide.** This method is used in seedling stage. It can simulate leaf senescence and abscission equivalent to natural drought condition (Singh and Chaudhary, 1998).

B. Direct selection:

The plants are grown directly in drought prone areas during dry season. Sowing time is usually adjusted by the end of the rainy season. Production of total biomass, yield and its components can be used as criteria for selection.

The Use of Mutation Techniques

A. Gamma Irradiation

Research on sorghum mutation breeding was carried out at the Center for Research and Development of Isotope and Radiation Technology, National Nuclear Energy Agency (BATAN). Through research collaboration with the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), a number of precious breeding materials were obtained (as listed in Table 1; only exchanged materials are listed in Table 1). In our previous mutation breeding program, Durra variety from ICRISAT was used as starting breeding material owing to its high yielding and white grain type with good quality to be used for food and animal feed source.

The seeds were irradiated with Gamma rays emitted from Cobalt-60 source which is installed in the Gamma Chamber 4000A model. The dose levels 0-1000 Gy with increment of 100 Gy was used in order to study the optimal dose estimated around LD-50. Best fitting software was used to calculate the relationship between the doses and growth rates and to estimate the optimal doses. For example, Figure 2 shows the relationship between doses of Gamma irradiation doses (Gy) and survival rates (%) of sorghum Durra variety. It was found that the fit function is as follows:

3rd degree Polynomial Fit: $y=a+bx+cx^2+dx^3$

Coefficient Data: $a = 95.984$; $b = -0.098$; $c = -7.615e-005$; $d = 7.966e-008$

$R = 0.99326615$

LD-50 = 395.88 Gy

Gamma irradiation had significantly increased sorghum genetic variation in the M_2 (SOERANTO et al., 2001). Plant selections based on phenotypic variation were started in the M_2 generation, focused on the improved agronomic characters compared to that of the control plants. Through selection processes, a number of mutant lines with various desirable agronomic characteristics had been identified (SOERANTO and NAKANISHI, 2003). Some mutant lines had been tested for drought tolerance in Gunungkidul and Bantul Districts of Yogyakarta Province during dry season 2001 (M_3), 2002 (M_4), 2003 (M_5), and 2004 (M_6). The drought tolerance lines had been obtained namely B-68, B-69, B-72, B-75, B-83, B-90, B-92, B-94, B-95, and B-100. Biomass production and grain yields of these mutant lines (3-4 ton/ha) were significantly higher compared to that of original variety Durra and the national check variety (UPCA and Higari) which yielded only 1-2 ton/ha in dry seasons. Visual performances of some mutant lines are presented in Figure 3.

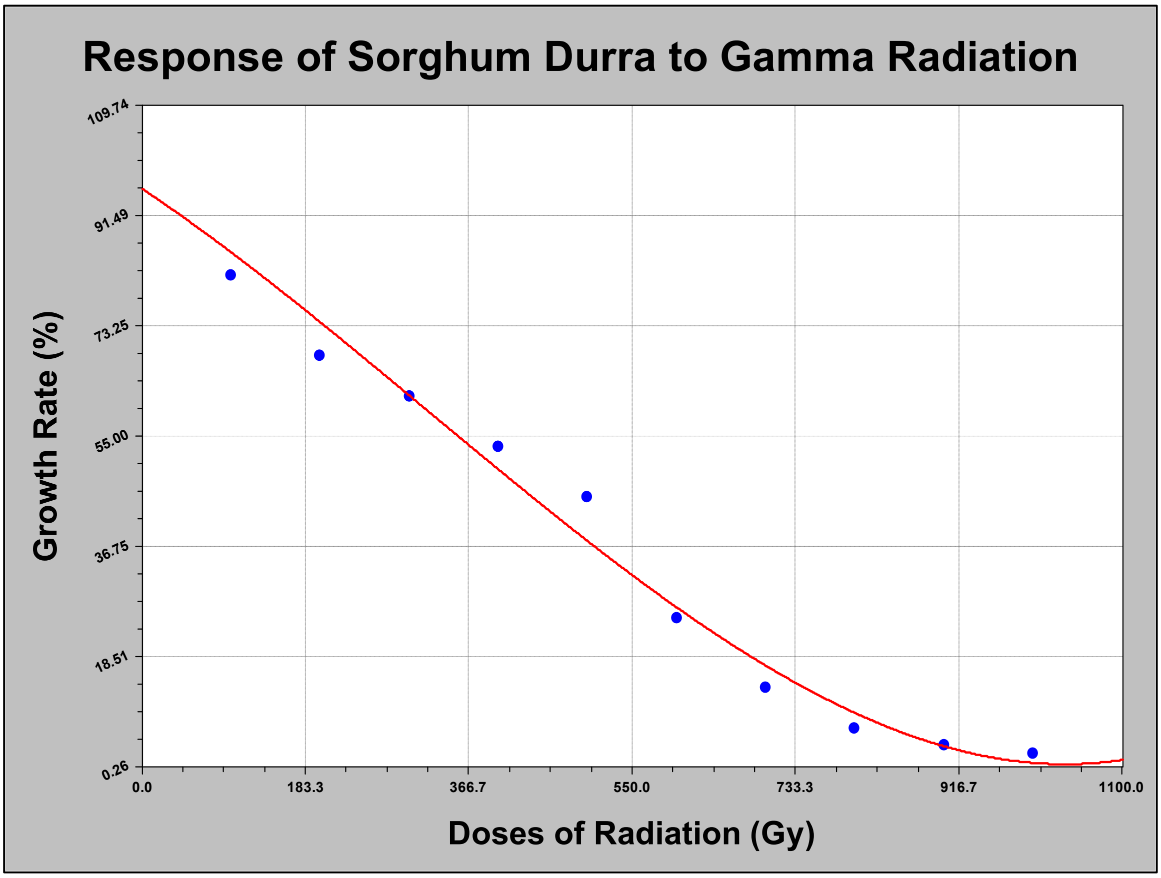

Figure 2. Response curve of sorghum Durra variety to Gamma irradiation in the M_1 generation

B. Ion-beam (C-ion) Irradiation

Mutation breeding in sorghum using Gamma irradiation was just started in 2005. Through FNCA Mutation Breeding Project framework, the utilization of ion beam (C-ion) for inducing mutation in sorghum was implemented to sorghum variety *Durra* and *Zhengzu*. Seed irradiation was conducted at TIARA facility of Japan Atomic Energy Agency (JAEA) with the dose levels of 0 (control), 50, 100, 150, 200 and 300 Gy. The irradiated seeds were evaluated in Indonesia. Response of sorghum to ion-beam was studied in the M_1 generation by its germination rate and growth. Relationship between doses and germination rate was studied using best fitting curve software. The curve functions were calculated and the LD-50 values were estimated. It seemed that each variety gave different response to ion-beam.

Within the ion-beam treatment, *Durra* and *Zhengzu* gave different response curves and the LD-50 values were found to be 376.30 Gy and 292.15 Gy, respectively. Meanwhile, the LD-50 value for Gamma radiation on sorghum Durra was 395.88 Gy. Comparing the ion beam and Gamma radiation, it seemed that LD-50 value for Gamma radiation was higher than ion beam radiation. The differences might be due to the highest dose levels used in the treatments. The highest dose level used in ion beam radiation treatment was 300 Gy while in Gamma radiation treatment was 1000 Gy. Results might suggest increasing the dose levels in ion beam radiation treatment since the LD-50 values were about the same or slightly higher than the highest dose levels used. The effects of ion beam treatments to plant genetic variability are measured in the M_2 generation by estimating genetic variance component of some agronomic characters.

In 2006, *Zhengzu* variety was irradiated again with ion-beam (C-ion, 320 MeV) at TIARA facility of Japan Atomic Energy Agency (JAEA) with the dose levels of 40 and 50 Gy. Meanwhile, sorghum variety *Durra* and *Zhengzu* were also irradiated again with ion-beam (C-ion) at RIKEN facility in Japan with the dose levels of 25, 50, 75, 150 and 200 Gy, respectively. All of these ion-beam irradiated materials are now being studied and evaluated in the field experiments in Indonesia. Until now, there is not yet found any desirable and useful sorghum mutants resulted from the ion-beam irradiation.

Highlight Results

1. A number of 10 drought tolerance mutant lines of sorghum have been obtained. In dry seasons, these lines have biomass production and grain yields significantly higher than that of original variety Durra and the national check variety (UPCA and Higari).
2. Our sorghum germplasm collections have been enhanced with these mutant lines, local and national sorghum varieties, exchanged breeding materials from China (through FNCA framework), and introduced genotypes from ICRISAT (Table of the data).
3. Some laboratory equipments for sorghum research have been provided by IAEA through

TC-Project INS/05/030.

4. Good sorghum research collaboration with some national and international counterparts and the end users has been established.
5. A private company (LIPPO Enterprises) has identified some of our sorghum mutant lines to be good for food, animal feed, starch and ethanol industry. (Will you write this collaboration more in detail with picture and data)

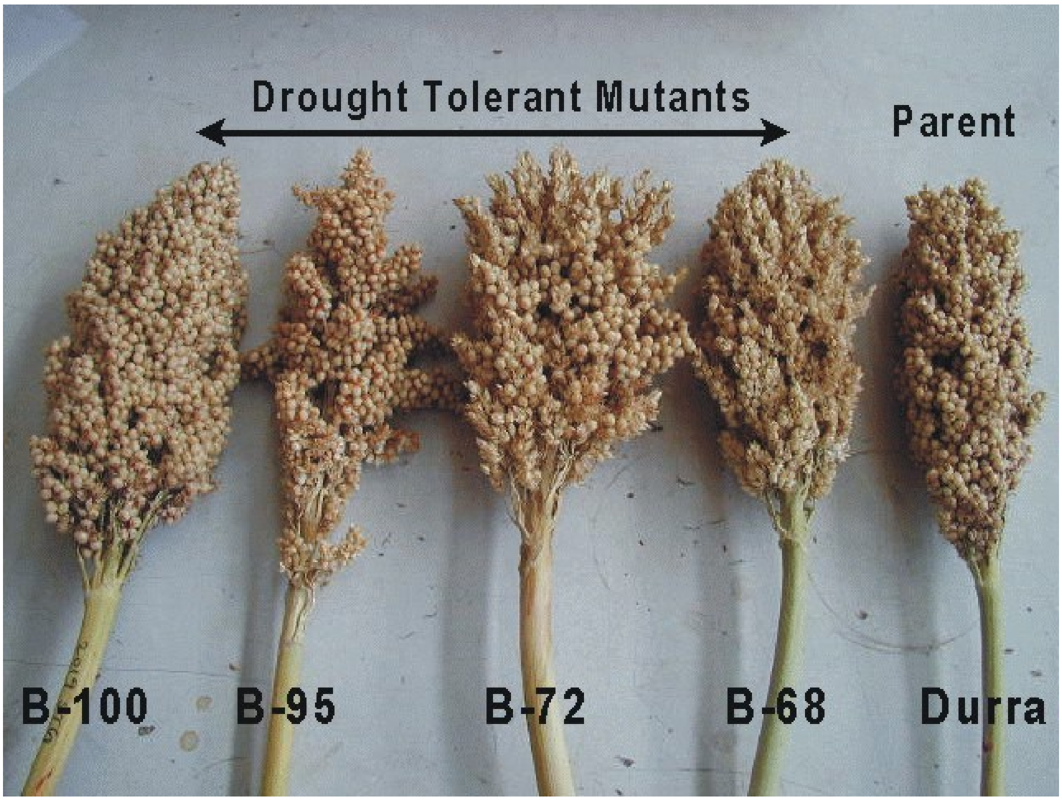

Figure 3. Variation of sorghum head form and size resulted from Gamma irradiation treatments

Other Supports

- LIPPO Enterprises (MOU with BATAN was signed on 12 April 2005) (as menteined abave.)
- International Atomic Energy Agency (through TC-Project INS/5/030)
- International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)
- Japan Society for the Promotion of Science (JSPS) through the Core University Program of Tokyo University

Future Plan

- Multi-location trials of sorghum mutant lines, at least in 12 locations, before being submitted for official releases as new sorghum varieties to the Ministry of Agriculture.
- Continuing mutation breeding to improve yields and quality of sorghum used as food, animal feed, and material for industry. The development of sorghum cultivation will be directed to make optimal use of the marginal land, especially in drought prone areas, so that it will not compete with the other crops in term of land utilization.
- Continuing and strengthening sorghum research collaboration with national and international counterparts
- Integrating Molecular Assisted Selection (MAS) and TILLING technology in pyramiding and characterization of the mutated gene(s) in sorghum.

Conclusions

Mutation breeding program using Gamma radiation in sorghum in Indonesia had resulted 10 promising mutant lines. These lines indicated drought tolerance and were promising to be developed further in Indonesia. Through FNCA Mutation Breeding for Drought Tolerance project, exchange of sorghum seeds had been implemented between counterparts of China and Indonesia. All sorghum from China could grow and perform well in Indonesia. *Zhengzu* has been included in our mutation-breeding program owing to its indication of drought tolerance and high yielding. Induced mutation using ion-beam irradiation is being studied on sorghum *Durra* and *Zhengzu*. Sorghum research in Indonesia is supported by some national and international counterparts.

Literatures

DEPKES RI. (1992). List of Food Source Nutrition Composition. Bhratara Publication. Jakarta. 57p.

HOUSE, L. R. (1985). A Guide to Sorghum Breeding. International Crops Research Institute for Semi-Arid Tropics. Andhra Pradesh, India. 238p.

HUGO, L.F. ROONEY, L.W. and TAYLOR, J.R.N. (2005). Bread-making with malted and fermented sorghum. Cereal Quality Laboratory, Soil and Crop Science Department, Texas A&M University, USA.

IAEA. (1977). Manual on Mutation Breeding. Tech. Rep. Ser. No. 119. Sec. Ed. Joint FAO/IAEA Div. of Atomic Energy in Food and Agriculture. 287 pp. ISBN 92-0-115077-6.

IAEA. (1984). Selection in mutation breeding. Proc. of Consultants Meeting, Joint FAO/IAEA, Vienna, 21-25 JunE 1982. STI/PUB/665. ISBN 92-0-111284-X.

ICRISAT. (1990). Industrial Utilization of Sorghum. Proceedings of Symposium on the Current Status and Potential of Industrial Uses of Sorghum. 59p.

ICRISAT/FAO. (1996). The World Sorghum and Millet Economies: Facts, trend and outlook. Published by FAO and ICRISAT. ISBN 92-5-103861-9. 68p.

RAJVANSHI, A.K. and NIMBKAR, N. (2004). Sweet Sorghum R & D at the Nimbkar Agricultural Research Institute (NARI). PO. Box 44, Phaltan – 415 523, Maharashtra, India.

RANA, B.S. and RAO, M.H. (2000). Technology for increasing sorghum production and value addition. National Research Center for Sorghum, Indian Council of Agricultural Research. Hyderabad, India. 65p.

SOERANTO, H., NAKANISHI, T.M. dan RAZZAK, T.M. (2001). Mutation breeding in sorghum in Indonesia. Radioisotope Journal, Vol. 50, No. 5. The Japan Radioisotope Association. P169-175.

SOERANTO, H., NAKANISHI, T.M. dan RAZAK, M.T. (2003). Obtaining induced mutations of drought tolerance in sorghum. Journal Radioisotopes Vol. 52, No. 1, January 2003. The Japan Radioisotope Association, p15-21.

SOERANTO, H., and NAKANISHI, T.M. (2003). Screening sorghum mutants for drought tolerance to support sustainable agriculture development. Proceedings of the 2nd Seminar of JSPS-DGHE Core University Program in Applied Biosciences. The University of Tokyo, Japan, 15-16 February 2003. P166-180.

UNDERSANDER, D.J. et al. (1990). Sorghum for syrup. Dept. of Agron. and Soil Sci., Coll. of Agric. and Life Sci., and Cooperative Extension Service, Univ. of Wisconsin-Madison, WI 53706.

U.S. GRAIN COUNCIL. (2005). White Sorghum, the New Food Grain. All About White Sorghum.

VAN HARTEN, A.M. (1998). Mutation Breeding: Theory and Practical Applications. Cambridge University Press. 353p. ISBN 0 521 47074 9.