Trop. Agr. Develop. 52(4) : 89−96, 2008

Genotype-environment Interaction in Chickpea (*C. arietinum* L.) for Adaptation to Humid Temperate and Semi-arid Tropical Environments

Junichi KASHIWAGI[1*], L. KRISHNAMURTHY[1], Pooran M. GAUR[1], Teruhisa UMEZAKI[2], Shao-Hui ZHENG[3], Yuhi HIRAOKA[4], Takayoshi TERAUCHI[4] and Kazuto IWAMA[4]

[1] *International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, AP, India*
[2] *Mie University, Kurimachiyachou, Tsu, 514-8507, Japan*
[3] *Coastal Bioenvironment Center, Saga University, 152-1 Shonan-cho, Karatsu, 847-0021, Japan*
[4] *Hokkaido University, Kita-ku Kita9 Nishi9, Sapporo, 060-8589, Japan*

Abstract Eight chickpea genotypes were evaluated for seed yield and maturity time at three temperate locations in Japan and one semi-arid tropical location in India over a two-year period to obtain baseline information on chickpea adaptation to Japan. The average seed productivity under Japanese environments, except in the northern area with growth under cool and semi-humid climatic conditions and a longer photoperiod, was lower than that in the semi-arid tropical environment in India. The kabuli chickpeas, especially, ICCV 92311 and ICCV 92337, showed a higher productivity in northern Japan. For chickpea cultivation in Japan, it is recommended to adopt modified agronomic practices to reduce humidity in the crop canopy, for example, wider plant spacing, cultivation under rain shelter, and selection of genotypes with a high assimilate remobilization rate as well as resistance to higher humidity-promoted diseases. Growing chickpea crop in the northern part of Japan by adopting such agronomic practices and the right genotypes could be suitable. However, a larger number of studies should be carried out to analyse the various mechanisms that contribute to a better adaptation of chickpea to environments with a high soil moisture and humidity.
Key Words: Principal, Component, Analysis

Introduction

Chickpea (*Cicer arietinum* L.) is the second most important food legume in the world. In 2006, the total cultivated area covered 11.2 million ha with a seed yield production of 9.2 million tons in 2006 (FAOSTAT, 2007). Arid or semi-arid regions of the Indian subcontinent, West Asian and North African countries and countries of the Mediterranean basin account for more than 75% of the global chickpea production. The crop is mostly cultivated under rainfed conditions in these regions using residual soil water after the rainy season. Chickpeas do not grow well in the rainy season because of a high incidence of foliar diseases.

Chickpeas are classified into two major types, desi and kabuli, largely on the basis of color, shape and size of seed. The desi chickpeas display an angular shape as well as small and dark-colored seeds, while the kabuli types show an owl shape and large cream-colored seeds (Upadhyaya *et al.,* 2002). Irrespective of the seed type, chickpea seeds are consumed as one of the most important vegetarian vegetable protein sources in South Asia, accounting for more than 65% of the world production. The demand for chickpeas is potentially high due to the ever-increasing consciousness on the benefits of vegetable protein and food fiber content for human health. Chickpea contains 13 to 31% of protein, 32 to 57% of starch, 2 to 11% of sugar, 3 to 9% of fat and 4 to 13% of crude fiber (Wood and Grusak, 2007). In addition, it is an abundant source of calcium, magnesium, potassium, phosphorus, iron, zinc and manganese (Wood and Grusak, 2007). Compared to soybean, the isoflavone quantity in the chickpea seed is lower (USDA-ARS, 2004) and anti-nutritive components are very few (Wood and Grusak, 2007), while more beneficial carotenoids, e.g. β-carotene (Abbo *et al.,* 2005) can be provided. From the nutrition point of view, therefore, chickpea is considered to be a rich and functional food source (Agharkar, 1991; Charles *et al.,* 2002). Several cooking recipes have been developed in the Mediterranean basin, West Asian countries and Indian subcontinent, e.g., sprouts as salad, flour for confectionery, well-soaked seed as ingredient in curry, paste (Hummus in West Asia) and green immature seeds as raw eating snack (Jambunathan and Umaid, 1990). These well-developed cooking methods associ-

Received Jul. 17, 2007
Accepted Apr. 12, 2008
* Corresponding author
jkashi@res.agr.hokudai.ac.jp
Present address: *Graduate School of Agriculture, Hokkaido University, Kita 9 Nishi 9, Sapporo 060-8589, Japan*

ated with a high nutritive value may account for the increase in awareness and cultivation of chickpea in non-traditional countries, e.g. Australia, Canada, China and U.S.A.

In Japan, however, there is no information or statistical data available on chickpea cultivation compared to the semi-arid regions (Saxena, 1984; Krishnamurthy *et al.,* 1996; Kashiwagi *et al.,* 2006). On the other hand, there is a growing health awareness among Japanese consumers. It is, therefore, necessary to analyse the opportunities to introduce new health food crops, viz., chickpea to Japanese consumers. The main objective of the present study was to obtain some basic information about the adaptability of chickpea in Japan.

Materials and Methods

Eight chickpea genotypes (Table 1), were evaluated under field conditions during the post-rainy seasons of 2004-05 and 2005-06 at one location in southern India, and 3 different locations across Japan (northern, central and southern regions) during the early summer season of 2004 and 2005 (Table 2).

In southern India (SI), the experiments were carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (17° 30'N; 78° 16'E, altitude 549m) on a precision field in Vertisol. These Vertisols with a depth of more than 1.2m could retain about 190mm of plant-available water within the 1.2m soil profile. In both seasons, the field was ploughed before sowing and surface application and incorporation of 18kg N ha^{-1} and 20kg P ha^{-1} as diammonium phosphate were carried out. The seeds which treated with a 0.5% Benlate (E.I. Dupont India Ltd., Gurgaon, India) + Thiram (Sudhama Chemicals Pvt. Ltd., Gujarat, India) mixture in both seasons were, then, drilled at a 5cm depth in rows using a 4-cone planter on Oct 8, 2004 and Nov 3, 2005 at a planting density of 33.3 plants m^{-2}. Immediately after sowing, a rhizobium inoculation (strain IC 59) was supplied as a water suspension. Irrigation (20 mm) was applied on the next day after sowing through perforated pipes to ensure complete emergence with no further irrigation, and about 15 days after sowing (DAS), the plants were thinned to maintain a plant to plant spacing of 10cm with a 30cm row width. Intensive protection against pod borer (*Helicoverpa armigera*) was given and the fields were kept weed-free by manual weeding.

In northern Japan (NJ), the experiments were conducted on the precision fields in Alluvial soil (ca. 0.8 m soil depth) at Hokkaido University, Sapporo (43° 04'N; 141° 20'E; altitude ca. 18 m) in 2004. Field preparation was performed in a similar way to that at Patancheru, and surface application of fertilizer (60kg N ha^{-1}, 100kg P_2O_5 ha^{-1} and 50kg K_2O ha^{-1}) was made. The seeds were treated with a 0.5% Benlate + Thiram mixture, and then were sown manually at a depth of 2-3

Table 1 Origin and pedigree of the chickpea genotypes tested in the multilpcational trial

Genotype	Released country	Pedigree	Remarks
ICCV 2	Swetha (India) Wad Hamid (Sudan) Yezin 3 (Myanmar)	[(K 850 x GW 5/7) x P 458] x (L 550 x Gaumuchil)	Kabuli, Extra-early maturity
ICCV 92311	KAK 2 (India)	(ICCV 2 x Surutato 77) x ICC 7344	Kabuli
ICCV 92337	JGK 1 (India)	(ICCV 2 x Surutato 77) x ICC 7344	Kabuli
ICCV 95334	Not released	[(ICCV 2 x Surutato 77) x ICC 7344] x Blancho Lechozo	Kabuli
ICCV 10	Bharati (India) Barichhola 2 (Bangladesh)	P 1231 x P 1265	Desi
ICCV 88202	Sona (Australia) Yezin 4 (Myanmar) Pratap Chaual (India)	PRR 1 x ICCC 1	Desi
ICCV 92809	Myles (USA)	(BDN 9-3 x K 1184) x ICP 87440	Desi
ICCV 93954	JG 11 (India)	(Phule G-5 x Narsingpur Bold) x ICCC 37	Desi

Table 2 Enviromental conditions and seed yield of sites used for genotype-environment trials in 8 chickpea germplasm accessions

Trial site	Location/ year	Latitude and Longitude	Treatments	Rainfall (mm)		Cumulative temperature (°C)	Sowing date	Range of maturity (DAS)	Mean YLD (g m^{-2})	ARR (g m^{-2} day^{-1})
				Vegetative growth	Post-anthesis					
Southern India	SI-2004	17°, 30N	Rainfed conditions	27.5	4.1	2341.2	8-Oct	90.0-123.0	139.0	2.28
	SI-2005	78°, 16E		14.0	6.7	2219.4	3-Nov	90.0-125.0	171.8	2.75
Southern Japan	SJ-2004	33°, 35N 130°, 23E	Rainfed conditions	243.4	135.1	1892.7	26-May	71.0	63.1	1.68
	SJ-2005	33°, 26N 129°, 59E		202.4	52.6	1727.8	11-Mar	108.0	91.8	1.70
Central Japan	CJ-2004	34°, 44N	Rainfed conditions	187.5	62.6	1754.5	25-May	63.7-72.3	43.0	1.41
	CJ-2005	136°, 31E		87.1	141.1	2247.5	21-May	79.7-93.0	19.4	0.39
Northern Japan	NJ-2004	43°, 03N 141°, 20E	In greenhouse (rain shelter) cultivation	–	–	2341.1	12-May	118.0	299.3	2.60

DAS = days after sowing, YLD = seed yield, ARR =assimilate remobilization rate, – = fully protected from rainfall with rain shelters, Base temperature of chickpea growth = 0 °C

cm with a plant spacing of 10cm and row width of 30cm (33.3 plant m^{-2}) on May 12, 2004. Adequate irrigation was given to ensure proper and uniform germination. Once uniform germination had occurred, the entire experimental area was covered with a rain shelter on June 2. The rain shelter consisted of a vinyl house structure without side walls so that it could avoid rainfall effects and maintain a moderately cool-humid environment. The standard soybean cultivation practices adopted at Hokkaido University (for disease and weed control) were applied for healthy plant growth.

In central Japan (CJ), the experiments were carried out on the precision fields with sandy loam soil (1.2 m soil depth, holding 144 mm of plant-available water) at Mie University, Tsu (34° 44'N; 136° 31'E; altitude 1.5 m) in 2004 and 2005. The field was prepared in the same way as that at Patancheru, and surface application of fertilizer was made at the rates of 30 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}. The seeds were treated with a 0.5% Benlate + Thiram mixture, and then manually sown to maintain a uniform planting density of 33.3 plants m^{-2} (plant spacing of 10cm and row width of 30cm) on May 25, 2004 and May 21, 2005. Adequate surface irrigation was given to ensure proper and uniform germination. Field management, for healthy plant growth, followed the standard soybean cultivation practices applied at Mie University.

In southern Japan (SJ), the experiment was conducted at Kyushu University, Fukuoka, (33° 35'N; 130° 23'E; altitude ca. 6 m) on May 26, 2004, and at Saga University, Saga (33° 26'N; 129° 59'E; altitude ca. 80 m) on March 11, 2005. The fields consisted of Alluvial soil (ca. 0.3 m soil depth, holding ca. 45 mm of plant-available water). At both locations, the field was prepared in a similar way to that at Patancheru, and fertilized at the rates of 30 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}, and adequate irrigation was given to ensure proper and uniform germination. The field and crop managements, to maintain a healthy plant stand at the rate of 33.3 plants m^{-2} (plant spacing of 10cm and row width of 30cm), included the standard soybean cultivation practices applied at each of these Universities.

More N fertilizer was applied at all the locations in Japan, compared to SI, as the native rhizobium for chickpea was not expected to be available in Japanese soils. Thus, since the quantity of fertilizer per unit area was determined based on the recommendations for soybean cultivation at each location for proper growth, it varied among the locations.

At all the locations, 50% flowering time (defined as the day when at least 50% of the plants in a plot reached flowering) was recorded, and when 80% of the pods became dry, physiological maturity for each genotype was assumed. At physiological maturity, the plant aerial parts were harvested in each plot. The harvested plants were dried to a constant weight in hot air dryers at 45°C, and then the seed weight was recorded after threshing. The assimilate remobilization rate was computed as the seed yield divided by the duration between the 50% flowering time and the physiological maturity.

The ANOVA was performed on yield data at each location individually using Genstat, Release 8.1 (Payne, 2002). The mean yields estimated by ANOVA were assembled into a genotype × environment (G × E) matrix, with genotypes as rows and environments as columns, so that the patterns of G × E interaction could be visualized using multivariate approaches (DeLacy *et al.,* 1996; Weikai and Tinker, 2005). Principal component analysis (PCA) based on the correlation matrix was used to construct a Biplot of genotypes (PC scores) and environments (PC factor loading, shown as Biplot vectors). Because the correlation matrix-based PCA was performed, the resultant Biplot was not dominated by the effects of either high-yielding locations or genotypes, and thus allowed G × E interaction patterns to emerge. Specific genotype performance in any given environment could be identified by projecting the genotype PC score to the Biplot vector defined by the location of interest.

Results

Climatic characterization of each location

In SI, the monthly mean maximum temperatures remained at around 30ºC, while the mean minimum temperature decreased to 10ºC in December to rise again in January, and the total precipitation was only 60.5mm in 2004 and 35.2mm in 2005 during the cropping seasons (Fig. 1A). The day length did not exceed 12hrs (max. 11.52 hrs) during the cropping season. The growth conditions in SI, therefore, can be considered to correspond to an arid tropical climate and short day length. Although at all the locations in Japan, day length was longer than in SI, NJ in Japan showed the longest day length (max. 15.23 hrs) among all the locations (max. 14.30hrs in CJ, 14.22hrs in SJ) (Fig. 1). In NJ, the monthly maximum temperature ranged from 20.2ºC to 26.2ºC. As the chickpea plants were protected from rainfall with a rain shelter, they were not subjected to excessive soil wetness. Thus, the NJ climate was classified as semi-humid cool with

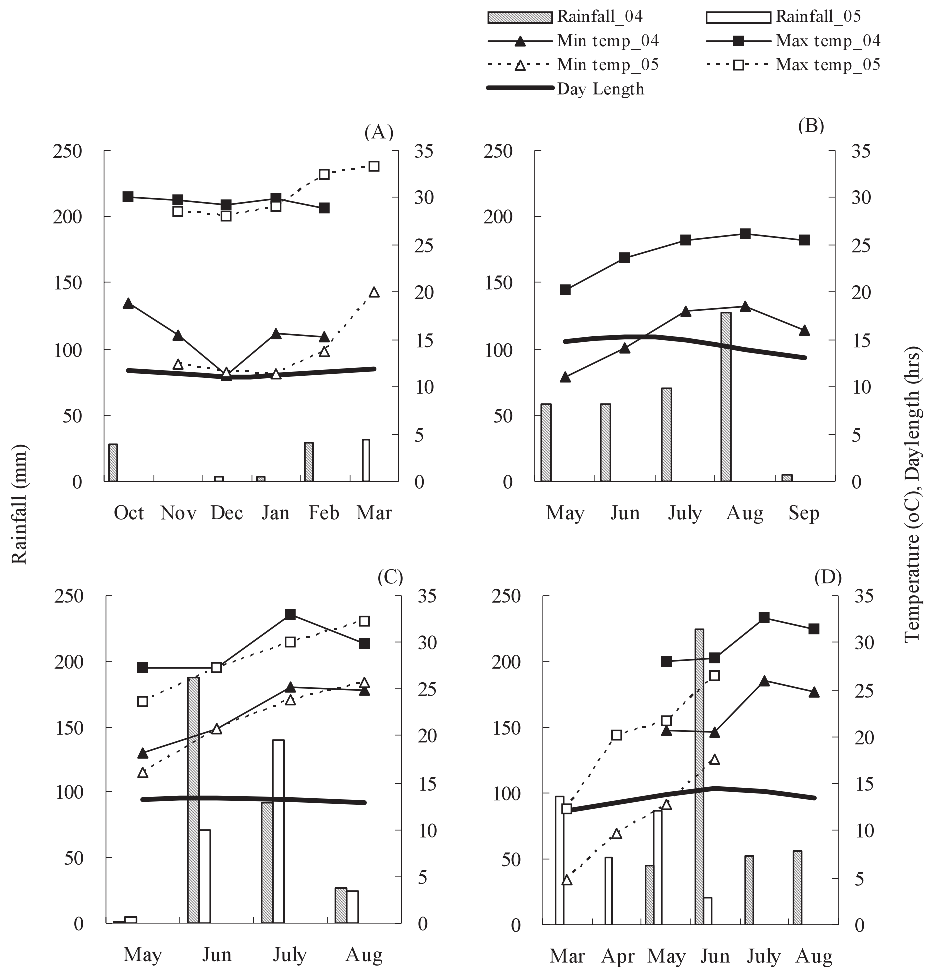

Fig. 1 Climatic conditions of 4 locations. (A) Southern India, (B) Northern Japan, (C) Central Japan, and (D) Southern Japan.

longer day length in these trials. Similar climatic conditions were observed between CJ during 2004, 2005 and SJ during 2004 in terms of changes in the temperature, precipitation and day length (Fig. 1C&D). These environments were characterized as humid temperate. The growth environment that prevailed in SJ during 2005 differed from that during 2004 due to early sowing (Fig. 1D). Especially, the dynamics of the mean maximum temperature was not similar to that of any other locations in Japan, viz., as low as 12.3°C in March, followed by a sharp rise up to 26.5°C in June.

A large variability was observed in the seed yield among the locations (Table 2). The highest yield was obtained in NJ under rain-free conditions in 2004 (299.3 g m^{-2}) and the lowest in CJ in 2005 (19.4 g m^{-2}). At two locations in Japan, SJ and CJ, the yields were very low in all the trials. The ANOVA showed that the location effects were the largest component of variation for the seed yield (Table 3). This large yield difference indicated the existence of highly diverse growth environments across the locations.

Identification of suitable genotypes for chickpea cultivation in Japan

A significant G × E interaction in seed yield was detected among 8 chickpea accessions and 7 location/year combinations (Table 3). The sum of squares of the G × E interaction was almost twice as large as that of the genotype effect alone. This large G × E interaction indicates the specificity in adaptability of these 8 chickpea accessions to different growth environments. Principal component analysis (PCA), therefore, was performed on the seed yield in order to classify the growth environments and to capture the performance pattern of each accession among the growth environments. The first 2 principal components (PC) on a biplot presented in Fig. 2 explained 71.8 % of the total variation. The PC-1 (x-axis) showed the closest correlation with the assimilate remobilization rate (dry matter remobilization from shoots to seeds during the reproductive stage) among the factors which could influence the chickpea productivity, e.g., quantity of fertilizer applied, soil types, climatic conditions, etc. ($r = -0.79$, $p<0.05$), while the PC-2 (y-axis) showed the closest correlation with the cumulative precipitation during the reproductive stage ($r = 0.97$, $p<0.01$). All the PC factor loads (growth environments) were directed towards upper or lower left quadrants, indicating a negative correlation with PC-1. On the other hand, the growth environments could be separated into 2 groups (lower left quadrant: SI-2004, SI-2005 and SJ-2005; upper left quadrant: CJ-2004, CJ-2005, NJ-2004 and SJ-2004) based on the PC-2.

Based on the environmental differences (Fig. 1) and PCA results (Fig. 2), the 7 location/year combinations were reclassified into 4 environmental groups, viz., (I) short day length arid tropics where SI in 2004 and 2005 wase included, (II) longer day length semi-humid cool with NJ in 2004, (III) humid temperate with CJ in 2004, 2005 and SJ in 2004, and (IV) early sowing in humid temperate with SJ in 2005. The mean yields of each environmental group were 299.3 g m^{-2} (environmental group II), 155.4 g m^{-2} (environmental group I), 91.8 g m^{-2} (environmental group IV), 41.8 g m^{-2} (environmental group III), respectively. All the kabuli lines performed better in the environmental group II

Table 3 Analysis of variance in chickpea genotypes in genotype-environment trial

Source of variation	d.f.(m.v.)	S.S.	F predicted
Location (E)	6	1466852	< 0.001
Genotype	7	132833	< 0.001
Location x Genotype	42	233541	< 0.001
Residual	48 (1)	89741	< 0.001

m.v. = missing value, S.S. = sum of square
(E) includes location/year combination.

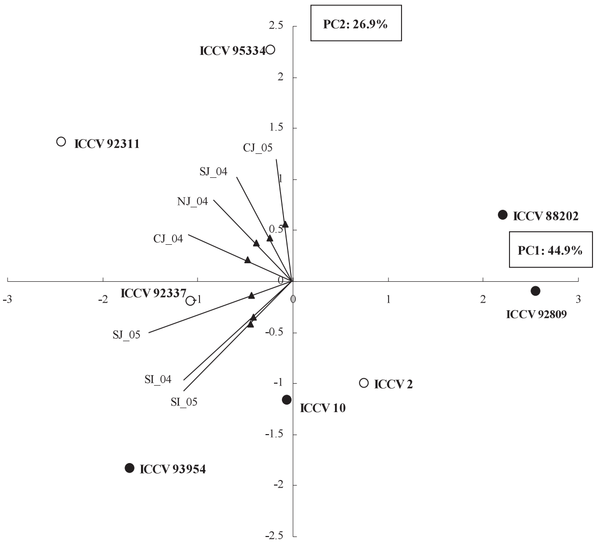

Fig. 2 Principal component analysis of 8 diverse chickpea genotypes using genotype × location matrix of the seed yield. (Biplot vectors indicate location factor loadings. Closed and open symbols denote desi and kabuli groups, respectively. NJ_04 = Northern Japan in 2004, CJ_04 = Central Japan in 2004, CJ_05 = Central Japan in 2005, SJ_04 = Southern Japan in 2004, SJ_05 = Southern Japan in 2005, SI_04 = Southern India in 2004, SI_05 = Southern India in 2005)

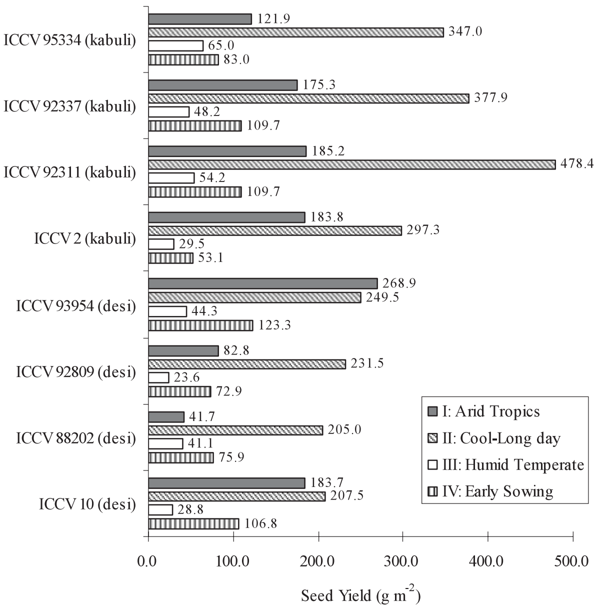

Fig. 3 Seed yields observed in 8 chickpea genotypes in various environmental groups. (I: Southern India in 2004, 2005, II: Northern Japan in 2004, III: Central Japan in 2004, 2005, and Southern Japan in 2004, IV: Southern Japan in 2005)

(longer day length semi-humid cool environment) than in the environmental group I and other Japanese environments (III and IV), and the highest yield was obtained from ICCV 92311, followed by ICCV 92337 and ICCV 95334 (Fig. 3). Interestingly, these kabuli lines shared a common pedigree (Table 1). Among the desi types, ICCV 92809 and ICCV 88202 cultivated in the environmental group II produced a higher yield than that in other environments, similar to the advantage observed in kabulis. The yields of the desi accessions ICCV 93954 and ICCV 10 in the environmental group II were higher than that in any other Japanese environment, but did not differ appreciably from that in group I. Irrespective of the seed types, desi or kabuli, the yields in the environmental group I were higher than those in the groups III and IV, except for ICCV 88202.

Discussion

Chickpea has been evolving under dry environments since it originated in Southeast Turkey with a Mediterranean climate, and, therefore, is well-adapted to such cool and dry environments (Kottek *et al.,* 2006). In our multi-locational trials, the mean seed yields obtained in traditionally chickpea growing SI were higher than those in CJ and SJ. NJ exhibited the highest yield among all the locations. These yield differences reflected highly diverse growth environments across the experimental locations. SI location was characterized by a lower rainfall and a relatively higher temperature during the growth period in both seasons, compared to those of Japanese locations, imposing a more severe drought stress. On the other hand, the CJ and SJ locations corresponded to environments with a relatively high humidity. As chickpeas are known to be photo-thermal responsive and longer photoperiods and warmer temperatures are known to shorten all the developmental phases, the flowering time shifted earlier (Summerfield *et al.,* 1990). This growth response is expected to force the chickpea crops cultivated in CJ and SJ to flower earlier, even before the plants displayed enough vegetative growth, which would ultimately resulting decrease of the grain yield. In addition, two typhoons that hit Japan on June 21 and July 31 in 2004, and one in 2005 (26 July) brought catastrophic damage caused by fungal diseases, e.g., Ascochyta blight. Ascochyta blight generally occurs in warmer environments with a high humidity, and also these genotypes included in the trial were known to be extremely susceptible to such diseases. However, genetic or location variation in the disease incidence was not recorded. This disease pressure could have reduced the number of flowers and filled pods, and consequently reduced the seed yield in CJ and SJ. An attempt was also made in SJ in 2005 to shift the sowing time earlier as a possible disease management practice to avoid this problem. The yield in SJ in 2005 was higher than that in CJ and SJ in 2004, indicating some success in the direction of disease management.

NJ seemed to provide a fairly suitable environment for chickpea growth and yield. Although we did not investigate the nodulation status, the large quantity of nitrogen fertilizer applied might have improved plant growth. Although the longer photoperiod experienced during the growth period might have shifted the flowering time earlier, flower production and subsequent pod setting were not affected by Ascochyta blight as the plants were protected from rainfall by the rain shelter. On the other hand, cooler temperatures may have contributed to extending the growth period, leading to the indeterminate growth habit (Saxena, 1984; Piara Singh *et al.,* 1990). In addition, it also appeared that the chickpea plants did not suffer from serious soil water deficits. Although the dynamics of the soil moisture status was not monitored across the growth period, close plant growth observations did not reveal any symptoms of drought stress, e.g. smaller leaves, short inter-node length, flower abortion, etc., caused by soil water deficit that are commonly observed in drought-stressed environments. As a consequence of such a favorable growth environment, chickpea plants in NJ displayed a higher productivity than at other locations in the present study.

Although several important known factors could have influenced the chickpea yield under different growth environments in these trials, e.g., day length, quantity of fertilizer applied, soil types, climatic conditions, etc., the results from principal component analysis (PCA) provided additional information about the behavior of chickpea in different growth environments. Thus, the growth environments could be classified based on two most influential factors in our trials represented by PC-1 (assimilate remobilization rate) and PC-2 (cumulative precipitation during the reproductive stage). The two PCs accounted for more than 70% of the total variation of yield performance. The upper left quadrant, where CJ-2004 and 2005, SJ-2004, and NJ 2004 appeared, could be considered to include environments that supported a high assimilate remobilization rate and received more precipitation during the reproductive stage. On the other hand, the environments in the lower left quadrant involving SJ in 2005, SI in 2004 and 2005 supported a high assimilate remobilization rate with less precipitation during the reproductive stage. In all these environments falling in both quadrants, the high assimilate remobilization rate seemed to have contributed to the yield, which would have a different meaning in each quadrant. In the environment in the upper left quadrant, the high assimilate remobilization rate could have been important to avoid a higher humidity effect, especially during the reproductive stage, whereas in the environments in the lower left quadrant, to avoid drought. There were no significant differences in the days to maturity among the eight genotypes studied (data not shown). However, there was a significant correlation between the assimilate remobilization rate and seed yield ($r = 0.82$, $p<0.05$). In the semi-arid environment, the assimilate remobilization rate has been identified as a major characteristic that confers large seed yield advantages under soil water deficient conditions (Krishnamurthy *et al.,* 1999). This characteristic is likely to play a major role in enabling to avoid other adverse conditions too, viz., high humidity-promoted disease pressure at the time of seed setting and pod filling. This also indicates that enhancing the abiotic stress escape mechanism is one of the promising breeding strategies in both India and Japan.

At the northern Japanese location, characterized here as longer day semi-humid cool environment, kabuli lines in general performed better than the desi lines. Kabulis normally exhibit a relatively lower assimilate remobilization rate and better shoot growth than the desi chickpeas, often bringing down the seed yield at the semi-arid Indian locations (author L. Krishnamurthy personal observation, 2003). However, the kabulis was well-adapted and showed a better growth and a higher seed yield performance in the cool Mediterranean climate (Wang *et al.,* 2006). It is likely that the growth environment in NJ would be more favorable for kabuli cultivation than for the desi types.

This is the first attempts on the efforts to explore the possibility of chickpea cultivation in Japan as well as in any other countries of the humid temperate zone. We expect that our results could provide useful information to local farmers who are interested in chickpea cultivation in Japan or in any other humid temperate countries, although proper evaluation of the physiological processes that determine the yield formation in chickpea should have been carried out in Japan before adopting the multi-locational approach. So far, very few attempts have been made to introduce into and cultivate the chickpea crop in temperate humid environments. FAO statistics (FAOSTAT, 2007) shows recent increases in the area of chickpea cultivation in inland China where the growth conditions are close to those of the semi-arid environments, but not in other countries in temperate Asia. Therefore, further studies should be conducted on the evaluation of existing varieties and the adaptability of chickpea to highly humid, high soil moisture and nontraditional niches. Recently, chickpea cultivation in Canada, where the latitude is similar to that of Hokkaido, has been increasing, with considerable improvements on early phenology and Ascochyta blight resistance (Gan *et al.,* 2007; Anbessa *et al.,* 2007). Therefore, interaction with Canadian Agricultural Research Institutes and Universities could lead to a better understanding of the crop cultivation practices for Japan.

In conclusion, chickpea accessions which display a strong sink activity as well as higher disease resistance are recommended for cultivation in the humid temperate zone of Japan. In addition, localizing the cultivation to low rainfall areas or use of rain shelters, greenhouse or polyhouse facilities and wider plant spacing for maintaining a lower humidity in the high rainfall areas could be useful to increase the seed yield in Japan. Locations in northern Japan, such as Hokkaido, could become suitable for growing chickpea crop with rain shelter facilities.

References

Abbo, S., Molina, C., Jungmann, R., Grusak, M. A., Berkovitch, Z., Ruth Reifen, Kahl, G., Winter, P., and Reifen, R. 2005. Quantitative trait loci governing carotenoid concentration and weight in seeds of chickpea (*Cicer arietinum* L.). Theor. Appl. Genet. **111**: 185-195.

Agharkar, S. P. 1991. Medical plants of Bombay Presidency, pp 62-63. Scientific Publications, Jodhpur, India.

Anbessa, Y., Warkentin, T., Bueckert, R., and Vandenberg, A. 2007. Short internode, double podding and early flowering effects on maturity and other agronomic characters in chickpea. Field Crops Res. **102**: 43-50.

Charles, M. T., Dominique, R., Kumar, J., and Dangi, O. P. 2002. A preliminary study of functional properties of chickpea leaves. In: Annual Meeting of the Canadian Society of Food and Nutrition, May 2002, Edmonton, Alberta, Canada.

DeLacy, I. H., Basford, K. E. Cooper, M., Bull, J. K., and McLaren, C.G. 1996. Analysis of multi-environment trials – A historical perspective. In: Plant adaptation and crop improvement. pp 39-124, Cooper, M. and Mammer, C,L, (eds), CAB International, Wallingford, UK.

FAOSTAT data. 2007. http://faostat.fao.org/faostat/ (last updated 8 June 2007)

Gan, Y., Gossen, B. D., Li, L., Ford, G., and Banniza, S. 2007. Cultivar type, plant production, and Ascochyta blight in chickpea. Agron. J. **99**: 1463-1470.

Jambunathan, R., and Umaid Singh. 1990. Present status and prospects for utilization of chickpea. In: Chickpea in the nineties: proceedings of the second international workshop on chickpea improvement, pp 41-46, 4-8 Dec 1989, ICRISAT Center, Patancheru, India.

Kashiwagi, J., Krishnamurthy, L., Crouch, J. H., and Serraj, R. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L) under terminal drought stress. Field Crops Res. **95**: 171-181.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F. 2006. World Map of the Köppen-Geiger climate classification updated. Meteorol. Z., **15**: 259-2630.

Krishnamurthy, L., Johansen, C., and Ito, O. 1996. Genetic variation in root system development and its implications for drought resistance in chickpea. In: Root and nitrogen in cropping systems of the semi-arid tropics. pp 234-250, Ito, O., Johansen, C., Adu-Gyamfi, J. J., Katayama, K., Kumar Rao, J. V. D. K., and Rego, T. J. (eds.), Culio Corporation, Tsukuba.

Krishnamurthy, L. Johansen, C., and Sethi, S. C. 1999. Investigation of factors determining genotypic differences in seed yield of non irrigated and irrigated chickpeas using physiological model of yield determination. J. Agron & Crop Sci., **183**: 9-17.

Payne, R. W. (ed.) 2002. The guide to GenStat ® Release 6.1. Part: 2 Statistics. VSN International Ltd, Oxford, UK.

Piara Singh, Saxena, N. P., Monteith, J. L., and Huda, A. K. S. 1990. Defining, modelling, and managing water requirement of chickpea. In: Proceedings of the Second International Workshop on Chickpea Improvement. 4-8 Dec 1989, ICRISAT Center, Patancheru, India.

Saxena, N. P. 1984. The Chickpea. In: Physiology of tropical field crops. pp 419-452, Goldsworthy, P. R. and Fisher, N. M. (eds.). New York, USA: Wiley.

Summerfield, R. J., Virmani, S. M., Roberts, E. H., and Ellis, R. H. 1990. Adaptation of chickpea to agroclimatic constraints. Chickpea in the Nineties: Proceedings of the Second International Workshop on Chickpea Improvement. 4-8 Dec 1989, ICRISAT Center, Patancheru, India.

Upadhyaya, H. D., Ortiz, R., Bramel, P., and Singh, S. 2002. Phenotypic diversity for morphological and agronomic characteristics in chickpea core collection. Euphytica, **123**: 333-342.

USDA-ARS, Beltville. 2004. Phytochemical database: Chickpea. http:/www.ars-grin.gov/cgi-bin/duke/ethnobot.pl.

Wang, J., Gan, YT., Clarke, F., and McDonald, C. L. 2006. Response of Chickpea Yield to High Temperature Stress during Reproductive Development. Crop Sci., **46**: 2171-2178.

Weikai, Yan, and Tinker, N. A. 2005. an integrated biplot analysis system for displaying, interpreting, and exploring genotype × environment interaction. Crop Sci., **45**: 1004-1016.

Wood, J. A. and Grusak, M. A. 2007. Chapter **5**: Nutritional value of chickpea. Pages 101-142 *in* Chickpea Breeding and Management (Yadav, S.S., Redden, B., Chen, W. and Sharma, B., eds.), CABI, UK.