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Utilization of Information from International Observation Trials for the Introduction of New Crops: An Introduction of Azuki Bean Varieties from China to Thailand

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Abstract

Azuki bean has never been commercially grown in Thailand, due in part to a lack of suitable varieties. A core collection of 114 azuki bean accessions, originally from different parts of China (northern, central, southern) representing the germplasm of Chinese land races, were evaluated in the experimental field of the Institute of Vegetable Crops, Jiangsu Academy of Agricultural Sciences, China from June to October 2004. The same experiment was repeated at Kamphaeng Saen campus of Kasetsart University, Thailand from February to May 2005. Yield, yield components, and agronomic traits were recorded in all accessions in order to identify certain genotypes for further investigation. The statistical parameters that were used as indicators of phenotypic variation were mean, coefficient of variability (*CV*), correlation coefficient (*r*), range, mean difference, and phenotypic clustering of the accessions. The results indicated that the azuki bean varieties planted in Kamphaeng Saen were shorter, earlier in growing duration, and lower in plant height, seed yield per plant, 100-seed weight, and pods per plant as compared to when they were grown in China. This discrepancy was caused largely by the combined effect of temperature, rainfall, and day length. The traits that were rather stable in both locations were branches per plant and seeds per pod. Azuki bean varieties from northern China showed higher response to the changing environments compared with those from central and southern China. Some agronomic traits showed high correlation coefficient between the environments in Thailand and China. The *CV* of agronomic traits in both locations were ranked in descending order as follows: seed yield per plant, pods per plant, branches per plant, plant height, 100-seed weight, seeds per pod, and growing duration. The *CV* of seeds per pod and branches per plant were almost the same in both locations. Yield per plant in China correlated well ($r = 0.75$) with pods per plant, but not with the other traits. Based on their response to both environments, the azuki bean accessions can be broadly divided into four groups, viz. northern 1, northern 2, central, and southern. This implied that there was more diversity, but probably less stability among the accessions originating from northern China.

Key words: azuki bean, *Vigna angularis*, phenotypic variation, response to environment

Introduction

Azuki bean (*Vigna angularis* (L.) Ohwi & Ohashi; 2n=2x=22) originated in northeast Asia (Tomooka et al. 2002). It is one of the twelve most important grain legumes in the world. The crop is described as an annual or a short-term perennial, depending on varieties. Chinese farmers like to plant azuki bean because of its bright red seed, which is usually associated with celebration or spirit dwelt from ancient custom, meaning success and good fortune. In China, azuki bean is consumed in much the same ways as mungbean, i.e. cooked with rice, made into soup, cakes, ice stick, bundle, sweetened bean paste dumpling, etc. Although some cultivars are considered heat tolerant, the crop has never been tested in Thailand on a large scale. A limited number of studies were conducted to examine the relationship between agronomic traits of azuki bean grown in either the same or different environments. Nomura (1968) reported positive correlations between seed yield and plant height, length of the longest branch, and branches per plant. Han and Choe (1975) described the importance of pods per plant in

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influencing positive change in seed yield. They observed that genotypic correlations between seed yield and 100-seed weight, plant height, total dry matter, and time to flowering were negative in one year but positive in another. This suggested that there is a high environmental effect on these quantitative traits. Zhang (2004) compared four azuki bean accessions introduced from Japan with 'Rong Xiaodou No. 2' variety and analyzed the correlation between yield and other agronomic traits. The results showed that agronomic characteristics influencing the yield were, in descending order: seeds per plant, pods per plant, weight per plant, 100-seed weight, and branches per plant. Zong et al. (2003) selected a set of azuki bean complex comprising 123 cultivated accessions and 23 wild or weedy accessions from Bhutan, China (including Taiwan), India, Japan, Korea, and Nepal and analyzed their DNA using amplified fragment length polymorphism (AFLP) markers. The results indicated that there were five major groups of azuki bean germplasm primarily associated with geographical origin of the accessions and their forms (wild, weedy, or cultivated). These groups include (*i*) Himalayan wild, (*ii*) Nepal-Bhutan cultivated, (*iii*) Chinese wild, (*iv*) Taiwan wild-Bhutan cultivated, and (*v*) northeast Asian accessions.

Lawn (1979) studied phenological development of four cultivars each of four *Vigna* species (*V. radiata*, mungbean; *V. mungo*, black gram; *V. angularis*, azuki bean; and *V. umbellata*, rice bean) over 17 weekly sowing dates at Lawes, south-eastern Queensland. He observed large effects of cultivars and sowing dates on phenology, in which day length and temperature regimes at post-flowering were the responsible factors. This finding was recently confirmed by Han et al. (2005) in six long-day crops, viz. flax, sugar beet, broad bean, triticale, wheat and rapeseed and seven short-day crops, viz. azuki bean, potato, rice, peanut, mungbean, cotton and corn. They reported pre-flowering photoperiod effects on floral initiation, flowering date and yield components. Whereas there were strong genotypic differences in sensitivity and magnitude of response to post-flowering photoperiod.

When Chinese land race core collection of azuki bean was introduced to Warwik, Australia, accessions from southern China were found later flowering with smaller seed and grew taller than those from central China. Grain yield was the highest for accessions from central China, whereas both north Chinese and Japanese check accessions were low yielding. Desborough et al. (2003) studied in a core collection representing 7% of 2,946 Chinese landrace azuki bean under temperature regimes at Grafton and Armidale, New South Wales (both locating at 30°S), while response to photoperiod was measured in controlled temperature during winter at Biloela, Queensland. The mean difference in flowering was 13.6 days longer at Armidale than Grafton without interaction between varieties and temperature. The day length experiment confirmed that azuki bean is a short-day crop with the critical photoperiod of 12-13 h.

The objectives of this study are (1) to examine the phenotypic variation of 114 azuki bean varieties from China planted in two different climatic locations, viz. Nanjing city in China (subtropical climate) and Kamphaeng Saen in Thailand (tropical climate); (2) to group them according to their agronomic characteristics, and (3) to primarily identify cultivars that are worth further investigation in Thailand.

Materials and Methods

A population of 114 azuki bean varieties from different origins of China was used in this experiment. Thirty-eight of these were from northern China (the provinces of Heilongjiang, Liaoning, Jilin, Hebei, Shanxi, and Beijing). Forty-three accessions were from central China (the provinces of Jiangsu and Shandong). The rest accessions were from southern China, including Taiwan. The list of all accessions is shown in Fig. 1.

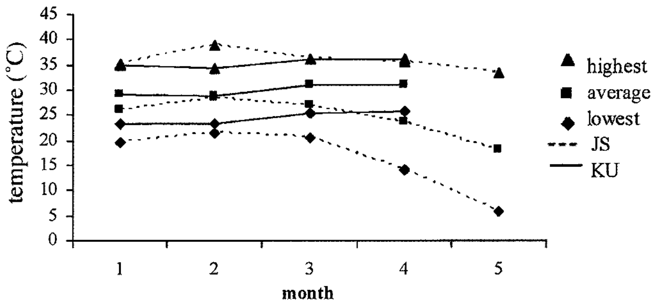

Fig. 1. Monthly highest, lowest, and average temperatures in Jiangsu (JS), China and Kamphaeng Saen (KU), Thailand during the azuki bean trials.

The experiment was conducted in two locations, one each in China and Thailand. They were (1) the Institute of Vegetable Crops, Jiangsu Academy of Agricultural Sciences, Nanjing, Jiangsu province, central China, representing a subtropical area and abbreviated as JS, and (2) Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom province, central Thailand, representing a tropical area and abbreviated as KU.

The experiment was conducted from June to October 2004 in China and from February to May 2005 in Thailand. Each accession was sown in hills in a three-row plot of 5 m-long without replication. Each hill contained two plants, with the space of 12.5 cm between hills and 50 cm between rows. The agronomic characteristics were observed as follows:

1) Days to the first flowering
2) Growing duration (d)
3) Plant height (cm)
4) Number of branches/plant
5) Number of pods/plant
6) Number of seeds/pod
7) Number of pods/cluster
8) 100-seed weight (g)
9) Seed yield/plant (g)
10) Pod color
11) Seed coat color
12) Leaflet shape
13) Leaflet color

Growing duration of each accession was recorded from germination until 90% of the pods were mature. Leaflet colors were coded as: 1=yellow, 2=green, and 3=dark green. Mature pod colors were coded as: 1=white, 2=brown, and 3=black. Seed coat colors were divided into either red or dark red. The mean difference between locations of the above agronomic traits was determined by the formula:

Mean difference (%)
= (trait mean at JS - trait mean at KU) *100/(trait mean at JS)

The data were analyzed using the SPSS software version 11.0 (SPSS, Inc., Chicago, Illinois). The software was also used to classify the azuki bean accessions into different groups based on their agronomic traits.

Results and Discussion

Mean difference and coefficient of variability of agronomic traits

On average, the trial in Jiangsu gave greater observed values than the one in Kamphaeng Sean in all traits observed (Table 1). Yet, ranking of the line means was not very different across locations, revealing less significant genotype x environment interaction of the traits under study. When azuki bean accessions were planted in Thailand, most varieties from southern China had later flowering and maturity dates, superior yield per plant, smaller 100-seed weight, more pods per plant, taller plants, more synchronous maturity, and more yellowish and wider leaves. On the contrary, the accessions from northern China generally had earlier flowering and maturity, lower yield per plant, larger 100-seed weight, fewer pods per plant, shorter plant, and darker and smaller leaves. While those from central China displayed intermediate expression.

The results from mean difference percentage among agronomic traits of all accessions across both tests can be ranked in descending order as: yield per plant, plant height, pods per plant, 100-seed weight, growing duration, branches per plant, and seeds per pod (Table 2). The mean difference of the southern China accessions were ranked as: plant height, growing duration, yield per plant, 100-seed weight, pods per plant, branches per plant, and seeds per pod. In general, the diversity of agronomic traits from the north was higher than those from central China, which was higher than those from southern China, respectively. The accessions originated from southern China were more uniform compared with the other two groups, thus showing a tendency to better adapt under Thailand's conditions. Branches per plant and seeds per pods showed less variation in all three groups. The varieties originating from northern China showed more response to environment in all traits, except seeds per pod as compared with those originating from central and southern China. This may be due to the lower magnitude of contrasting differences between the environments where the varieties are normally cultivated versus the tested sites (i.e. southern China vs. Thailand as compared to northern and central China vs. Thailand).

Table 1. Mean and CV (%) of agronomic traits of azuki bean accessions from northern, central, and southern China grown in Jiangsu (JS) and Kamphaeng Saen (KU).

+Traits	Means				*CV* (%)			
	North	Central	South	All	North	Central	South	All
ph JS	55.6	57.1	51.6	55.0	21	20	15	22
ph KU	34.5	40.8	47.1	40.6	17	18	15	22
ypp JS	5.5	7.3	5.4	6.2	35	34	21	38
ypp KU	2.4	4.8	5.8	4.3	32	33	21	44
ppp JS	10.3	14.3	11.8	12.3	33	29	20	33
ppp KU	6.9	11.5	12.3	10.3	32	26	19	35
bpp JS	1.9	2.1	2.2	2.1	30	23	20	27
bpp KU	1.7	2.0	2.1	2.0	27	22	20	26
spp JS	4.9	4.9	4.5	4.8	16	16	16	18
spp KU	4.9	4.9	4.5	4.7	16	16	15	18
100sw JS	11.3	10.9	10.4	10.9	16	14	10	15
100sw KU	7.7	8.8	9.8	8.7	14	14	12	17
gd JS	111.2	97.8	103.0	103.7	6	8	6	9
gd KU	78.4	85.0	94.3	85.5	5	7	7	10

+ph=plant height (cm), ypp=seed yield per plant (g), ppp=pods per plant, bpp=branches per plant, spp=seeds per pod, 100sw=100-seed weight (g), gd=growing duration (days).

Table 2. Difference in mean agronomic traits between two locations, compared with those planted in Jiangsu, expressed in percentage.

Location	ph+	ypp	ppp	bpp	spp	100 sw	Gd
North	37.94	56.11	32.62	9.64	0.77	32.27	29.53
Central	28.52	35.23	19.97	5.49	1.29	19.85	13.13
South	8.74	-7.65	-4.29	1.88	1.67	5.75	8.44
All	26.24	30.40	16.65	5.65	1.22	20.17	17.49

+See Table 1 for abbreviations.

The coefficient of variability (*CV*) of agronomic characteristics in China and Thailand showed a similar trend (Table 1). It can be ranked in descending order as: seed yield per plant, pods per plant, branches per plant, plant height, 100-seed weight, seeds per pod, and growing duration. From the different groups and locations, the *CV*s of most agronomic traits of the northern China accessions were normally higher than those from central China, whereas the *CV* of agronomic traits of the southern China accessions was the smallest.

The average temperature during the growing season in Thailand ranged between 30-33 °C with the day length ranging between 12-13 h. The average temperature during the first two months of the growing season in Jiangsu was not much different from Kamphaeng Sean. The temperature at KU remained high throughout the growing season, while the temperature in JS became cooler upon flowering until harvesting (Fig. 1). This allowed longer seed dry matter accumulation in JS and thus resulted in a clear superiority in all agronomic traits except branches per plant and seeds per pod (Table 1). Growing duration of azuki beans in JS was one month longer than that in KU. JS location also obtained better monthly rainfall throughout the season (Fig. 2). The rainfall caused cloudiness and gave less monthly sunlight although the day length of JS was 14-16 h. The difference in mean agronomic traits between the two locations in shown in Table 2, confirming that JS environment promoted better growth and development in all traits observed, except for the materials from southern China which gave slightly higher yield per plant and pods per plant when grown at KU. Considering overall traits of all accessions, a slight advantage in total daily sunlight at KU could not compensate with the advantage of favorable temperature, rainfall, and daylength at JS.

Desborough et al. (2003) tested a Chinese landrace core collection of azuki bean in New South Wales, Australia and classified them into 4 groups based on latitude of origin, depending on their ceiling photoperiod beyond which there is no further response to photoperiod. In their sowing date experiment using 8 diverse accessions, they reported that, for November to February sowing, time of flowering was conditioned by accumulated temperature once the photoperiod threshold had been achieved. Similarly, Wang et al. (2001) evaluated the diversity of Chinese azuki bean at Warwick, Australia and found association with latitude of germplasm origin, which was either positive or negative according to the trait. The germplasm diversity in duration of crop growth phases, in yield expression, and in other quantitative traits was associated with latitude of landrace origin. They suggested that the Chinese collection was more diverse than the Japanese germplasm and thus should be utilized in the future azuki bean breeding program in Australia to replace the Japanese-derived standards being used then.

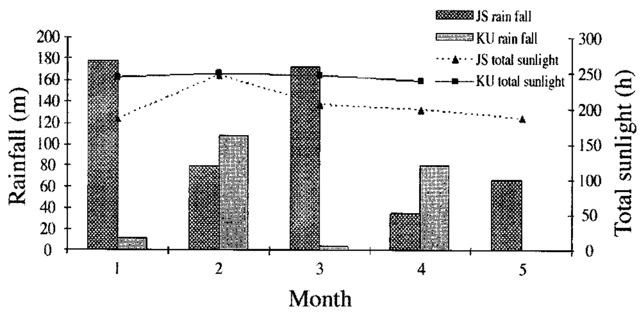

Fig. 2. Monthly rainfall (mm) and monthly sunlight (h) in Jiangsu (JS), China and Kamphaeng Saen (KU), Thailand during the azuki bean trials.

Correlation between yield and yield components

Yield per plant correlated well with pods per plant both in China and Thailand. It should be noted in Table 3 that the overall correlation of a trait is not the average correlation across the three germplasm sources, but rather a correlation calculated across all 114 accessions. These results agreed well with Zhang (2004) who reported that pods per plant showed the highest correlation with seed yield. The traits that expressed weak correlation with yield are branches per plant and growing duration. No correlation was found between yield per plant with the other two yield components, i.e. seeds per pod and 100-seed weight. Thus, accessions with higher number of pods per plant should be considered when choosing azuki bean cultivars for Thailand.

Table 3. Correlation coefficients between grain yield per plant with other traits, among varieties from different parts of China, grown in China and Thailand.

+Correlation with ypp	North	Central	South	All
ph JS	0.20	0.08	0.06	0.17
ph KU	0.17	0.14	0.20	0.49**
ppp JS	0.61**	0.78**	0.86**	0.75**
ppp KU	0.61**	0.70**	0.59**	0.81**
bpp JS	0.26*	0.36**	0.35**	0.30**
bpp KU	0.20	0.27**	0.08	0.25*
spp JS	0.10	0.10	0.05	0.14
spp KU	0.15	0.22	0.14	0.01
100sw JS	0.18	0.00	-0.12	0.07
100sw KU	0.10	0.14	-0.18	0.10
gd JS	0.45**	0.30**	0.32**	0.37**
gd KU	0.25*	0.19	0.40**	0.33**

+See Table 1 for abbreviations.
*,** Significant at P=0.05 and 0.01, respectively.

Correlation between the same trait in two locations

Correlation of the same trait revealed good agreement in cultivar ranking in both locations. Most agronomic traits showed positive correlation between two locations, especially seeds per pod and pods per plant showed high values of 0.88 and 0.70, respectively (Table 4), while yield per plant and 100-seed weight gave lower correlation coefficients of 0.50 and 0.53, respectively. Among different groups, the accessions from southern China generally gave higher correlation coefficients than those from the other areas. These cultivars seemed to adapt better to the higher temperature and shorter day length of Thailand.

Table 4. Correlation coefficients of the same agronomic traits among varieties from different parts of China grown in China and Thailand.

Location	hpp+	wpp	ppp	bpp	spp	100 sw	Gd
North	0.80**	0.77**	0.66**	0.41*	0.90**	0.82**	0.41*
Central	0.79**	0.69**	0.77**	0.70**	0.85**	0.79**	0.52**
South	0.87**	0.80**	0.83**	0.84**	0.89**	0.90**	0.84**
All	0.57**	0.50**	0.70**	0.61**	0.88**	0.53**	0.56**

+See Table 1 for abbreviations.
*,** Significant at P=0.05 and 0.01, respectively.

Grouping of the azuki bean accessions

Based on average agronomic traits, the azuki bean accessions can be broadly classified into two groups, one comprising mainly the northern varieties while the other comprising mainly the southern ones (Fig. 3). The accessions from central China joined with both groups. Further division with less distance between groups resulted in four distinct groups belonging to north 1, north 2, middle, and south China. The accessions from northern China showed more variation compare with the other two origins. This implied that, although the northern accessions were not well adapted to Thailand's growing conditions, they were the better germplasm source for azuki bean breeding.

Identification of azuki bean varieties suitable for central Thailand

From our experiment, Guilin1 (acc. 103) from Guangxi province, Vanzi63 and Vanzi0312 (acc. 94 and 62) from Taiwan, all originating from southern China, can be considered as good varieties for growing in central Thailand because of

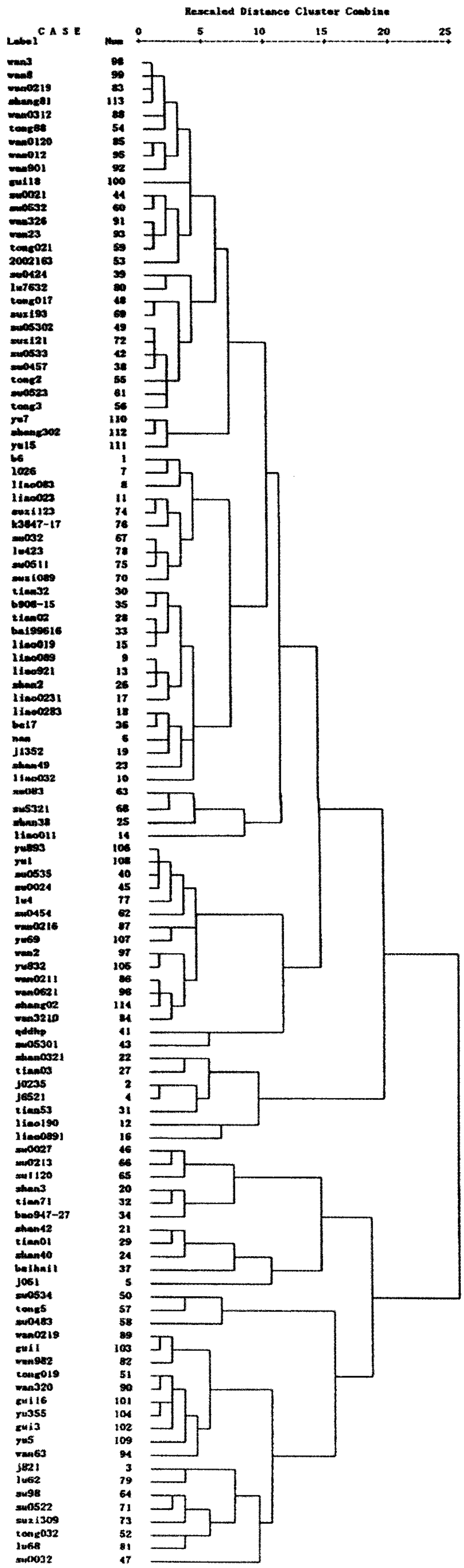

Fig. 3. Grouping of 114 azuki bean accessions from China based on their average phenotypic values observed from Jiangsu, China and Kamphang Saen, Thailand.

their good agronomic characteristics and yield per plants of over 10 g. Among the middle China accessions, we can choose Luzi62 and Luzi68 (acc. 79 and 81) from Shandong as good cultivars owing to their good agronomic traits. None of the northern accessions in this experiment were found to be suitable for Kamphaeng Saen conditions, although they were found to be useful as a germplasm for azuki bean breeding. More accessions should be tested in more environments in order to identify azuki bean cultivars suitable for particular parts of Thailand, as well as to be used in a breeding program.

Conclusions

Agronomic traits of azuki bean accessions originating from northern China showed higher phenotypic (and presumably genetic) variation compared with those from central and southern China in both Jiangsu province of China and Kamphaeng Saen district of Thailand. Yield per plant, pods per plant, and plant height gave higher variation as measured by *CV* values, while branches per plant and seeds per pods gave smaller values. When grown in Thailand, azuki bean from southern China showed more stable agronomic traits than those from northern and central China. However, some azuki bean varieties from central China also gave good traits such as high seed yield per plant, pods per plant, and 100-seed weight. More new cultivars have been bred from this area compared to those bred from the south. The accessions in this experiment can be broadly divided into four groups, two of which were the accessions from northern China. This implied that the northern cultivars, which are grown in the main production area, had relatively more variation. This area is also considered as the center of origin of the azuki bean in China.

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References

Desborough P, Lawrence P, Redden B, Xuxiao Z. 2003. Flowering characteristics of adzuki bean from China. Proceedings of the 11th Australian Society of Agronomy Conference. The Regional Institute Ltd. p 9

Han KS, Choe ZR. 1975. Studies on the breeding of azuki bean (*Phaseolus angularis* W. F. Wight) with a stable and high yielding capacity. I. Changes in heritabilities, genotypic and phenotypic correlations and path coefficients of each trait of

Phaseolus angularis cultivated under the different meteorological conditions (in Korean, English Summary). J. Gyeongsang Natl. Univ. 14: 171-176

Han T, Wu C, Mentreddy RS, Zhao J, Xu X, Gai J. 2005. Post-flowering photoperiod effects on reproductive development and agronomic traits of long-day and short-day crops. J. Agron. Crop Sci. 191: 255-262

Lawn RJ. 1979. Agronomic studies on *Vigna* spp. in south-eastern Queensland. I. Phenological response of cultivars to sowing date. Aust. J. Agr. Res. 30: 855-870

Nomura N. 1968. Genotypic and phenotypic correlation of azuki beans (*Phaseolus angularis* W. F. Wight) (in Japanese, English summary). Bull. Hokkaido Pref. Agric. Exp. Stn. 16: 114-120

Tomooka N, Vaughan DA, Moss H, Maxted N. 2002. The Asian *Vigna*: Genus *Vigna* Subgenus Ceratotropis Genetic Resources. Kluwer Academic Publishers, London. pp 270

Wang SM, Redden JR, Hu Jiapeng PJ, Desborough JP, Lawrence LP, Usher T. 2001. Chinese adzuki bean germplasm: 1. Evaluation of agronomic traits. Aust. J. Agr. Res. 52: 671-681

Zhang YZ. 2004. A study on the correlations between azuki bean yield and main agronomic characteristics. Heilongjiang Agric. J. 4: 32-38

Zong XX, Kaga A, Tomooka N, Wang WX, Han OK, Vaughan D. 2003. The genetic diversity of the *Vigna angularis* complex in Asia. Genome 46: 647-658