Selection of Elite Bambarra Groundnut (*Voandzeia subterranea (L.)* Thouars) Varieties and Investigations on Cultural Methods Adapted to Subtropical Islands in Japan

Hiroshi NAKANO[a], Daisuke MATSUMOTO[b], Koji YASUDA[c], Tetsuo MAOKA[d], Kazufumi NISHI[e], Kazuo OGATA[f], Shigeki FURUYA[g], Harushige SAKUMA[h], Makoto KOBAYASHI[i] and Takayoshi TERAUCHI[d]

a,b,c,d,g,h,i) Okinawa Subtropical Station, Japan International Research Center for Agricultural Sciences (Ishigaki, Okinawa, 907-0002 Japan)

e) National Agriculture Research Center (Kannondai, Tsukuba, Ibaraki, 305-8666 Japan)

f) Institute of Tropical Agriculture, Kyushu University (Hakozaki, Higashi-ku, Fukuoka, 812-8571 Japan)

Received June 10, 1999

Abstract

Three elite lines adapted to the soil and climatic conditions of the subtropical islands of Japan were successfully bred by pure line selection from the germplasm of bambarra groundnut (*Voandzeia subterranean* (L.) Thouars) introduced from Indonesia and Zambia. Cultural practices were investigated for summer cultivation of bambarra groundnut in the area. Optimal sowing time occurred in early and late May and optimal harvest time in mid-October for the selected lines. The most effective herbicide applied to soil without injury to the bambarra groundnut was a linuron-alachlor mixture, and sethoxydim (post-emergence herbicide) was also effective without causing damage. Weeding by ridging after the flowering stage was harmful to flowering and pod setting and decreased the grain yield. The two types of herbicides and ridging before the flowering stage could be combined for effective weed control. Mulching with various types of plastic or paper sheets was effective for increasing the number of flowers and pod yield. But the pedicel could not penetrate through any types of sheets, and pods grown on the sheets were smaller than those grown underground. Groundnut harvester could be applied to harvest grains of bambarra groundnuts. Bambarra groundnut was highly sensitive to salty wind. However covering the plants with a wind-break net was effective for alleviating the salt damage associated with typhoons. Root wilt caused by *Corticium rolfsii* Curzi, a disease caused by a Potyvirus and a non-identified disease were observed. Sensitive lines to the Potyvirus were excluded from the breeding trials and the non-identified disease could be controlled by spraying of fungicides. Tobacco cutworm and two-striped leaf beetle were serious insect pests. Carbosulfan was able to two-striped leaf beetle unlike tobacco cutworm. Bean salad cooked at home and bean sweet processed in a factory using dry grains of bambarra groundnut were appreciated by the Japanese people, although they did not like the bean flavor.

Key words: bean, germplasm, legume, tropical crop, *Voandzeia subterranea*

Present address:

a) Hokkaido National Agricultural Experiment Station, Shinsei, Memurocho, Kasaigun, Hokkaido, 082-0071, Japan

c) National Institute of Agro-Environmental Sciences, Kannondai 3-1-1, Tsukuba, Ibaraki 305-8604, Japan

e) Kyushu National Agricultural Experiment Station, Suya 2421, Nishigoushi, Kikuchigun, Kumamoto 861-1192, Japan

g) National Research Institute of Vegetables, Ornamental Plants and Tea, Kusawa 360, Ano, Agegun, Mie 514-2392, Japan

h) Chugoku National Agricultural Experiment Station, Ueno 200, Uenocho, Ayabe, Kyoto, 623-0035

i) National Grassland Research Insitute, Senbonmatsu 768, Nishinasunocho, Nasugun 329-2793, Japan

Introduction

Bambarra groundnut (*Voandzeia subterranea* (L.) Thouars) originated in the periphery of the Sahara Desert, probably in and around the northern part of present Nigeria[4,11,12]. The bambarra groundnut is a crop adapted to high temperature and dry conditions[8]. It is a major leguminous crop after groundnut and cowpea in terms of production in Africa[4,12]. It has been distributed to South America and Southeast Asia for a long time, i.e. Thailand, the Philippines, Malaysia, Indonesia[4,11,12]. In Africa, the ripened grains are dried and cooked with some spices in family kitchens. Sometimes, non-dried immature grains are also used for home cooking as a kind of vegetable[11]. Immature grains are cooked in Southeast Asia, too.

Subtropical islands (Nansei islands) experience a shortage of vegetables in summer, because most of the temperate vegetables can not be produced due to the high temperature[6]. Heat-tolerant tropical vegetables are not originally distributed there. Vegetables must be imported from mainland Japan in summer and transport is costly. On the other hand, farmers in the islands produce only less profitable upland crops, mainly sugarcane. They need a larger number of more profitable upland crops to combine various farming systems with sugarcane cultivation. Against this background, Japan International Research Center for Agricultural Sciences, Okinawa Subtropical Station (JIRCAS Okinawa) has continued to introduce and acclimate germplasm of tropical crops and heat-tolerant germplasm of temperate crops in the area. We decided to introduce the bambarra groundnut germplasm, because it is tolerant to drought stress and high temperature. We tried to select varieties adapted to the soil and climatic conditions of the islands and to investigate techniques for cultivation of this leguminous crop and methods for utilization of grains.

In Japan, the literature on bambarra groundnut is limited. Results of studies on day-length sensitivity to flowering and maturation[7,9], mechanisms of drought tolerance[8] and embryo development have been reported in bambarra groundnut[10]. However, these studies did not provide sufficient information for the acclimation of bambarra groundnut in Japan. In this paper, we report the results of investigations carried out with a view; 1) to breeding varieties adapted to the soil and climatic conditions of the subtropical islands of Japan, 2) to identifying the constraints on the cultivation of bambarra groundnut in the area and to developing countermeasures to overcome the constraints, 3) to developing cultural practices adapted to the area for selected bambarra groundnut varieties.

Materials and Methods

General cultivation procedures and breeding

Except for the initial evaluation conducted in 1988 for the selection of germplasm introduced from Indonesia, all the cultivation tests were performed in the experimental fields of JIRCAS Okinawa located at lat. 24° 20' N . Soil of the field is an acidic yellow soil. Except in special cases, all the tests including breeding trials were performed as indicated below. The plots for the cultivation tests were amended with calcium carbonate (100g/m^2) and chemical fertilizer (N: 15g/m^2, P_2O_5: 30g/m^2, K_2O: 20g/m^2). Sowing was performed on May 10 and harvesting took place around mid-October. Plants were grown in open culture at a row spacing of 90cm and plant spacing of 80cm with one plant per hill. Tests were performed with 3 replications.

Germplasm was introduced from Indonesia and Zambia from 1988 to 1990. The first evaluation was performed for germplasm introduced from Indonesia at the National Agriculture Research Center in Tsukuba (NARC) located in the central part of Japan in 1988. Since 1990, the selection has been continued at JIRCAS Okinawa. A total of 1288 seeds were sown individually and plants with outstanding growth and grain yield were selected. Besides the selected plants, 10 early maturing lines were introduced from the International Institute for Tropical Agriculture (IITA, Nigeria) in 1992. With this germplasm, single plant selection and line selection were performed until 1994.

Optimal sowing time and harvest time

Using BB29, a line that had been selected from the germplasm introduced from Indonesia in 1988, tests were carried out to identify the optimal sowing time and optimal harvest time by determining the yield of fully mature grains from 1992 to 1994. Especially in 1993, samplings of pods were carried out at regular intervals and the growing stages of the pods were observed. From 1991 and 1993, optimal harvest time was observed for the lines, *i.e.* ZB29-14, ZD29-1 and L16-1-1, *etc.* that were cultivated in the breeding trials, too. However, not only in the experiments to identify the optimal sowing time and harvest time, but also in other experiments, BB29 was used unless otherwise noted.

Weeding

Tests to identify the optimal time for intertillage and ridging were carried out under the assumption that the practice led to grain yield decrease due to the covering of flowers or flower buds with soil. For investigations on the weeding effect of herbicides and injury to bambarra groundnuts, five breeding lines (ZB29-14, ZD29-1, L16-1-1, BB29 and BD881-3) were used. Herbicides (Fig. 8) were applied to the bambarra groundnuts at the recommended rate for common dicotyledonous vegetable and leguminous crops. They were applied on the soil surface immediately after sowing. Another herbicide, post-emergence herbicide (sethoxydim) was applied to the seven breeding lines (ZB29-14, ZD29-1, L16-1-1, BB29, BD881-3, AP79-349 and L14-12) at the flowering stage and weeding and injury effects on the bambarra groundnut were also examined.

Advantage of mulching culture and possibility of winter culture

To examine the effect of mulching culture on the grain yield, the plants were sown on June 1 and they were transplanted to a field covered with a mulching sheet on June 22. They were cultivated in rows 120cm wide and at a spacing of 90cm. The experiment was conducted with two replications, and the number of flowers was counted everyday from Aug. 13 to Oct. 12. For the winter culture, six breeding lines of bambarra groundnut (ZB29-14, ZD29-1, L14-12, BB29, BD881-3 and AP79-349) were sown on Nov.5, 1992 in a glass house without any heating facility and they were cultivated in rows separated by a distance of 50cm and at a spacing of 30cm. Flowering and maturation habit, and grain yield were examined in the winter culture.

Salty wind damage and methods of protection

Salt sensitivity of bambarra groundnut was compared with that of other leguminous upland crops and non-leguminous vegetables. They were cultivated in a 12cm diameter plastic pot with amended soil in an air-conditioned glass house at day/night air temperatures of 27.5℃/27.0℃. When the leguminous crops developed the fifth leaf and the other vegetables developed the fourth leaf, they were sprayed with 15ml of 100mM to 500mM sodium chloride (NaCl) solution on the leaves. Leaf damage from spraying was observed after two weeks. In 1993, bambarra groundnuts were sown in mid-June and cultivated in a a/5000 Wagner pot with amended soil in an air-conditioned glass house at day/night air temperatures of 27.5 ℃ /27.0 ℃ . When a typhoon (Typhoon No.13) hit the experimental site, they were transferred outside and they were covered by some kinds of net for two days. After they were transferred back to the glass house and kept for 3 days there, preventive effect of covering with these kinds of net against salty wind was examined.

Disease and insect damage and methods of control

In order to identify the pests damaging pods, insects coming around underground pods were collected at the late maturation stage in 1993 when pod setting was very poor in all the lines in the breeding trial. Feeding experiment of the collected insects with immature pods *in vitro* confirmed that they ate pests of bambarra groundnut. In 1994, in order to control the pests identified, an insecticide (carbosulfan) was applied to the soil surface around the plants from Aug. 2 at 25-day intervals and the effect was examined.

Harvest method

Adaptability of a groundnut harvester was tested. Harvest was performed with a hand tractor (model

YC650-G, Yammer Co. Ltd.) with an attachment for groundnut harvest (model KH-8, Joetsu Agricultural Machine Co. Ltd.) in mid-October which corresponded to the optimal harvest stage.

Processing, cooking and taste of bambarra groundnut

Mature grains were processed for making "amanatto", a Japanese traditional sweet. It is made of various kinds of bean, kidney bean, adzuki bean, faba bean, pea, *etc*. Dry grains of bambarra groundnut were processed by the same procedure as that for other beans in a factory (Okamedo Co. Ltd, Honbetsu, Kasaigun, Hokkaido). For home cooking, dry grains of bambarra groundnut were soaked in water overnight and boiled two times after changing of water. To prepare a bean salad, boiled grains, pork ham and cucumber were mixed with mayonnaise and mustard. The taste of bambarra groundnut amanatto was evaluated by 50 persons and that of the bean salad by 20 persons.

Results

Breeding for varieties adapted to Japanese subtropical islands

Germplasm introduced from Indonesia and Zambia for this study consisted of a population of heterogeneous seeds based on the wide variation of the seed color and seed size (Fig. 1). In the initial evaluation conducted at NARC in 1988, the accessions from Indonesia (517 seeds) were planted in early June and three plants with an outstanding grain yield (including BB29) were selected. In the evaluation conducted at JIRCAS Okinawa in 1990, 30 progenies of the 3 plants (10 progenies per each plant) selected at NARC and 254 seeds introduced from Zambia were evaluated. In addition to 110 progenies of the 11 plants selected in 1990, 517 seeds newly introduced from Zambia were tested in the evaluation of 1991. In 1992, ten lines given by IITA were included in the selection. The selection of plants with outstanding grain yield was continued until April 1993 and 7 lines with 5 plants in each line were selected in winter culture of 1992/1993. These materials were arranged into 7 groups with a total of 35 lines in summer culture, in 1993. With the lines and control variety (a commercial variety from Indonesia, Pt. Benih Prima), line selection was conducted in 1993 and 1994. Finally three lines, ZB29-14, ZD29-1, L16-1-1 were bred through plant selection and line selection procedures.

Morphological and agronomic characteristics of the 3 lines are shown in Table 1. Grains of ZB29-14 were light brown, those of ZD29-1 dark purple and those of L16-1-1 dark red. Grain yield of the 3 lines and a control variety over a period for 4 years is shown in Fig. 2. Since it was assumed that the low grain yield in 1993 was caused by insect damage, pest control with an insecticide (carbosulfan) was implemented in 1994. Grain yield in 1994 recovered and was comparable to that in 1992.

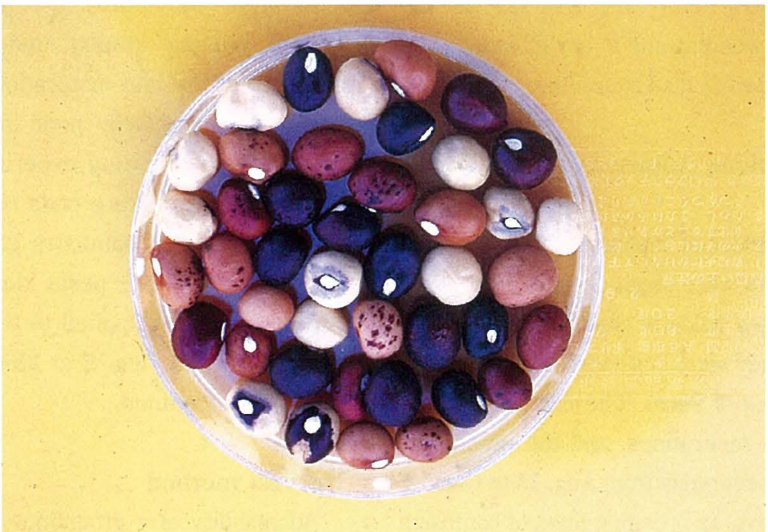

Fig.1. Bambarra groundnut grains with various colors introduced from Zambia for this study.

Table 1. Morphological and agronomic characteristics of the selected bambarra groundnut lines

	ZD29-1	ZB29-14	L16-1
Terminal leaflet shape	Lanceolate	Lanceolate	Lanceolate
Petiole color*	Green	Purple	Green
Leaf color**	Green	Dark green	Green
Growth habit	Bunch type	Bunch type	Bunch type
Number of days to flowering	40	40	40
Pod shape	Without point	Without point	Without point
Pod color	Medium brown	Medium brown	Medium brown
Pod texture	Smooth	Smooth	Smooth
Seed color	Dark purple	Light brown	Dark red
Testa pattern	No pattern	No pattern	No pattern
Eye pattern	No eye	No eye	No eye
100-seed weight	78.8g	74.0g	67.8g

*: Color of the base of petiole.

**: Color of plant canopy at the flowering stage.

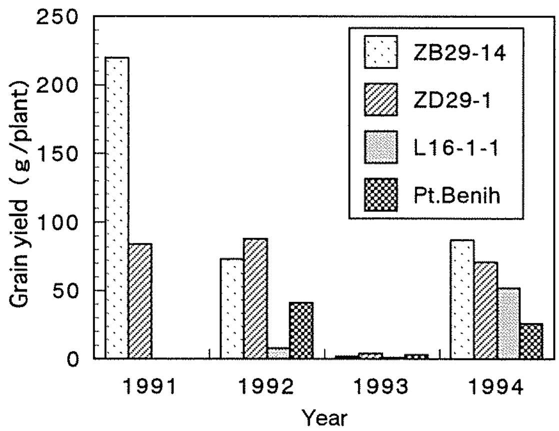

Fig. 2. Grain yield of the lines of bambarra groundnut selected at JIRCAS Okinawa Subtropical Station.
Pt. Benih (commercial variety from Indonesia) was cultivated as a control variety in breeding trials. Only two lines were tested in 1991.

Genetic stability of varieties is determined by the frequency of natural crossing in crops. It was reported that ants mediated pollination of the bambarra groundnut in Africa[2,3]. However, the frequency of natural crossing depended on the varieties in bambarra groundnut[2]. Many ants were observed around roots of the bambarra groundnut from early July to harvest time in the experimental field of Okinawa, too. Survey in mid-July showed that ants collected consisted of *Pheidole* sp. and *Camponotus* sp. However, it seemed that the ants did not mediate the pollination of the selected 3 lines. No genetic segregation in seed color could be detected in the 3 lines from the 1992 summer culture to the 1994 summer culture. As the 3 lines and other lines were cultivated in close proximity to each other in the same field, the observation suggested that the frequency of natural crossing was very low in the 3 lines.

Optimal sowing time, flowering habit and optimal harvest time

In 1992, BB29 was sown on June 8 and July 6. Although harvest was delayed until late November for the plants sown on July 6, the vegetative growth was poor even at harvest time and the grain yield (50g/plant) was lower than that of the plants sown on June 8 (170g/plant). In 1993, sowing was performed

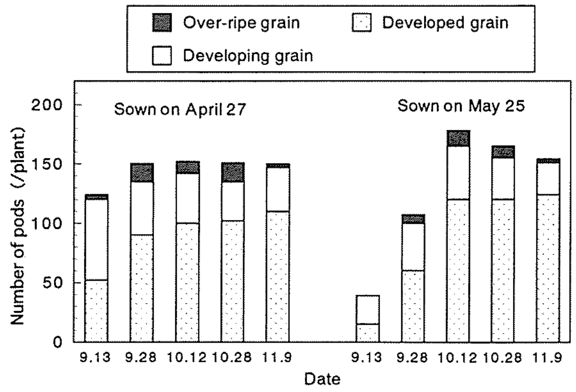

Fig. 3. Influence of sowing time on pod setting and pod ripening from September to November in bambarra groundnut (var. BB29) in 1993.

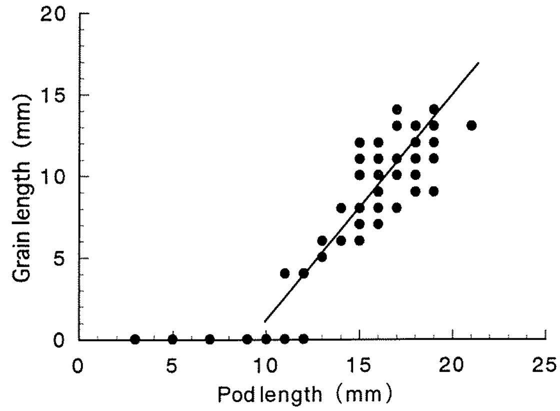

Fig. 5. Relation of pod length and grain length (axis from hilum to raphe) in fresh pods of var. ZB29-3 of bambarra groundnut in 1993.

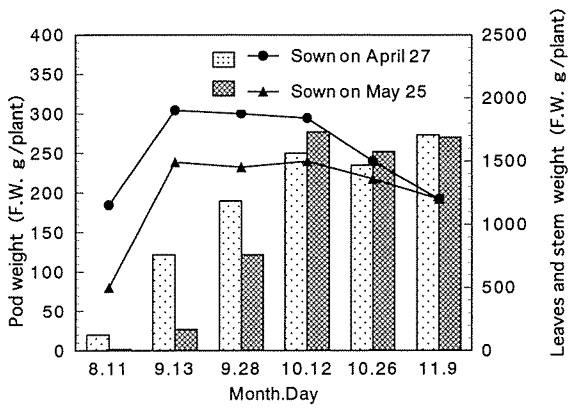

Fig. 4. Influence of sowing time on vegetative growth (lines) and on the increase of pod weight (bars) at reproductive growth stage of bambarra groundnut in the same test as that cited in Fig. 3.

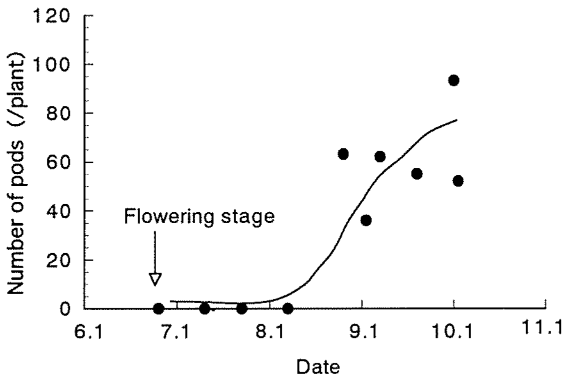

Fig. 6. Seasonal changes in the number of enlarged pods longer than 10mm in var. ZB29-3 of bambarra groundnut in 1993.

on April 27 and May 25, and the pod number and pod weight did not differ between the two sowing times (Figs. 3 and 4). Furthermore in 1994, in the May 14 sowing, grain yield (24g/plant) was higher than that on June 14 (5g/plant). On the basis of these results, it was concluded that the optimal sowing time of the tested line (BB29) was from early to late May.

In 1993, in all the 7 tested lines in the breeding trial, which were sown on May 10, flowers were opened from late June to harvest time and the plants did not set pods for a long period of time after the flowering stage. For example, the size of the grains did not start to increase until the pod length exceeded 10mm in ZB29-3 (a sister line of ZB29-14) (Fig. 5) and the line could not set pods longer than 10mm until around 60 days after the flowering stage (Fig.6). In the observation on BB29 in 1993, in the plants sown on April 27, flowers were opened on June 13, in those

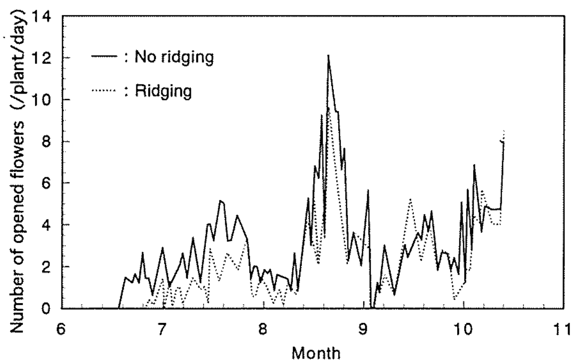

Fig. 7. Effect of ridging on flowering habit in bambarra groundnut (var. BB29) in 1993.
Sowing was performed on May 11 and the flowering stage occurred on June 19. Ridging was performed on June 26.

sown on May 11, flowers were opened on June 19 and in those sown on May 25, flowers were opened on July 6. In these plants all the early opened flowers fell (Figs. 3, 4 and 7). Furthermore in both cases of sowing on April 27 and May 25, the numbers and weight of the enlarged pods and grain yield reached maximum values in mid-October (Figs. 3 and 4). These results indicated that the optimal harvest time for BB29 was mid-October when they were sown from late April to late May.

Weeding

Five breeding lines, namely, the 3 selected lines (ZB29-14, ZD29-1and L16-1-1) and two other lines were used for a test of herbicides applied to soil. Among the tested herbicides applied to soil, DCMU and Prometryne-Bendiocarb mixture injured germinated seedlings in all the tested lines (Fig. 8). On the other hand, Alachlor-Linuron mixture was very effective in weed control and did not damage the tested lines. Sethoxydim (post-emergence herbicide) that was applied to the 3 selected lines and four other lines at the flowering stage, was effective without causing any damage to bambarra groundnut for the control of all the monocotyledonous weeds, *i.e.*, *Digitaria violascens* Link., *Eleusine indica* Gaertn., *Paspalum distichum* L., *etc.* which are very common weeds in the sub-tropical area of Japan. Weeding by intertillage and ridging was also tested on the 3 breeding lines and Pt. Benih (a control variety in the breeding trial) (Fig.9). Intertillage and ridging disturbed the development of leaves and flowers in a breeding line (ZB29-14) and Pt. Benih and it was assumed that the practice decreased the grain yield (Fig.9). In all the breeding lines, including BB29, even though the flowers had been opened for a long time after the flowering stage, pod setting did not take place (Figs. 4, 6 and 7). However, intertillage and ridging conducted one week and five weeks after the flowering stage decreased the grain yield of BB29 (Fig. 10). These results suggested that intertillage and ridging for weeding should be performed before the flowering stage.

Advantage of mulching culture and possibility of winter culture

Mulching was effective in weed control but the

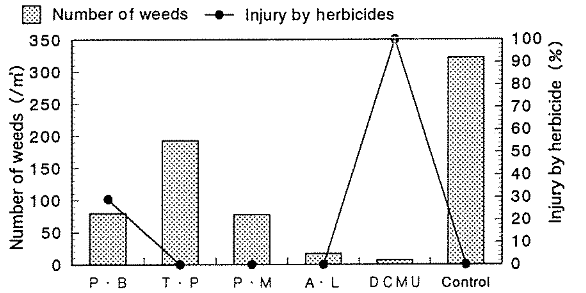

Fig. 8. Weeding effects of herbicides applied to soil in bambarra groundnut cultivation in 1993.
Injury by herbicide: ratio of sum of number of injured seedlings and number of non-germinated seeds to that of seeds sown. Number of weeds was counted 24 days after the application. Both graphs show means of data in five lines (BB29, ZB29-14, ZD29-1, L16-1-1 and BD881-3).
P•B: prometryne bendiocarb, T•P: triforine prometryne, P • M: prometryne metolachlor, AL: alachlor linuron, DCMU: diuron (I), control: no application.

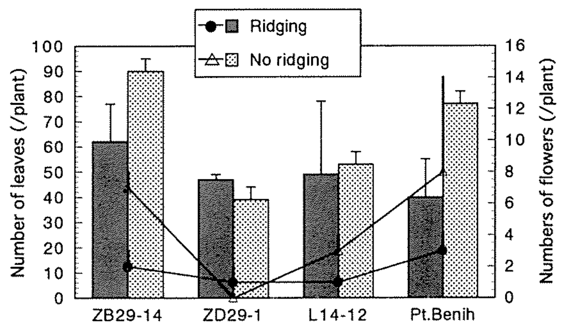

Fig. 9. Effects of ridging at flowering stage on flower setting and leaf emergence of the selected bambarra groundnut lines and control variety in 1993.
Cumulative number of flowers (lines) and leaves (bars) developed during 18 days after ridging was counted.

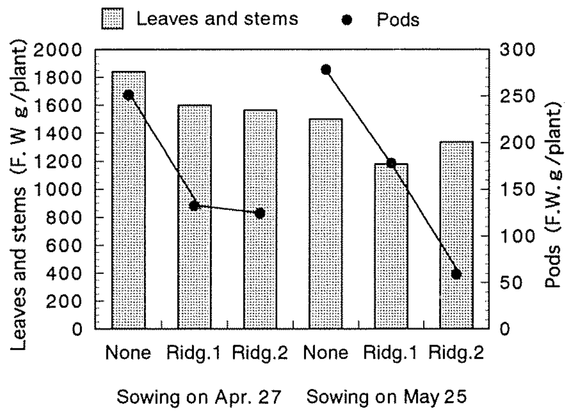

Fig. 10. Effects of ridging on the vegetative growth and pod yield of bambarra groundnut (var. BB29) sown on Apr. 27 and May 25 in 1993.
None: No ridging, Ridg.1: ridging one week after flowering stage, Ridg.2: ridging 5 weeks after flowering stage.

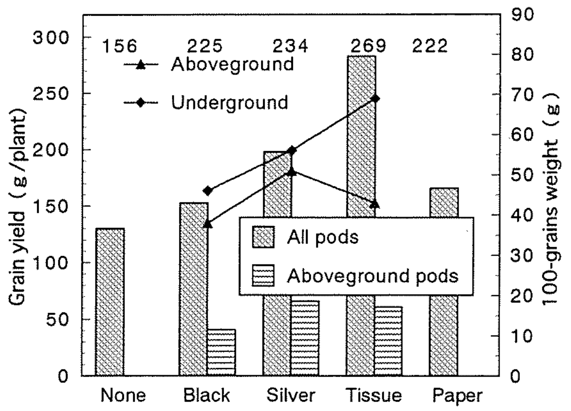

Fig.11. Effects of mulching culture on the grain yield and grain size of bambarra groundnut (var. BB29) in 1993.
Bar graph indicates grain yield with all the pods and only aboveground pods. In the control and the treatment of mulching with a paper sheet, as aboveground pods and underground pods could not be distinguished, only grain yield with all the pods was given. Line graph indicates grain size of above- and underground pods, respectively. Numbers in the figure indicate number of flowers opened for 2 months from flowering stage. None: open culture, Black: black plastic film (0.02mm thick), Silver: silver plastic film (0.07mm thick), Tissue: tissue paper mulching sheet, Paper: paper mulching sheet.

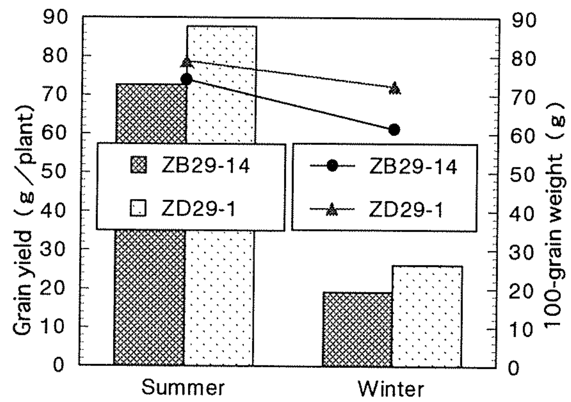

Fig.12. Grain yield (bars) and 100-grain weight (lines) of bambarra groundnut in open culture in summer 1992 and non-heated glass house culture in winter 1992/1993, respectively.

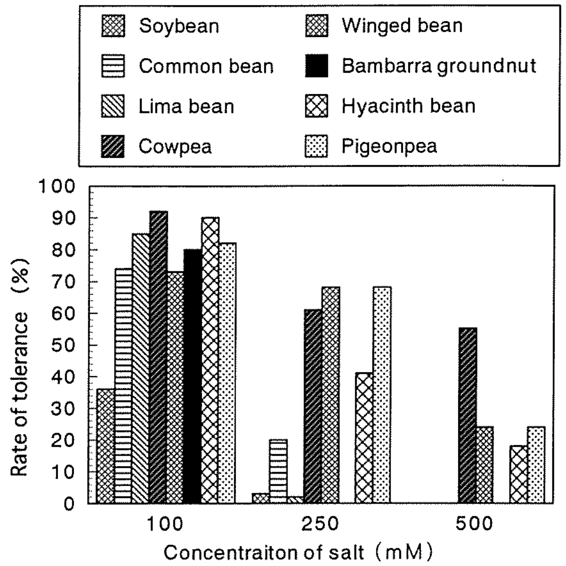

Fig.13. Effect of spraying of salt water (NaCl solution) on the leaves of leguminous crops.
Rate of tolerance is indicated by the percentage of leaf area of non-damaged part to total leaf area.

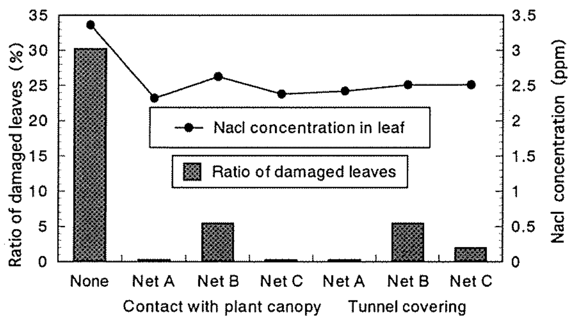

Fig.14. Effects of covering with different kinds of net on salty wind damage to bambarra groundnut (var. BB29) in 1993.
Ratio of damaged leaf: percentage of number of damaged leaves to number of all developed leaves. None: no covering, Net A: common cheesecloth (T200, white color), Net B: shading net (silver tafbel 3800S, Kanebo Co. Ltd.), Net C: wind-break net (2mm mesh, blue color). Rainfall was 240mm and precipitation of sodium ion was 1.18mg/dm^2 during the experiment.

elongating pedicels after flowering hardly penetrated into the mulching sheet. Consequently pods developed only on the surface of the mulching sheet. Pods could develop underground only when the pedicels elongated through the soil surface that was not covered with a mulching sheet around the base of the main stem. Although the size of the pods on the surface of the mulching sheet could not increase fully unlike those underground, grain yield increased by mulching (Fig. 11). It was considered that the increase of grain yield was due to the promotion of leaf and stem growth by mulching.

In winter culture of 6 breeding lines under short day-length, flowers were opened at around 40 days after sowing like in summer culture. On the other hand, the leaf color did not turn brown even 5 months after sowing (at harvest in early April) in these lines. In the winter culture, vegetative growth was poor and grain yield was not as high as that in summer culture (Fig. 12; only data of ZB29-14 and ZD29-1 are shown). However, the size of many grains fully increased and was similar to that in summer culture.

Salty wind damage and methods of protection

Rate of tolerance of leaves against spraying with 500mM Nacl solution was lower than 23% in the leguminous crops except for cowpea (Fig. 13) and it ranged from 100% to 30% in the tested vegetables, *i.e.* cabbage (*Brassica oleracea* L.), Chinese cabbages (*Brassica pekinensis* Rupr. and *Brassica campestris* L. var. amplexicaulis), swamp cabbage (*Ipomea aquatica* Forsk.), Ganges amaranthus (*Amaranthus gangeticus* Linn), *etc*. These results indicated that the tested leguminous crops except for cowpea were more sensitive to salty wind than all the tested vegetables. Furthermore, bambarra groundnut was the most sensitive among the tested 8 leguminous crops under spraying with 250mM Nacl solution (Fig. 13). In the experiment in which bambarra groundnuts were covered with some kinds of net against typhoons in 1993, a wind-break net and a cheesecloth were effective for protection against salty wind (Fig. 14).

Diseases and control

After the onset of the breeding trial in 1988, no severe disease and insect damage was recorded. However, in 1992, it rained frequently for 28 days during a period of 72 days from August 1 (early pod setting stage) to October 10 (harvest time). Under these wet conditions, round brown spots appeared on leaves (Fig. 15). Although the pathogen of the disease was not identified, it was assumed to be a fungus. By spraying of fungicides (zineb in early August and benlate one week later), the occurrence of the symptoms stopped in almost all the lines in the breeding trial. Furthermore, from mid-August, root wilt occurred in almost all the lines. Many hyphae of *Corticium rolfsii* Curzi were detected in the roots of the damaged plants. Another fungicide (metalaxyl) was sprayed onto the soil surface of the test field but the occurrence of root wilt continued until harvest time. The selected 3 lines were also sensitive to root wilt, although the damage was not serious. Among the lines introduced form IITA in 1992, some showed symptoms of virus disease, that is, mosaic and leaf shrinkage. Exudate of the leaf with the symptoms was examined by electron microscopy. It contained virus particles characteristic of the Potyvirus group (Fig 16). Lines that were infected with the virus were excluded from the breeding trial.

Pests and control

Every year, snails damaged the seedlings of bambarra groundnut at the early growing stage. After flowering also, they were observed inside the plant canopy. Damage by rats was also frequently observed every year. However, snails and rats could be controlled easily by the application of chemicals. Aphids attacked bambarra groundnut leaves. However, they could be controlled by mixing an insecticide (disulfoton) into soil at sowing time,

Fig.15. Lesions (round brown spots) observed on bambarra groundnut leaves whose pathogen was not identified.

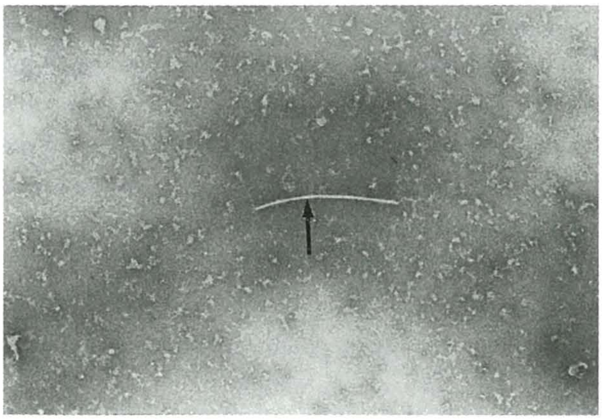

Fig.16. Potyvirus particles (arrow) observed in bambarra groundnut leaves (x20,000).

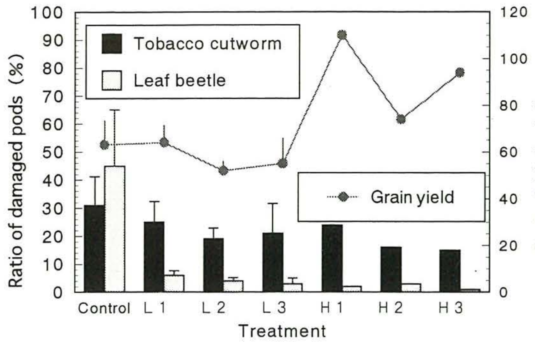

Fig.17. Effect of carbosulfan to control tobacco cutworm and two-striped leaf beetle on the grain yield of bambarra groundnut (var. BB29) in 1994.
L1 to H3: L indicates application rate of 0.38g/m^2 and H that of 0.75g/m^2. Numbers attached to L or H indicate frequency of application. Vertical bars indicate standard deviation.

Fig.18. Mechanical harvest of bambarra groundnut by an operator.

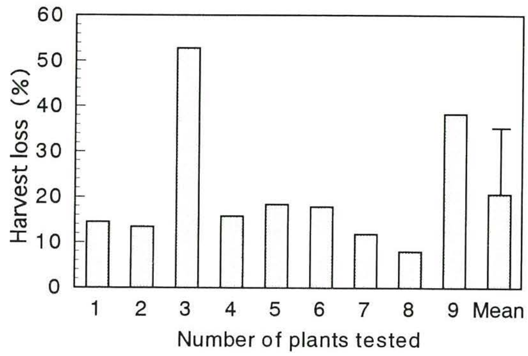

Fig.19. Harvest loss of bambarra groundnut (var. ZB29-3) pods associated with the use of a mechanical harvester with a groundnut harvester attachment in 1992.
Harvest loss: percentage of number of pods detached to that of total pods per plant. Vertical bar indicates standard deviation.

though the occurrence was serious in the late growing period of bambarra groundnut in 1992.

In 1993, the grain yield was very low. However, as the growth of leaf and stem was as good as that of plants in the years 1991 and 1992 when yields were high (Fig.2), it was considered that the low rate of pod setting was caused by insects that damaged pods underground. Survey and identification of the insects living around and inside the pods of bambarra groundnut underground were performed in 1993. Many larvae of the tobacco cutworm (*Prodenia litura* Fabricius) were observed around the pods and two-striped leaf beetle (*Medythia suturalis* Motschulsky) was observed inside immature pods. Damage by each insect could be distinguished. In Japan, the tobacco cutworm is widely distributed in warm areas and the two-striped leaf beetle is distributed only in the subtropical islands. Feeding experiment *in vitro* with immature pods of bambarra groundnut confirmed that the tobacco cutworm ate immature pods and grains. Based on these observations, carbosulfan that was considered to be effective for the control of the two-striped leaf beetle and the tobacco cutworm, was applied on the soil surface around the base of the plants in 1994. The application was effective for suppressing the damage of pods by the two-striped leaf beetle and grain yield also increased by the application (Fig. 17). However, carbosulfan was less effective for the control of the tobacco cutworm. Grain yield (93g/ m^2) of the line of BB29 treated with 0.75g/m^2 of carbosulfan in the breeding trial of 1994 was still lower than that (268g/ m^2) in 1991.

Harvest technique

Harvest loss was high (20%) when the mechanical harvester was used (Fig. 18,19). These results indicated that the pedicel of bambarra groundnut (especially pedicel with ripened pods) was less resistant to the tension applied by the harvester than that of groundnut. Ripened pods of bambarra groundnut were easily removed from the stem by the harvester and they were left underground. However, the harvester was useful because ripened pods of bambarra groundnut were easily detached from the stem by manual harvesting (Fig. 20).

Processing, cooking and taste of bambarra groundnut

Taste of amanatto (a Japanese traditional sweet) made of bambarra groundnut was compared with that of adzuki bean amannatto that is a very common sweet in Japan (a commercial product of R. Co. Ltd. Obihiro, Hokkaido). Although the taste of bambarra groundnut amanatto was as good as that of adzuki bean amanatto, its flavor was not appreciated by some of the panelists (Fig. 21). On the other hand, bean salad was appreciated. Furthermore, when young pods of bambarra groundnut were boiled with salt water, cooked as vegetable soybean and vegetable groundnut, the Japanese liked them. These results suggested that it was possible to cook bambarra groundnut in a way that would be acceptable to the Japanese people.

Fig.20. Pods of bambarra groundnut detached from a plant during manual harvest.

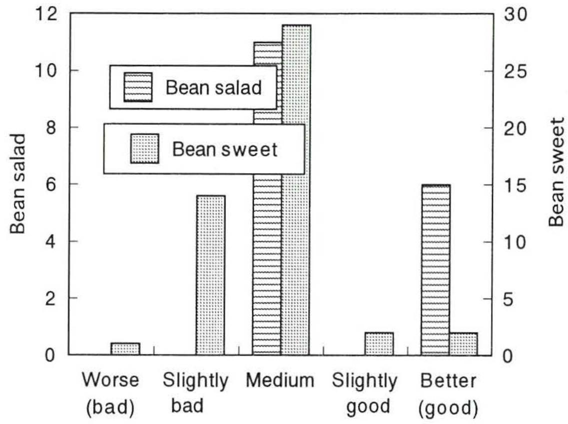

Fig.21. Taste of bean salad and processed sweet made of dry grains of bambarra groundnut (mixed varieties). Taste of the salad was scored in three grades without control and the beans sweet was evaluated in five grades in compared witn that made of azuki beans. Bars indicate numbers of votes cast for each grade by testers.

Discussion

Introduction and domestication of a new crop generally require many years. Furthermore, cooking methods must be adapted to the taste of the people in the area. However, presently, the introduction of germplasm and domestication must be achieved within a short period of time. Therefore, for the domestication, many technical constraints should be overcome through cooperation with scientists in various fields. Breeding of varieties adapted to the subtropical islands of Japan and development of cultural practices adapted to the area were achieved in this study.

In the case of breeding, 3 lines (ZB29-14, ZD29-1, L16-1-1) were bred. They were derived from the germplasm introduced from Zambia. The range of genetic diversity is very wide in pod color and grain color in bambarra groundnut[4,14]. Even in the germplasm introduced for this study, more than 10 lines differing in grain characteristics (grain color, eye color, *etc.*) were observed and in the 3 selected lines the grain color varied. If different types of grain color, *etc.* are necessary to meet the requirements of the Japanese people, it appears that genetic resources are available in Africa.

Although it was reported that the degree of natural crossing was high in bambarra groundnut, other reports suggested that the degree depended on the varieties[2]. As some species of ants mediated pollination of bambarra groundnut in Africa, two species of ants were frequently observed in the bambarra groundnut field at JIRCAS Okinawa, too. However it was confirmed that natural crossing did not occur or that the frequency was very low in the 3 selected lines at JIRCAS Okinawa. Some facilities or additional care to prevent outcrossing are required for seed propagation of lines with a high outcrossing rate. Furthermore, if contamination of grains differing in morphological and physiological characteristics occurs, the commercial value of agricultural products decreases as food material. For seed propagation and farmer's production, uniformity of seed quality in lines with a low outcrossing rate could be achieved in this study.

The optimal sowing time and harvest time for

BB29 were examined in detail. All the early opened flowers fell for around two months after the flowering stage of the line. In the breeding trials, all the tested plants were sown in mid-May that corresponded to the optimal sowing time determined for BB29. Breeding lines including the selected 3 lines (ZB29-14, ZD29-1, L16-1-1) also exhibited a similar flowering and pod-setting behavior as that of BB29. In the cultivation for the breeding trial in 1991, tested plants were harvested in late October when the leaves of almost all the plants turned brown. At harvest, many pods were already over-ripe and rotten in the plants. On the other hand, in the breeding trial of 1992, as the tested plants were harvested in early October when the leaf color of almost all the plants was still green, their grains were small compared with those harvested in 1991 and they were not fully colored. In 1993, the leaf color of the 3 selected lines started to turn brown in mid-October and at the same time rotten pods appeared. These observations indicated that the optimal harvest time of the 3 selected lines was also usually in mid-October in the same way as for BB29 but the change of leaf color should be monitored to determine the optimal harvest time. Although the pod weight did not decrease by the delay in harvest time until early November, in an experiment on sowing time with BB29 in 1993 (Fig. 4), grain yield of the line decreased due to over-ripening of grains at harvest in early November 1992. These results suggested that harvest should be performed at the optimal stage (mid-October) to obtain good yield constantly.

When short-day crops are introduced to higher latitude areas than their original location, they require more days to flower and mature in summer culture. Because day-length in high latitude areas is longer than in low latitude areas in summer, they may not flower and develop seed grains before the winter. Nishitani *et al.* detected varietal differences in the photoperiod sensitivity of the bambarra groundnut germplasm introduced from tropical countries[7,9]. They classified their materials from non-photosensitive varieties to highly photosensitive varieties in terms of both days to flowering and days to maturation. Optimal harvest time of the 3 lines bred in this study corresponded to mid-October when they were sown from April to May. The results suggested that their photosensitivity was similar. Their photosensitivity to maturation is suitable for cultivation in the Japanese subtropical islands, because the mean air temperature from June (optimal sowing time) to October (optimal harvest time) exceeds 25 ℃ at JIRCAS Okinawa and no heating facilities like plastic house and plastic tunnel were required until harvest time for the cultivation of the varieties.

In this study, bambarra groundnut was cultivated without inoculation of *Rhizobia* and the field for cultivation changed every year in the campus of JIRCAS Okinawa. Until the second year after the onset of cultivation, root nodule formation was very poor, and irregularly shaped root nodules without a red color, which were considered to be non-effective nodules in symbiotic N_2 fixation, were formed. However, thereafter, normally shaped root nodules with the red color of leghemoglobin predominated. *Rhizobia* effective for the bambarra groundnut should be inoculated for the cultivation in fields where the bambarra groundnut had never been cultivated. No investigations on fertilizer application for the bambarra groundnut were carried out in this study. Methods for fertilizer application used in other leguminous crops, especially grain legumes with grains with a low protein content, were applied to bambarra groundnut, because it was assumed that the requirement of fertilizer, especially nitrogen, of bambarra groundnut was similar to that of the grain legumes. Detailed investigations must be conducted to develop methods of fertilizer application adapted to the soil conditions of the Japanese subtropical islands. Optimum plant spacing should be also studied in future, because, although the plant canopy closed after the pod-setting stage (from mid-August) in the breeding trials and other tests each year, grain yield per unit area was not high even in the selected 3 lines.

It was found that ridging after the flowering stage decreased the grain yield by inhibiting pod setting. Although Dart and Krantz (1977) reported that ridging promoted pod development underground[1], it was assumed that covering of flowers and flower buds on the ground surface with soil at the time of ridging caused a yield decrease. On the basis of these observations, an efficient method of weed control for bambarra groundnut, which consisted of a combination of spraying of herbicide (alachlor-linuron mixture) applied to soil and post-emergence herbicide (sethoxydim) with ridging before the flowering stage, was proposed. Furthermore, it was confirmed that mulching with various types of sheets was effective not only for weed control but also for yield increase. However, pedicels with a fertilized ovary could not penetrate into any types of the tested mulching sheets and they could not develop fully enlarged pods aboveground for unknown reasons. Further investigations should be carried out to develop cultivation methods with mulching, for example, studies on physical hardness of various mulching sheets and methods of covering, *etc*. In terms of penetration force of the pedicel of bambarra groundnut, soil hardness and soil management methods should be investigated to facilitate the penetration of immature pods into the ground in the case of open culture without mulching.

Warm climate in winter is one of the advantages of subtropical islands for crop production. In the experiment of sowing time with BB29, although the flowering stage was delayed by late sowing, optimal harvest time remained the same, irrespective of sowing time when sowing took place from late April to late May. This suggested that days to flowering were relatively constant, irrespective of day-length or climatic conditions unlike days to maturation. Therefore, even in winter culture, the flowering stage of the tested lines was around 40 days after sowing like in summer culture but leaf senescence was not observed 5 months after sowing that corresponded to harvest time in summer culture. It was considered that the delay in leaf senescence was due to the longer day-length or higher air temperature of the glass house in April (harvest time in winter culture) than those outside in October (harvest time in summer culture). However, the size of many grains was similar to that in summer culture. These results suggested that winter culture of bambarra groundnut could be realized through the improvement of cultural practices.

On the other hand, salty wind damage is a serious constraint on crop cultivation in the Japanese subtropical islands. This study showed that bambarra groundnut was a sensitive crop to salty wind. Cultural practices to prevent the damage caused by salt adhering to the crop surface should be developed for the cultivation of the crop. This study suggested that the use of a wind-break net and cheesecloth was effective for protecting bambarra groundnut against salty wind. However, the experiment was conducted when the precipitation was 240mm. In the case of typhoons without rainfall, bambarra groundnuts may be more damaged even under covering with these kinds of net. The experience obtained in the cultivation for the breeding trials indicated that washing leaves with a sprinkler after a typhoon was also effective for bambarra groundnuts to recover from the damage caused by salty wind.

In this study, some plant diseases were observed in bambarra groundnuts. Plants affected by a viral disease were discarded immediately from the field and sensitive lines in which the infected plants appeared were excluded from the breeding trial. It was confirmed that the virus belonged to the Potyvirus group. Among several viral diseases previously reported in bambarra groundnut[4,5,13], bean mosaic virus and bean necrosis mosaic virus belong to the Potyvirus group. Identification of the virus observed in this study should be completed in future. Another disease, in which the symptoms did not enable to identify the pathogen was also observed. However, the application of zineb and benlate was effective to control it. Root wilt caused by *Corticium rolfsii* Curzi also appeared and control methods for root wilt could not be developed.

Among the pests of bambarra groundnut, tobacco cutworm and a two-striped leaf beetle were observed. The latter could be controlled by the application of a chemical (carbosulfan) unlike the former. Effective chemicals and application methods to control the larvae of the tobacco cutworm living underground must be identified. In 1994, grain yield of bambarra groundnut increased by the application of carbosulfan, suggesting that the annual fluctuations in the grain yield were at least partly due to these pests, although other factors might be also responsible for the fluctuations.

Manual harvest is very laborious because bambarra groundnuts set pods underground. In terms of harvest method, groundnut harvester equipped with a hand tractor could be used for bambarra groundnut. However, in order to decrease the harvest loss, some modifications are required to improve and adjust the groundnut harvester to bambarra groundnut harvest. Another important area that was not sufficiently investigated in this study deals with methods of utilization of immature and mature dry grains of bambarra groundnut. In this study, three varieties were bred whose grain color was different from one another. These varieties could be used for cooking and food processing depending on the variation in the grain color. Bean salad and bambarra groundnut sweet were very much appreciated but home cooking and commercial foods that meet the taste of Japanese consumers must be further investigated.

This paper reported the results of a study on the introduction to and domestication of bambarra groundnut in the subtropical islands in Japan. Although we could not develop cultural practices to achieve a high yield constantly, we pointed out some constraints that should be studied in future.

Acknowledgements

We thank Dr. Nq (IITA) for giving us IITA germplasm of bambarra groundnut for our studies. We thank the staff members of Yaeyama Station of Improvement and Extension for Agriculture Techni-ques for preparing the bean salad of bambarra groundnut. We thank Okamedo Co. Ltd. for preparing a bambarra groundnut sweet. We thank Mr. Fumio Wada (Kagoshima Prefecture Agricultural Experi-ment Station) for his advice concerning bambarra ground cultivation. We thank Dr. T. Yamashita, Director of JIRCAS Okinawa for his advice and encouragement.

References

1) Dart, P.J. and Krantz, B. A. (1977). Legumes in the semi-arid tropics. *In* Proceedings of a workshop on exploiting the legume-rhizobium symbiosis in tropical agriculture, held at Hawaii, USA 119-154.

2) Doku, E. V. (1968). Flowering, pollination and pod formation in bambarra groundnut (*Voandzeia suberranea*). *Economic Bot.* **25**:357-362.

3) Doku, E. V.and Karikari, S. K. (1971). The role of ants in pollination and pod production of bambarra groundnut (*Voandzeia suberranea*) in Ghana. *Exper. Agric*. **4**:41-48.

4) Duke, J. A. (1983). *In* handbook of legumes of world economic importance. Plenum Press, New york and London , translated into Japanese by Hoshiai K., Zatto-Yunyu-Kikinkyokai, Tokyo 490-494.

5) Klessser, P.J. (1961). The virus diseases of beans. *Bothalia* **7**:521-558.

6) Nakamura, H. and Igarashi, I. (1983). Situations of vegetable production in the summer in Okinawa. *Nettai Noken Shuho* **46**: 50-58. (In Japanese).

7) Nishitani, T. and Inoue, J. (1981). The growth habits of Bambarra groundnut (*Voandzeia suberranea* Thouars) and Kersting's groundnut (*Kertingiella geocarpa* Harms) . *Jap. J . Trop. Agr.* **25**: 163-169. (In Japanese with English summary).

8) Nishitani, T. , Muraki, K. and Inoue, J. (1984). On the water storage cells in the leaves of Bambarra groundnut (*Voandzeia suberranea* Thouars) and Kersting's groundnut (*Macrotyloma geocarpum* (Harms) Marechal & Baudet) *Japan J. Trop. Agr.* **28**:149-154. (In Japanese with English summary).

9) Nishitani, T. , Muraki, K. and Inoue, J. (1988). Effect of daylength on the flowering and fruiting in bambarra groundnut (*Vigna subterranea* (L.) Verdec). *Japan J. Trop. Agr.* **32**:80-84. (In Japanese with English summary).

10) Nishitani , T. Jin, I. and Inoue, J. (1988) . Developments of embryosac and embryo in bambarra groundnut (*Vigna subterranea* (L.) Verdec). *Japan J. Trop. Agr.* **32**:75-79. (In Japanese with English summary).

11) Purseglove, J. W. (1977). *In* Tropical Crops: Dicotyledons. Longman Group Ltd., London, 329-332.

12) Rachie, K. O. and Roberts, L.M. (1974). Grain legumes of the lowland tropics. In Advance in Agronomy 26(Ed.) Brady N. C., Academic Press, New York. 2-118.

13) Robertson, D.G. (1971). Report on the plant pathology division. *In* : Report of the federal department of agricultural research for the years 1965-1966. Lagos, Nigeria. Federal Department of Agricultural Research, 16.

14) Yen, M., Yuasa, H. and Kakuma, M. (1987). Bambara bean – tropical leguminous resources (II). *J. Agr. Assoc. China* **138**:3-15. (In Chinese with English summary).

本邦亜熱帯地域におけるバンバラマメ実用栽培の可能性について

中野　寛[a]、松本大助[b]、安田耕司[c]、真岡　真[d]、西　和文[e]、
緒方一夫[f]、古谷茂貴[g]、佐久間青成[h]、小林　真[i]、寺内方克[j]

a,b,c,d,g,h,i,j) 国際農林水産業研究センター・沖縄支所（〒907-0002　沖縄県石垣市真栄里川良原 1091）
e) 農業研究センター・病害虫防除部（〒305-8666　茨城県つくば市観音台 3-1-1）
f) 九州大学・熱帯農学研究センター（〒812-8571　福岡県福岡市東区箱崎 6 丁目 10-1）

摘　要

我が国の亜熱帯、南西諸島の夏作物・野菜作目を拡大するために、サハラ砂漠周辺地域原産のバンバラマメを導入し、適品種を育成するとともに地域に適した栽培技術を検討した。本研究を通じて、ザンビアの遺伝資源から当該地域に適する品種として３系統を選抜育成した。当該地域での適播種期は５月中下旬、開花期は６月中下旬であったが、初期に開花した花は無効花となり、莢実の肥大が始まるのは遅く、収穫適期は１０月中旬の茎葉の枯れ上がり初めであった。播種期の除草剤と生育期の細葉雑草用の茎葉処理剤処理と中耕培土を組み合わせた除草法が有効であることが確認されたが、開花期以降の中耕培土による除草は収量を低下させた。マルチ栽培によって増収したが、資材で覆われた部分では子房柄は資材を貫通できず、莢実は地表で結莢することとなり、子実は小さくなった。冬期の無加温ガラス室栽培では収量は低かった。しかし、生育期間は特に短くならず子実の大きさも夏栽培と同程度であり、栽培法を改善すれば冬期栽培も可能であることをうかがわせた。バンバラマメは潮風害に弱い作物であることが判明したが、台風襲来時はネット類のべたがけが対策技術として有効であることが確認された。子実収量の年次変動が著しく大きかった。その一因と思われる莢実害虫のうち、フトスジヒメハムシには薬剤防除が有効であったが、ハスモンヨトウに有効な防除法は見いだせなかった。また、白絹病に対する防除法も未解決に残された。収穫には落花生の掘り取り機が活用できること、完熟粒を用いた家庭料理や甘納豆の食味が日本人の嗜好に適うことが確認された。

キーワード　；遺伝資源、沖縄、新規作物、導入、熱帯作物、マメ、*Voandzeia subterranea*

現在の住所；
a) 北海道農業試験場畑作研究センター（〒082-0071　北海道河西郡芽室町新生）
c) 農業環境技術研究所企画調整部（〒305-8604　茨城県つくば市観音台 3-1-1）
d) 北海道農業試験場生産環境部（〒062-8555　北海道札幌市豊平区羊ヶ丘 1）
e) 九州農業試験場地域基盤研究部（〒861-1192　熊本県菊池郡西合志町大字須屋 2421）
g) 野菜・茶業試験場野菜育種部（〒514-2392　三重県安芸郡安濃町草生 360）
h) 中国農業試験場畑地利用部（〒623-0035　京都府綾部市上野町上野 200）
i) 草地試験場育種部（〒329-2793　栃木県那須郡西那須町千本松）