CSIRO Publishing

Australian Journal of Agricultural Research

VOLUME 52, 2001

A journal for the publication of original contributions towards the understanding of an agricultural system

All enquiries and manuscripts should be directed to:

Australian Journal of Agricultural Research
CSIRO Publishing
PO Box 1139 (150 Oxford St)
Collingwood, Vic. 3066, Australia

Telephone: +61 3 9662 7628
Fax: +61 3 9662 7611
Email: ajar@publish.csiro.au

CSIRO PUBLISHING

Published by CSIRO Publishing
for CSIRO and the Australian Academy of Science

www.publish.csiro.au/journals/ajar

Aust. J. Agric. Res., 2001, **52**, 671–681

Chinese adzuki bean germplasm: 1. Evaluation of agronomic traits

S. M. Wang[A], *R. J. Redden*[B], *J. P. Hu Jiapeng*[A], *P. J. Desborough*[C], *P. L. Lawrence*[D], *and T. Usher*[E]

[A]Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Science, Beijing, China.
[B]Department of Primary Industries, Dalby, Qld 4405, Australia.
[C]New South Wales Agriculture, Grafton, NSW 2460, Australia.
[D]Australian Tropical Crops Genetic Resource Centre, DPI, Biloela, Qld 4715, Australia.
[E]Hermitage Research Station, DPI, Warwick, Qld 4370, Australia.

Abstract. A core collection of adzuki beans, representing the germplasm of Chinese land races, was screened at Warwick Australia in a replicated yield trial sown mid-summer. Grain yield, yield components, phenologic traits, vegetative characteristics, and morphologic descriptors were recorded for all accessions plus Japanese-derived check varieties.

Accessions from southern China were later flowering, had smaller seed, and grew taller than those from central China. Grain yield was greatest for accessions from central China, whereas both north Chinese and Japanese check accessions were generally low yielding.

The evaluation of diversity displayed trends associated with latitude of germplasm origin, which were positive or negative according to the trait. Similarly, the germplasm diversity in duration of crop growth phases and in rate of yield expression was also associated with latitude of landrace origin.

Localised variations from these trends were found for seed size and for number of pods per plant. Various trends with latitude of origin were found for natural incidence of powdery mildew, for growth habit, plant height, vining and leaf colour. However, traits not associated with latitude of germplasm origin included primary and secondary seed colour, mature pod colour, and degree of branching.

The evaluation suggests that selections from this greater range of genetic diversity may allow higher yielding varieties than the current Japanese-derived standards to be developed for Australia.

Additional keywords: yield, agronomy, morphology.

Introduction

Adzuki bean (*Vigna angularis*) is mainly cultivated in northern and central China, Korea, and Japan (Lumpkin and McClary 1994), and cultivation extends through southern Asia to India. The probable wild progenitor species occurs at low frequency throughout the cultivated zone, sometimes in association with weedy types (Lumpkin and McClary 1994). The question of the centre of origin of adzuki bean has not been resolved; most studies include China but a wider geographic base has also been suggested (Lumpkin and McClary 1994).

Documentation of genetic diversity is most complete for accessions from Japan, which appear to have low genetic differentiation among cultivars, and low polymorphism on RAPD analyses with wild forms of *V. angularis* (Kaga *et al.* 1996). In a study of accessions from a wider geographic range, Yee *et al.* (1999) found with RAPD and AFLP markers a higher level of molecular genetic variation particularly amongst the 5 accessions from China, whereas germplasm from Japan, Korea, and the Philippines was more uniform. With less application of plant breeding in China it likely that local varieties reflect ancestral landraces and may indicate at least part of the crop evolution through association of patterns of diversity with putative origins (Villand *et al.* 1998; Yee *et al.* 1999). No association with origin was revealed by cluster analyses in the above study of Yee *et al.* (1999).

The gene bank for Chinese adzuki beans, at the Institute of Crop Germplasm Resources in the Chinese Academy of Agricultural Sciences, Beijing, has 3993 accessions from all sources but predominantly of landraces directly collected from farms in 24 provinces from north to south China,

 10.1071/AR00104 0004-9409/01/060671

representing the known geographic and morphologic diversity in cultivation. These were evaluated for morphologic traits mainly in respective provinces prior to entry into the gene bank (J. Hu pers. comm. 1996). They contained a wide diversity in seed size from 6 to 16 g/100 seed; seed colour from predominantly red to white, green, black, and speckled; and a broad differentiation in maturity with accessions from south China short-day responsive, but insensitive from north China (Hu 1984).

Core collections formed by stratified sampling of germplasm of known origin by geographic, agro-ecologic, and morphologic diversity were proposed by Frankel (1984) for efficient and intensive evaluation of genetic resources. This procedure has been applied for the characterisation of diversity in a range of crops, and verified as a technique to truly represent the full collection (Skroch *et al.* 1998; Villand *et al.* 1998).

This study reports on evaluation of the Chinese adzuki core collection in Australia for agronomic and morphologic traits. Wang *et al.* (2001) has provided a characterisation of this core collection evaluated in China. The intention in this paper is to broadly characterise the extent and patterns of genetic diversity in adzuki beans from China, and to investigate whether broad associations with geographic origin are present.

Methods

A core germplasm of 231 entries (5.9%) from a germplasm collection of 3908 landraces in China was grown by The Institute of Crop Germplasm Resources (Beijing) in China, to represent geographic diversity of origin plus random choice within each province (Table 1, Fig. 1).

A subset of this core collection was screened for agronomic traits in Australia, at Hermitage Research Station, Warwick (28°10′S, 152°02′E, altitude 480 m), which is within the latitude range of adzuki beans in southern China.

The trial was sown on 29 December 1998, with the trial flowering and maturing into shortening days, ensuring that known short-day responsive entries from southern China would have some opportunity to set seed. Other evaluations in Australia of phenologic responses to temperature and to photoperiod treatments will be described in subsequent papers.

Seed of the core collection destined for Australia was first increased in China both in glasshouses and in an insect-proof screenhouse for production of virus-free seed. About 17% of the full core set failed to produce sufficient seed in China. Then, due to seed supply difficulties for some entries either during or after a generation in Australian quarantine, 63 entries of the received core collection were missing from the trial at Hermitage Research Station. These 63 accessions were derived from south to north Chinese provinces as: Guizhou 2, Hubei 3, Henan 4, Jiangsu 7, Shaanxi 1, Shandong 7, Shanxi 10, Beijing 7, Liaoning 5, Jilin 5, Heilongjiang 12.

In the Australian evaluation trial the numbers of accessions by provinces from south to north are provided in Table 1.

Table 1. Provincial representation of Chinese core collection in Australia and China (number of accessions)

Province	Mean latitude	Whole collection	Full-core collection	Australia, core collection by province	China, core collection over 5 sites by province
Heilongjiang	46	258	23	5	14
Jilin	43	253	23	12	23
Neimengguo	42.5	84	5	5	4
Liaoning	41	150	17	9	8
Tianjin	40	39	8	7	1
Beijing	39.5	141	8	7	7
Hebei	39	385	33	25	48
Shanxi	37	600	66	30	47
Shandong	36	225	18	14	17
Henan	34.5	371	28	24	28
Shaanxi	34.2	322	29	28	13
Gansu	34	62	4	3	0
Anhui	33.9	207	8	8	6
Jiangsu	33	86	6	5	2
Sichuan	31	22	4	4	2
Hubei	30.5	416	24	20	9
Hunan	29	56	4	4	0
Guizhou	26.5	135	8	6	1
Yunnan	24	67	6	6	2
Guangxi	23	8	0	0	0
Hainan	19	1	0	0	0
Ningxia	37.5	17	0	0	0
Taiwan	23.5	3	0	0	0
Total		3908	314	215	231

Fig. 1 Map of China: locations of provinces, autonomous regions, and municipalities.

From Australian sources, 6 more entries were included: the local Japanese-derived Bloodwood check (Desborough 1980), the Japanese varieties Erimo and Chagarawase (Lumpkin and McClary 1994), VA 5015 from Asian Vegetable Crops Research Centre in Taiwan, and a Japanese-derived accession from the Northern Territory, Australia (NT 5313), and another from Argentina. One additional entry, Ding Kiang, had been collected in Shanxi before project initiation. The northern Chinese provinces of Liaoning, Jilin, and especially Heilongjiang were disproportionately affected by missing entries, and this core germplasm evaluation underrepresents the diversity from these provinces (Table 1). To some extent, this gap in representation from latitudes 42°–50°N is compensated by additional entries of Japanese origin, despite potential differences in evolution under human and natural selection.

Experimental design

The trial was designed as a 3 replicate randomised complete block, with each plot consisting of 2 rows 35 cm apart and 5 m length, with 70-cm lateral spacing between plots, and a 1-m path between plot ends. At least 2 guard plots of Japanese varieties were sown along the sides of each block and across the ends of each field. Each replicate had 8 ranges of 28 plots.

Two replicates were sown sequentially in one field, and the third in an adjacent field, both with soil type Elphinstone clay (McKeown 1978) and fertilised with 200 kg/ha of urea. Each block was laid out for subsurface drip irrigation using tape at depth 30 cm and 1 m apart, across the direction of sowing.

Due to high rainfall, irrigation was limited to site pre-irrigation, and 2 applications during the trial.

Total rainfall in the trial was 220 mm, plus 138 mm of irrigation. Mean monthly maximum/minimum temperatures for the trial were: January 28.2°C/16.3°C, February 27.3°C/16.2°C, March 26.4°C/15.3°C, April 23.4°C/9.7°C, with harvest over the period 23 March–9 April.

A sowing rate of 525 000 seeds/ha was used with a standard plot planter, for a target plant population of 500 000/ha.

Herbicides trifluralin and fluazifop-p, and insecticides thiodcarb, deltamethrin, and diazinon were applied following standard procedures.

Data collection

Data were collected on whole-plot ratings, except for plant height (HGT) including height of canopy (CHT) and length of vine or twining stem (LVIN) measured on 10 sampled plants/plot, 1-m-length plot subsections for population counts pre-flowering and at harvest, and for the counts of mature pod numbers (PDNO) that were recorded for Replicates 1 and 2 only and converted to millions of pods per hectare (MP/H). The traits directly recorded and the derived traits are listed with their abbreviations in Table 3.

Phenological development was measured as DFF (days from planting to 50% of plants with at least one flower), DFM (days from planting to 50% of plants with at least one mature pod), and MAT (days from planting to 90% of pods mature in a plot).

Other directly recorded traits included: branching (BR: 1, 0–2; 2, 3–4; 3, >5 branches); leaf colour (LFC: 1, yellow-green; 2, normal; 3, dark green); growth habit (GH: 1, determinate; 2, semi-determinate; 3, indeterminate); primary seed colour (PRIMC: 1, white/off white; 2, buff; 3, tan; 4, orange; 5, pink; 6, red; 7, green; 8, brown; 9, blue; 10, black); secondary seed colour pattern (1, none; 2, splashed; 3, mottled; 4, flecked); pod colour at maturity (PDC: 1, yellow-white; 2, brown; 3, black); powdery mildew (*Erysiphe ploygone* D.C.) rated on a plot basis for level of infection from 1, none, to 9, severe; 100-seed weight; and grain yield.

Grain yield (YLD) data were based on machine-threshed hand-harvested plots cut with secateurs, including split seed after oven drying at 35° for 48 h and undersized graded seed. Seed size (CSW) was based on 2 estimates per plot of 100-seed weight of graded whole seeds.

Derived traits were estimated: reproductive duration (RD = MAT–DFF, time from first flowering to maturity); duration of seed fill (SD = DFM–DFF, time from first flowering to first mature pod); synchronous maturity (SM = MAT–DFM, difference from first to full maturity); rate of grain fill (RGF = yield/RD); and rate of grain yield (RGY = yield/days to full maturity).

Other derived traits were number of seed/pod (estimated from (yield/CSW)/MP/H), pods per plant (P/PL = PDNO/population at maturity), and millions of seed/ha (MSPH = (YLD/CSW)*10^6).

All plots were harvested. A few in Replicate 3 with uneven establishment were reduced to half-lengths of effective plots.

Analyses

Standard analyses of variance were used for each direct and derived trait, as well as the GENSTAT package (GENSTAT 5 Committee 1993). There were 4 missing values estimated for yield and flowering and 10 for maturity. Genwin plot functions were used to graph trends in relation to latitude of origin.

Results

The mean establishment pre-flowering was 422 000 plants/ha, which was 84% of the target population with no significant differences amongst entries at the first sampling at flowering, and for only a few accessions (B0715 Liaoning, B2678 Jiangsu, B2268 Henan, and B0425 Shanxi) were there significantly lower populations at harvest.

Trait distribution

The results (Table 2) provided high levels of discrimination with coefficient of variation below 20% and expression of wide genetic diversity for most traits, the exceptions being for synchronous maturity (24%), branching (20.2%), pods/plant (29.9%), and powdery mildew (30%). The large differences amongst replicates for all traits except flowering time and seed colours/patterns were due to the poorer establishment and growth in Replicate 3. The percentage of seed fragments in relation to yield was only 2.3%; it was not considered further and only the graded yield estimate was used.The mean yield was 2060 kg/ha, with a range of 2266 kg/ha.

Table 2. Adzuki bean germplasm trial, Hermitage 1999, summary of data on directly recorded and derived traits

Trait	Mean	Range	Coefficient of variation (%)	l.s.d. (P = 0.05)
Yield (kg/ha)	2060	2954–688	14.1	469
100-seed weight (g)	10.1	16.1–4.0	8.5	1.4
Days to 50% first flower	47	67–38	1.2	0.94
Days to 50% first mature pod	82	100–65	3.6	4.8
Days to 90% maturity	94	114–78	2	3.0
Days to seed development	34.8	43–27	8.5	4.8
Synchronous maturity (days)	23.9	27–5	24	4.6
Reproductive duration (days)	46.7	57–36	4.2	3.2
Rate of grain fill (kg/day)	46.2	74–15	13.6	10.3
Rate of grain yield (kg/day)	22.5	33–10	13.8	5.1
Millions of seed/ha	23.6	58–6	17	6.5
Pods/plant	10.0	26.8–3.5	29.9	5.9
Pods/ha (millions)	4.5	7.8–2.1	19.5	1.7
Powdery mildew	3.6	9–1	30	1.8
Leaf colour	2.1	3–1	13.7	0.5
Pod colour	1.5	3–1	15	0.4
Growth habit	1.8	3–1	19.2	0.6
Branching	2.6	3–1	20.2	0.8
Canopy height (cm)	42	65–18	10.3	7.0
Total height (cm)	47	80–18	1.4	8.6
Length vine (cm)	4.7	38–0	4.8	3.6

The highest yielding accession was B2172 from Anhui at 2.95 t/ha, and 3 more accessions exceeded 2.8 t/ha with 2 of these, B2180 and B2158, also from Anhui, and one, B2760, from Henan Province. The check varieties were lower yielding at 1.64 t/ha for Erimo, and 1.6 t/ha for Bloodwood. Among the upper 10% for yield were 5 from Anhui, 2 from Henan, 5 from Hubei, 3 from Jiangsu, 1 from Guizhou, 1 from Shanxi, 2 from Shaanxi, and 1 from Yunnan province, predominantly from southern and middle China (Fig. 1). The respective yields of Erimo, Bloodwood, VA5015, and Chagarawase were (t/ha):1.64, 1.60, 1.51, and 1.30.

Ranges in expression for key quantitative traits were, as a percentage of the trial mean, 79% for flowering, 80% for first maturity, 43% for full maturity, 176% for synchronous maturity, 144% for pods/ha, 218% for seed number/ha, 118% for 100-seed weight, and 111% for total height.

Very little lodging occurred, only 9 accessions exceeding minor lodging levels up to 20%, and only 4 from central and southern China showed moderate lodging of 40–50%.

For qualitative traits, branching, growth habit, and colours of leaves, pods, and seed, the full range was present (Table 2), but skewed to pale leaf colour, indeterminate habit, high level of branching, pale pod colour, red seed colour, and absence of powdery mildew.

The distribution of primary seed colour in Chinese accessions was: red 48.6%, tan 31.5%, green 8.1%, buff 5.4%, orange-brown 5%, white 1%, and blue 0.4%. Secondary seed colour was observed in 18 accessions, with 15 having black flecks on a tan primary colour, and 3 with a light or dark red splash on a tan or brown primary colour.

Correlations amongst yield and yield components, and their regressions with latitude of origin for the core germplasm

Since it was already known from seed production of the core collection in China that accessions from the south were phenologically responsive to short days, traits were plotted against the latitude of origin for each accession (Fig. 2). A general polynomial trend (R^2 = 0.49) occurred of yield declining with increase in latitude of origin north of Anhui. Accessions originating south of Anhui and Jiangsu were also lower yielding. Superior yields in Australia at latitude 28° were expressed by accessions from middle China, for a mid-summer date of sowing. Correlations with yield (Table 3) were highly significant for number of seed/ha (MSPH) (0.76) but slightly negative for CSW (–0.17). The importance of MSPH was also reflected in correlations with RGF (0.77) and RGY (0.77). Respective correlations of the RGF and RGY of 0.94 and 0.98 with grain yield were also mirrored in similar negative polynomial response trends with latitude. The trends for north Chinese accessions were consistent with the Japanese-derived varieties.

Other correlations with yield were found of 0.22 with GH, 0.24 for total height including vine, and 0.21 with length of vine, all demonstrating a partial association of grain yield with indeterminate habit in the trial conditions at Hermitage Research Station.

Plots of seed weight against latitude of origin (Fig. 2), showed a strong positive association (R^2 = 0.41) of seed size with increasing latitude, a general reverse of the yield trend. Accessions from Jiangsu (lat. 32–33°) compared well for large seed with the northern provinces and were a major exception to this trend. The largest seeds (14.9–16.1 g/100 seed) were associated with Beijing, Liaoning, and Tianjin origins (lat. 39–43°). The checks Erimo and Bloodwood had 100-seed weights of 14.2 and 14.0 g.

Seed number per ha as the alternative yield component showed a stronger (R^2 = 0.55) and more consistent trend than yield to be negatively associated with latitude (Fig. 2). Highest seed number/ha was found in Hubei province (lat. 29–33°), but was lower than expected for accessions from Jiangsu (lat. 24–30°) on a negative linear trend of 15 million seed/ha. Yunnan (lat. 23–28°) was highly variable with a wide separation between maximum and minimum values. Entries from Hubei and Shaanxi (lat. 32–38°) were similarly highly variable for yield and its components.

A less pronounced but clear polynomial trend was found for pods/ha to also decline as latitude increased. The highest values for pods/ha were found in accessions from Shaanxi, Henan, Hebei, Yunnan, Guizhou, Hunan, and Anhui provinces. Consistent with its low seed number/ha, Jiangsu accessions also had fewer pods/ha than other southern provinces. A mild negative association of pods/plant with latitude was found (Fig. 2). However, accessions B1555 from Shaanxi and B2916 from Henan displayed exceptionally high pod set per plant. Of these, only B1555 was above average in yield at 2.3 t/ha, but B2916 was low yielding at 1.57 t/ha as a result of a very low seed weight of 4.9 g/100 seed.

The correlation of seed weight with seed number/ha was highly negative at –0.64. Other correlations of seed weight were 0.18 with maturity, 0.21 with pod colour, –0.22 with rate of grain fill, and –0.20 with rate of grain yield (Table 3). Seed weight was not correlated with SD, but weakly correlated at 0.17 with RD.

Seed number per ha had weak positive correlations of 0.19 with GH, 0.18 with total plant height, and 0.16 with vining, indicating a positive association with indeterminate habit.

Correlations and responses with latitude of origin for phenology traits

Days to flower had a marked and consistent negative trend with increasing latitude (R^2 = 0.72, Fig. 2). Mean days to flower were 64.5 at Guizhou and 38.8 at Heilongjiang, or 1.3 days earlier for each degree increase in latitude of origin. But south of Guizhou, accessions from Yunnan were 5 days earlier for 2–3° reduction in latitude. The checks Erimo and

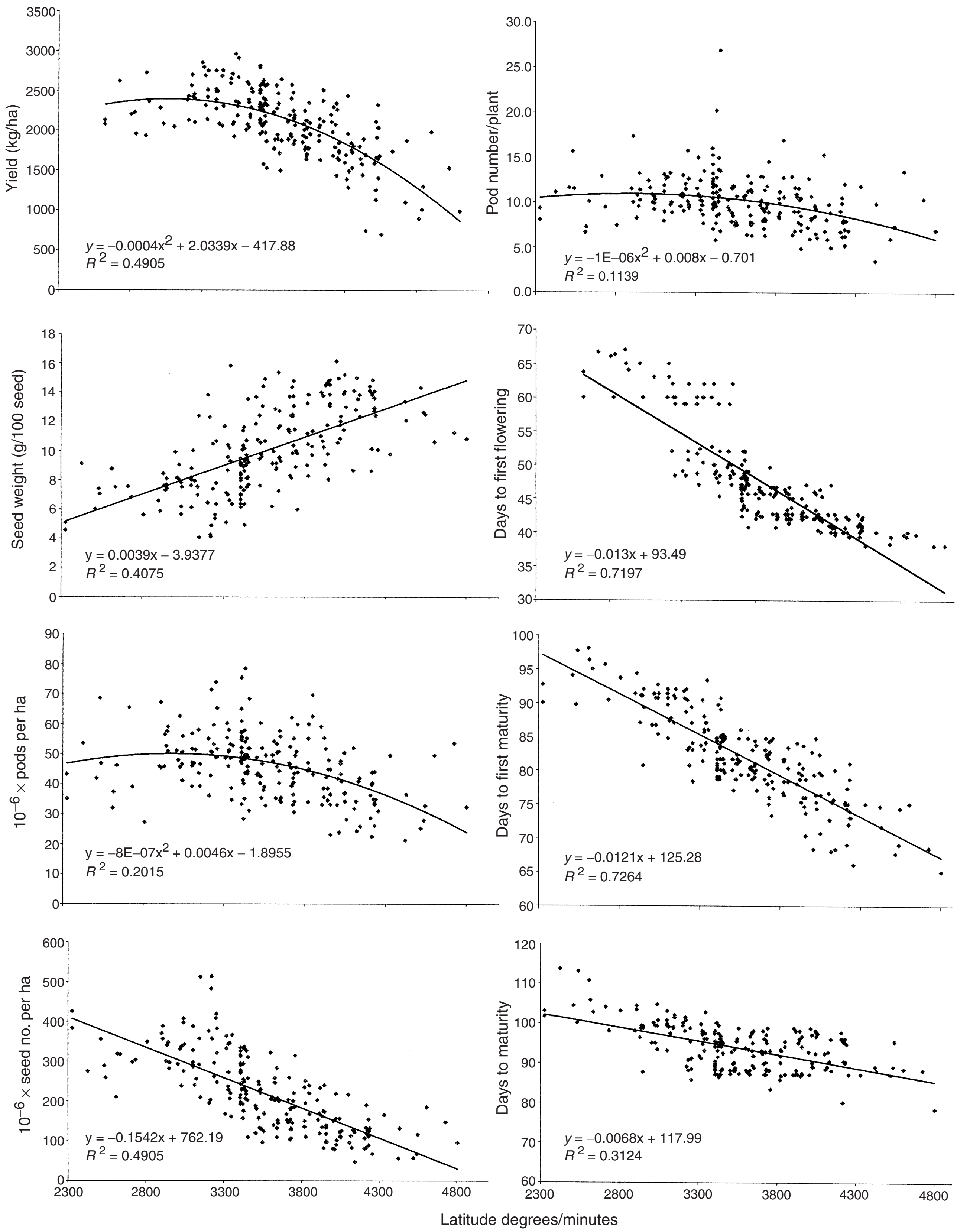

Fig. 2. Core germplasm traits plotted against latitude of origin of accessions.

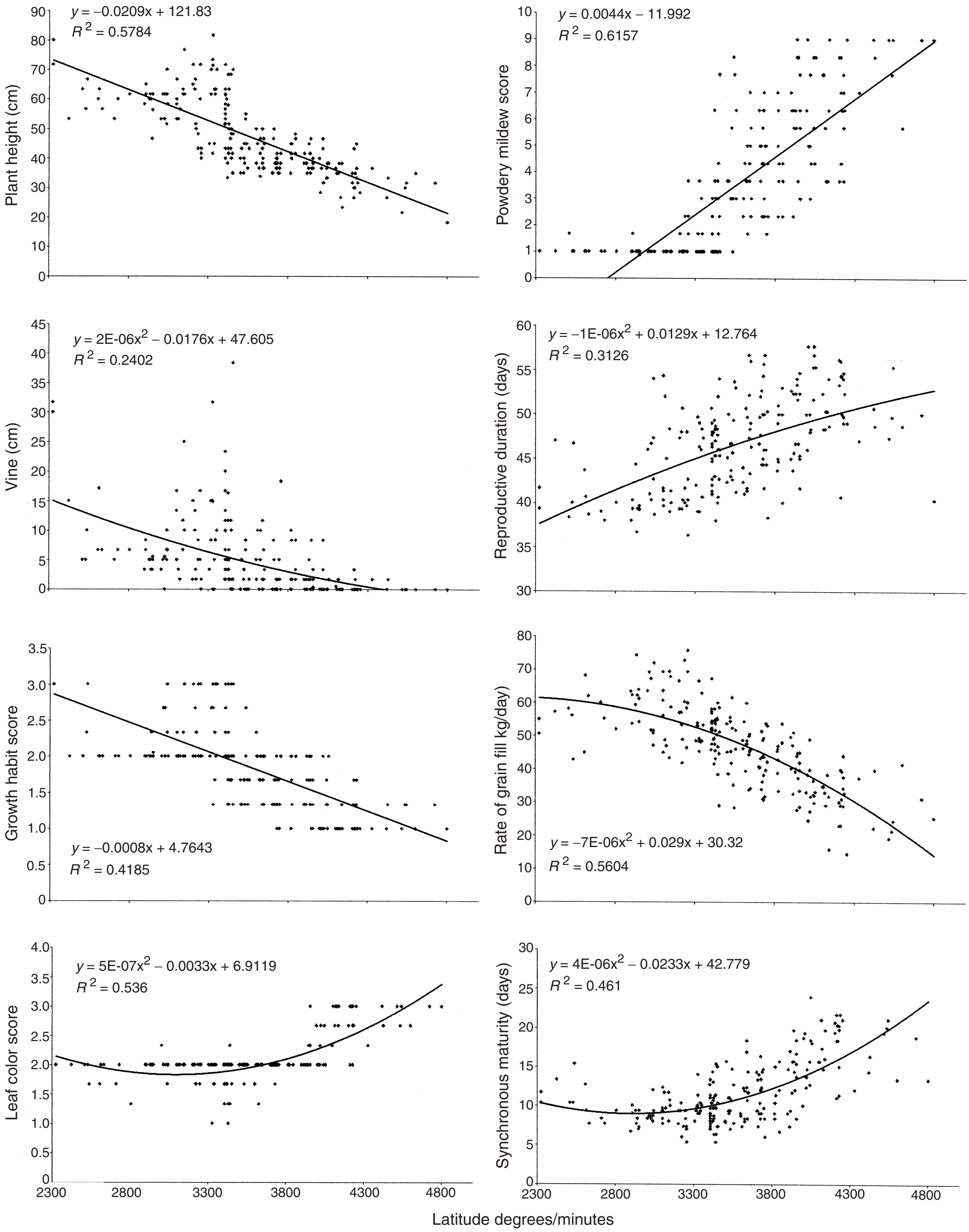

Fig. 2. (continued)

Table 3. Correlations amongst traits evaluated in the adzuki core germplasm

Bold numbers are significant at $P = 0.05$. REP, replicates; DFF, days to 50% first flower; PM, powdery mildew; LFC, leaf colour; DFM, days from planting to 50% first mature pod; MAT, days from planting to 90% mature pods; GH, growth habit; PDC, pod colour; BR, branching; CHT, canopy height (cm); HGT, plant height (cm); CSW, 100-seed wt (g);. PRIMC, primary seed colour; YLD, yield (kg/ha); SD, seed development period; SM, synchronous maturity; RD, reproductive duration; RGF, rate of grain fill; RGY, rate of grain yield; LVIN, length of vines; S#P, seed no. per pod; P/PL, pods per plant; MSPH, millions of seed per ha.; MP/H, millions of pods per ha

Multivariance

	YLD	DFF	PM	LFC	DFM	MAT	GH	PDC	BR	CHT	HGT	CSW	PRIMC	SD	SM	RD	RGF	RGY	LVIN	MSPH
YLD	1																			
DFF	0.02	1																		
PM	0.01	0.03	1																	
LFC	-0.06	0.03	-0.05	1																
DFM	0.09	0.19	-0.13	-0.06	1															
MAT	0.05	0	-0.08	0.01	**0.35**	1														
GH	**0.22**	-0	-0.05	-0.03	-0.02	0.08	1													
PDC	-0.13	0.04	-0.04	0.01	0.16	0.14	-0.14	1												
BR	0.02	0.07	0.02	0.06	0.03	0.01	-0.01	-0.12	1											
CHT	0.06	0	-0.13	-0.06	0.15	0.09	0.18	0.04	0.03	1										
HGT	**0.24**	0.06	-0.15	-0.06	**0.20**	0.16	**0.22**	0.04	0.01	**0.51**	1									
CSW	-0.17	0.01	0.14	0.04	0.10	0.18	-0.10	**0.21**	0.00	-0.06	-0.08	1								
PRIMC	0.09	0.04	0.03	0.06	-0.03	0.00	0.11	0.04	0.06	-0.03	-0.02	0.01	1							
SD	0.08	-0.01	-0.14	-0.07	**0.98**	**0.36**	-0.02	0.15	0.01	0.15	0.19	0.09	-0.04	1						
SM	-0.06	-0.19	0.07	0.07	**-0.79**	**0.30**	0.07	-0.07	-0.02	-0.09	-0.10	0.02	0.03	**-0.76**	1					
RD	0.04	**-0.29**	-0.09	0.00	**0.28**	**0.96**	0.08	0.12	-0.01	0.09	0.14	0.17	-0.01	**0.34**	**0.34**	1				
RGF	**0.94**	0.1	0.03	-0.05	0.00	**-0.23**	0.18	-0.15	0.02	0.02	0.19	**-0.22**	0.09	-0.02	-0.15	-0.25	1			
RGY	**0.98**	0.02	0.02	-0.06	0.03	-0.10	**0.21**	-0.16	0.02	0.04	**0.21**	**-0.20**	0.09	0.03	-0.10	-0.10	**0.98**	1		
LVIN	**0.21**	0.07	-0.05	-0.02	0.09	0.10	0.08	0.00	-0.01	**-0.32**	**0.65**	-0.03	0.01	0.08	-0.02	0.08	0.19	**0.20**	1	
MSPH	**0.76**	0.03	-0.06	-0.04	0.04	-0.05	0.19	-0.14	0.01	0.04	0.18	**-0.64**	0.08	0.04	-0.08	-0.06	0.77	**0.77**	0.16	1

REP[A]

	YLD	P/PL	MP/H	MSPH	S#P
YLD	1				
P/PL	**0.24**	1			
MP/H	**0.29**	**0.72**	1		
MSPH	**0.71**	0.18	**0.22**	1	
S#P	**0.33**	**-0.37**	**-0.60**	-0.01	1

[A]P.PL and MP/H measured on 2 out of 3 replicates; all other traits based on 3 replicates.

Bloodwood were early flowering at 40 and 41 days, respectively, typical for northern Chinese accessions, and were also similar for other phenologic expressions.

The negative response of days to first maturity (Fig. 2) with increasing latitude (R^2 = 0.73) closely mirrored the response of days to flower, also with 25 days difference in means between Guizhou and Heilongjiang. However, these provinces differed by only 16.7 days for full maturity, which had a weaker negative association with latitude (R^2 = 0.46, Fig. 2). Full maturity had a positive correlation of 0.35 with first maturity, a very high correlation of 0.96 with reproductive duration, 0.36 with seed duration, 0.30 with synchronous maturity, but –0.23 with rate of grain fill.

The SM, with a distribution strongly skewed to low values, had large negative correlations of –0.79 with DFM and –0.76 with SD, but neutral with vining. SM was positively associated with latitude (R^2 = 0.46), but exceptions included the accession from Tianjin, which had the largest seed size. Thus the more synchronous maturation or lower values were associated with southern China.

The RD was positively associated with increase in latitude of origin (R^2 = 0.31), despite northern Chinese accessions being earlier to flower and to mature, a result of the weaker association with latitude, shown by maturity rather than by days to flower. This RD response was associated with the seed weight response to latitude (R^2 = 0.17). Reproductive duration was also positively (0.34) correlated with seed development, 0.34 with synchronous maturity, but had a negative (–0.25) correlation with rate of grain fill. SD, being derived from DFM, was highly correlated with RD at R^2 = 0.98, and with MAT at R^2 = 0.36. However, unlike RD, the relationship of SD with latitude was polynomial with a peak in middle China.

Correlation and responses with latitude of origin for growth, colour, and disease traits

Total height including the vine was positively correlated with yield, RGF, RGY, seed number/ha, and especially with vining with a correlation of 0.65. Both total height and canopy height were negatively associated with latitude of origin (Fig. 2). Taller and indeterminate accessions were associated with southern China. Total height and canopy height had a strong correlation of 0.51.

The only disease prevalent at Hermitage was powdery mildew, which was positively associated with latitude, mainly infecting northern Chinese accessions. All accessions from Heilongjiang had maximum susceptibility, whereas southern Chinese accessions were mostly resistant.

Growth habit was indeterminate in accessions from southern China, and determinate in those from the north. It was positively correlated with yield (0.22), plant height (0.22), and rate of grain yield (0.21), and approached significance (0.2) in correlations with rate of grain fill (0.18) and seed number/ha (0.19).

No trends with latitude or origin occurred for seed colour and pattern, and pod colour. Darker leaves (2–3 rating) were found in northern China, plus B2958 from Hubei. In central and southern provinces, leaf colour was mainly standard (2 rating) or with light colours also found in central China.

Darker pod colour was associated with larger seed (0.21 correlation), but weakly negative or paler with yield (–0.13) and with seed number/ha (–0.14). No correlations with other traits were observed with leaf colour, primary seed colour, or branching.

Geographic origin

Accessions from southern China generally had late flowering and late maturity, superior yield, small seed, large seed number/ha, many pods/plant, tall height, indeterminate habit, short reproductive duration, resistance to powdery mildew, and synchronous maturity.

From northern China, accessions generally had early flowering and maturity, low yield, large seed, few seed/ha and few pods/plant, short height, determinate habit, long reproductive period, susceptibility to powdery mildew, and dark green leaves. From central China accessions displayed intermediate expressions. The Japanese-derived varieties closely mirrored the growth characteristics of the north Chinese accessions. No clear trends with latitude occurred for pod colour or for seed colour.

Yield expression in Warwick, Australia, was mainly associated with seed number/ha. Days to first maturity were highly positively associated with duration of seed fill, but negatively associated with synchronous maturity. Yield was also positively associated with indeterminate habit, increased height, and vining.

Discussion

These results demonstrate a definite association of Chinese adzuki germplasm diversity with putative geographic origin, for most of the observed traits. This finding indicates a much wider genetic diversity amongst Chinese landraces than in previous studies with mainly Japanese germplasm resources (Yee *et al.* 1999). This supports previous suggestions that China is the centre of origin for adzuki beans (Tasaki 1963; Lumpkin and McClary 1994). If Japanese germplasm was mainly derived from northern China it could be expected to be much narrower in diversity. The Japanese-derived varieties in this study displayed the relatively narrow diversity of the northern Chinese accessions, as well as phenotypic similarity.

There are an additional 45 accessions mainly from northern China that are yet to be evaluated. It is planned to evaluate these along with a representative range of the current germplasm to provide integration of the two data sets. This will add to the characterisation of northern Chinese accessions and further comparison with Japanese accessions.

The Chinese core germplasm is representative of local traditional landraces still existing at the time of collection in the 1970s. Possibly the key locally evolved traits that had a major role in the observed geographic differentiation were phenologic responses to short photoperiod and to temperature. With a mid-summer planting in Australia, flowering was approached with days shortening from late January to late March for a first flower appearance range from 38 days to 68 days, although the critical photoperiod response may occur with development of flowering primordia at 18–23 days before anthesis (Duan 1989). Expression of time to flowering, with a highly negative correlation with latitude of origin, was in agreement with previous findings of early maturing accessions, mainly from high latitudes, being insensitive to photoperiod (Tasaki 1963). Negative linear responses to latitude of origin were also shown by time to first mature pods and to full maturity, but with reductions in rate of response at full physiological maturity.

These phenologic responses resulted in a shorter growing season for the early maturing accessions from northern China. In a non-limiting situation with near optimal temperatures the resultant outcome was associated reductions in both vegetative and reproductive growth, reduced canopy and total heights, reduced vining, a more determinate habit, and a reduction in pods/ha. Thus daylength insensitivity with optimal growth temperatures near 24°C (Duan 1989) resulted in less vegetative development and fewer nodes to bear inflorescent racemes, leading to relatively low yields. Conversely, accessions from southern China had the largest bushes and, in a more complex curvilinear response, shared the greatest yields with accessions from middle China.

Yield expression was influenced by the response of seed weight to increasing latitude of origin. Because flowering was more negatively associated with latitude of origin than time to first maturity, seed development period was also associated positively with latitude and displayed a positive correlation of 0.98 with seed weight. Thus, seed size appears to be strongly influenced by the time period for seed growth and negatively by rate of grain fill. To achieve the desired commercial combination of high yield and large seed, the negative association between these traits needs to be overcome, although the low negative correlation indicates that sufficient genetic variation may be available. The mean row width of 52.5 cm may have disadvantaged the shorter, more determinate entries from northern latitudes, which performed relatively better in 17–30 cm rows (Redden *et al.* 2001).

Jiangsu, a coastal province near Shanghai, deviated from the trend with large seed in middle China, plus a generally high yield expression. This province in the very fertile Yangtze River delta may have had evolutionary selection for larger seed in an environment consistently conducive to full expression of seed size potential. Soybeans from this province also are noted for large seed size (J. Hu, pers. comm.). Correspondingly, this province deviated below the trend line for seed number per ha, further suggesting that persistent selection for large seed resulted in unique evolution in this province. Associated factors are the sweet cuisine of Jiangsu, favouring preparation of sweet dessert dishes of adzuki for which large seed size is prized, and a very high level of intensive crop management.

Anhui, with adzuki cultivation on the very fertile flood plain of the Yangtze River, especially the north bank, had mainly high-yielding accessions, but with moderate above-average deviations for both increased seed size and seed number/ha relative to regressions with latitude.

Within-province diversity was notable in southern and middle China. The exceptional high pod set per plant of B1555 from Shaanxi and B2966 from Henan, both provinces on the Yellow River, was consistent with expressions in respective provincial evaluations at the time of collection (J. Hu pers. comm., ICGR database). This indicates a useful source of genetic variation for this yield component.

The consistently largest seed were from Beijing, Tianjin (B1780), and Liaoning provinces. The Beijing–Tianjin region is supplied by the Ying Ding River with a very fertile delta; however, farmers prefer to sow mid-size seed rather than large, possibly for economies of plant population establishment per kg of seed.

The lower yielding, more determinate and earlier accessions from northern China were actually less synchronous in maturity with the mid-summer sowing in Australia, than accessions from southern China that also had a greater tendency to vine. This unexpected result appears to be due to a more uneven maturity amongst pods for northern China accessions, with reduced intra-plant competition at lower yield levels enabling small late pods to complete seed fill. For mechanical harvesting, a more synchronous maturity with fewer days per maturation period is desirable.

Vining, however, was <20 cm in all but a few accessions from Yunan, Shaanxi, Henan, and Jiangsu, a relatively low level of indeterminacy. But this result is associated with a mid-summer sowing and shortening days of the trial at Hermitage. A tendency to vine and to be indeterminate would be expected to be greater with a spring sowing. Hence, the results of this trial may be strongly predicated by sowing time, prevailing temperature, and photoperiod.

Incidence of powdery mildew was low, but became severe on northern Chinese accessions. Summer growing seasons are dry in northern but wet in southern China. Conditions more conducive to this disease in southern China may have resulted in evolution and selection for resistance, but absence of such selection in northern China may have resulted in absence of resistance.

Gummy pod was noted in only 2 accessions, one from Jilin and one from Heilongjiang, possibly indicating susceptibility to heat stress.

This trial had no incidence of virus, and provided estimates of yield without the constraint of viruses, which are endemic in China. Thus yield and agronomic potential were assessed largely independent of disease or biotic stresses.

Colour factors for pods and primary seed colour were largely independent of latitude of origin, although green seed was mainly from middle China. Both traits were uncorrelated with yield, agronomic or phenologic traits, and some high yielding accessions had green seed. But leaf colour, similarly uncorrelated with growth traits, displayed a pronounced trend for northern Chinese accessions to have darker leaves (higher scores). This may represent increased rate of photosynthesis (Ma *et al.* 1995), and possibly greater transpiration efficiency, which if true may be a useful adaptation trait for the generally drier growing conditions of northern China.

An exception to lack of trends with primary seed colour was secondary seed colour, which was more prevalent in northern China, in the Yellow River valley (Gansu, Shanxi), and north from Hebei with the exception of the Beijing–Tianjin region. Interestingly, multi-coloured *Phaseolus vulgaris* seed, red splash or mottle on a white background, is also prized in northern China (R. J. Redden, pers. comm.). Cultural factors therefore may be relevant to secondary seed colour expressions in adzuki bean.

In general, diverse germplasm expressions were found in colour, phenologic, morphologic, and yield traits. These expressions fitted a pattern of responses to latitude of origin for all except some colour traits. These results illustrate relationships between genetic diversity and geographic origin that add evidence for understanding the domestication and evolution of this crop (Villand *et al.* 1998; Yee *et al*. 1999).

These data will be further examined by cluster analyses and by results from Chinese evaluation sites in subsequent papers.

Owing to logistic difficulties of pure seed production for a core collection trial and the detailed data recording, only one full agronomic screening trial was feasible to identify selections for subsequent multi-location yield trials in 2000. However, the expressions of phenologic traits in the current study were consistent with those in companion studies of adzuki germplasm responses to temperature and photoperiod (P. L. Lawrence and P. J. Desborough, unpublished data).

Yield in the current study was measured with a nitrogen fertiliser input to avoid possible confounding with rhizobial strain specificity amongst the germplasm. However, nodulation in the core germplasm was assessed in the response to temperature screening at Grafton. No genotypic variation for nodulation was detected under conditions where the commercial adzuki strain was used at sowing as well as in the presence of an adapted local strain in the soil (P. J. Desborough, pers. obs.).

This study shows the importance of access to genetic diversity for the breeding of recently introduced crops. Although desirable quality traits such as seed size were negatively associated with yield, these correlations were not high. There is scope to select accessions (from Jiangsu) with high expression of both traits, and to breed for desirable combinations in yield, seed size, seed colour, and synchronous maturity. Although this study is specific to one screening trial at one location, it is possible that both Chinese and Japanese accessions may perform differently in yield, morphology, and seed characteristics at other sites. Verification trials of selected Chinese lines with high yield and large red seed are in progress from 2000 at 2 diverse Australian sites. These trials include Grafton where Redden *et al*. (2001) observed high yields of 3.1 t/ha for Bloodwood and 3.3 t/ha for Erimo.

The core germplasm is available from the Australian Tropical Crops Genetic Resource Centre, Biloela, Queensland.

Acknowledgment

The financial support of ACIAR is gratefully acknowledged.

References

Desborough PJ (1980) Adzuki bean cv. Bloodwood. *Journal Australian Institute Agricultural Science* **46** (4), 264.

Duan H (1989) Adzuki beans. In 'Edible bean crops'. (Eds J Long, L Lin, H Kushen, H Duan) pp. 160–171. (Scientific Publishing House: Beijing)

Frankel OH (1984) Genetic perspective of germplasm conservation In 'Genetic manipulation: impact on man and society'. (Eds W Arber *et al.*) pp. 161–170. (Cambridge University Press: Cambridge, England)

GENSTAT 5 Committee (1993) 'GENSTAT 5 reference manual.' (Clarendon Press: Oxford)

Hu JP (1984) Preliminary report on adzuki germplasm resources. *Crop Germplasm Resources* **1**, 21–25.

Kaga A, Tomooka N, Egasura Y, Hosaka K, Kamijimo O (1996) Species relationships in the subgenus *Ceratotropis* (genus *Vigna*) as revealed by RAPD analysis. *Euphytica* **88**, 17–24.

Lumpkin TA, McClary DC (1994) 'Azuki bean: botany, production and uses.' (CAB International: Wallingford,UK)

Ma BL, Morrison MJ, Voldeng HD (1995) Leaf greenness and photosynthetic rates in soybean. *Crop Science* **35**, 1411–1414.

McKeown FR (1978) 'A land classification of the Hermitage Research Station.' (DPI: Hermitage Research Station, Qld)

Redden RJ, Desborough P, Tompkins W, Usher T, Kelly A (2001) Growth responses of adzuki beans as affected by row spacing, plant population and variety. *Australian Journal of Experimental Agriculture* **41**, 235–243.

Skroch PW, Nienhuis J, Beebe S, Tohme J, Pedroza F (1998) Comparison of Mexican common bean (*Phaseolus vulgaris* L.) core and reserve collections. *Crop Science* **38**, 488–496.

Tasaki J (1963) Geneological studies in the azuki bean (*Phaseolus radiatus* L. var aurea, Prain) with special reference to the plant types used for classification of ecotypes. *Japanese Journal of Breeding* **13**, 32–44.

Villand J, Skroch PW, Lai T, Hanson P, Kao CG, Nienhuis J (1998) Genetic variation among tomato accessions from primary and secondary centres of diversity. 1988. *Crop Science* **38**, 1339–1347.

Wang S, Yongsheng C, Hu Jiapeng JP, Redden RJ, Islam FMA (2001) Establishment of the core collection of adzuki bean and preliminary study on diversity in China. *Journal of Plant Genetic Resources* (in press).

Yee E, Kidwell KK, Sills GR, Lumpkin TA (1999) Diversity among selected *Vigna angularis* (azuki) accessions on the basis of RAPD and AFLP markers. *Crop Science* **39**, 268–275.

Manuscript received 6 July 2000, accepted 7 February 2001