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Usefulness of Andigena (*Solanum tuberosum* ssp. andigena) genotypes as parents in breeding early bulking potato cultivars

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Summary

Seven *Solanum tuberosum* ssp. tuberosum and three *Solanum tuberosum* ssp. andigena accessions were crossed to produce 12 Tuberosum × Tuberosum (T × T) and 9 Tuberosum × Andigena (T × A) progenies. These families were evaluated for five important traits for two successive clonal generations under short day sub-tropical plains. The differences in yield, average tuber weight and tuber number between T × T and T × A families in an early (75 days) crop were not significant. Compared to conventional intra-Tuberosum families, T × A families had significantly higher % tuber dry matter and specific gravity. In contrast to intra-Tuberosum crosses, T × A crosses exhibited a positive heterosis for tuber yield. Compared to T × T families, T × A families showed significantly higher heterosis for yield and tuber number. Comparison of T × T and T × A families and parents using canonical analysis led to the identification of superior hybrid families and superior parents. Some T × A progenies were close to breeding goal and thus can be used for selecting high-yielding cultivars. This revealed the usefulness of Andigena genotypes as parents in developing early bulking potato cultivars with broad genetic base for short day sub-tropical plains.

Introduction

Potato breeding programmes based on *Solanum tuberosum* L. have a narrow genetic base (Simmonds, 1962). Most breeders agree that it is increasingly difficult to obtain improvement in yield and other traits from among recombinants produced by crossing presently available parental clones. Primitive cultivated potatoes of *Solanum tuberosum* group Andigena are being used to broaden the genetic base of group Tuberosum material. Andigena is a rich source of genetic diversity. However, Andigena selections are known to exert a strong influence in crosses with clones of *Solanum tuberosum* group Tuberosum (Tai & Tarn, 1980) and high frequency of late maturity, small tubers occurring in some better crosses remains a problem for the breeder. Simmonds (1976) has emphasized the need to learn how to utilize Tuberosum × Andigena (T × A) hybrids. The immediate usefulness of Andigena material is in the form of T × A hybrids. The potential of Andigena accessions in increasing yield in T × A crosses due to heterosis, is well-established (Glendenning, 1969, 1975; Cubillos & Plaisted, 1976; Tarn & Tai, 1977, 1983). Short day adapted Andigena accessions can be useful parents in breeding programmes for short day sub-tropical environment. Multivariate statistical methods are very useful in summarizing and describing the variability found in natural or breeding populations. An approach that is very useful for determining breeding methods to obtain hybrids close to a chosen ideal is the multivariate technique of canonical analysis (Whitehouse, 1971). In potatoes, canonical analysis has been used for discriminating different type of families and to study their relationship to their parents (Tai & Tarn, 1980; Tai & De Jong, 1980; Tarn & Tai, 1983). The potato crop in sub-tropical Indian plains is normally harvested 90–110 days after planting. Early bulking genotypes giving high yield at early (75 days) harvest are highly desirable for their multiple advantages (Shekhawat, 1994). The present study was conducted with the objective to know the usefulness of late maturing Andigena genotypes in developing early (75 days) bulking potato cultivars for sub-tropical Indian plains. For this T × A families were compared to conventional Tuberosum × Tuberosum (T × T) families and breeding goals using canonical analysis.

Materials and methods

Crosses were performed between seven Tuberosum and three Andigena parents in line × tester design during summer 2001 at Central Potato Research Station, Kufri (31°08′N, 77°18′E, 2530m amsl). Four Tuberosum male parents (CP 1704, MS/82–797, JN 2207 and Kufri Badshah) and three Andigena male parents (JEX/A 805, EX/A 680-16 and JEX/A 318) were crossed to three Tuberosum female parents (Kufri Jyoti, Kufri Ashoka and MS/89-1095). The Tuberosum parents were selected primarily on the basis of large tuber size; high yielding ability and most of them are used frequently in intra-Tuberosum crosses in cultivar development programmes. Andigena parents were selected on the basis of good tuber size and yield. Seedlings and subsequent clonal generations were raised at Central Potato Research Station Jalandhar (31 ° 02′N, 75 ° 02′E, 237m amsl). Seedlings of each cross at the 6-7-leave stage were transplanted to field. At harvest 3 tubers per seedling for each of 30 randomly selected genotypes per progeny were retained to form three replications of first clonal generation. The same procedure was applied to form material for second clonal generation (SCG). In the 2002–2003 and 2003–2004 autumn crop seasons, trials were laid out in Randomised Complete Block Design with three replications and a plot size of 3.6 square metres comprising 2 rows planted at intra and inter row spacing of 20 and 60 cm, respectively. Normal management and pest control practices were carried out. Haulm cutting of the crop was done 75 days after planting. The crop was harvested in each season 20 days after haulm cutting.

Characters studied

1. Tuber number per plot
2. Average tuber weight in grams per tuber calculated by total yield per plot/ total number of tubers per plot
3. Total yield in kilograms per plot
4. % dry matter
5. Specific gravity

For % dry matter estimation, 500 g tubers pieces were cut into small pieces and oven-dried at 80 °C to a constant weight. Specific gravity was determined by the weight-in-air and weight-in-water method.

Statistical analyses

Homogeneity of error variance was tested by two-tailed F test. Combining ability analysis was done based on Kempthorne (1957). Heterosis and heterobeltiosis were calculated as per the following formulae:

$$\text{Heterosis (\%)} = (F_1 - MP)/MP \times 100$$
$$\text{Heterobeltiosis (\%)} = (F_1 - BP)/BP \times 100$$

F_1 is the mean value of hybrid progeny. MP is the average value of two parental clones. BP is the value of better parent in a cross. Significance of differences in average performance for parents and progeny means, heterosis (%) and heterobeltiosis (%) were tested using Student's t test for comparing means based on samples of different size. Canonical analysis was done using SPAR1 software package (IASRI, New Delhi). Two-dimensional canonical diagrams were prepared based on scores of first, second and third canonical variates of hybrid families and their Tuberosum and Andigena parents.

Results

Analysis of variance for parents and progenies over two clonal generations showed that mean squares due to parents, progenies and parents versus progenies were significant for the characters tuber number, average tuber weight, yield, % dry matter and specific gravity (data not shown). The interactions parent × clonal generation, progeny × clonal generation and parent versus progeny × clonal generation were non-significant for all the five characters.

Compared to the three Andigena accessions, seven Tuberosum parents included in this study had wider range for yield, average tuber weight, tuber number and specific gravity (Table 1). Andigena parents differed from Tuberosum parents by having low average tuber weight and yield and higher % dry matter and

Table 1. Mean of the traits for parents and families

Trait	Tuberosum (T)	Andigena (A)	Differences in means (T – A)	Tuberosum × Tuberosum (T × T)	Tuberosum × Andigena (T × A)	Differences in progeny means (T × A) – (T × T)
Tuber number/ plot	173.38 (130.35/207.66)	165.34 (153.34/182.67)	8.04	207.97 (141.01/250.0)	232.56 (187.35/270.35)	24.60
Average tuber weight (g)	63.83 (51.75/82.13)	36.98 (31.87/41.95)	26.85**	47.80 (28.27/57.83)	40.73 (29.55/53.87)	−7.07
Yield (kg/plot)	10.78 (9.40/11.95)	6.02 (5.54/6.70)	4.76**	9.54 (5.51/12.64)	9.14 (6.25/11.84)	−0.40
% Dry matter	16.49 (15.68/17.43)	19.08 (18.00/19.87)	−2.59**	15.57 (14.43/16.22)	17.23 (15.52/18.47)	1.66**
Specific gravity	1.032 (1.018/1.042)	1.043 (1.039/1.048)	−0.011*	1.025 (1.020/1.029)	1.031 (1.017/1.043)	0.006*

Values in parentheses indicate minimum/maximum values for the traits.
* and ** : significant at $p < 0.05$ and $p < 0.01$, respectively.

specific gravity. T × T families had lower average tuber weight and yield than their parents, while tuber number increased in families. The range for specific gravity and % dry matter were wider in T × A families compared to T × T families, while reverse was true for tuber number, average tuber weight and yield. Compared to T × T families representative of those used in present day breeding programmes, T × A families had more % dry matter and specific gravity. Average tuber weight, tuber number and yield did not differ significantly in these two types of families. Average tuber weight in T × A families was not significantly lower than T × T families.

Families were below mid-parent values for average tuber weight, % dry matter, specific gravity and above mid-parental values for tuber number (Table 2). T × A families exhibited a positive overall heterosis for tuber yield, while negative heterosis for tuber yield was observed in intra-Tuberosum crosses. As compared to intra-Tuberosum families, the deviation of T × A families above mid-parental value for tuber number was more. T × A families had less deviation below mid-parental value for average tuber weight, % dry matter and specific gravity.

The range for heterosis in T × A families for yield and % dry matter were wider than intra-Tuberosum families, while reverse was true for tuber number. For other characters, differences in range of heterosis in T × T and T × A families were negligible. T × A progenies exhibited more heterosis compared to intra-Tuberosum progenies for all the 5 characters studied. However, the differences in heterosis in two types of progenies were significantly only for yield/plot and tuber number/plot. While mean heterosis for tuber yield was positive in T × A families, it was negative in intra-Tuberosum families. The range for better parent heterosis or heterobeltiosis in T × A progenies were greater than T × T progenies for yield, % dry matter and specific gravity, while reverse was true for tuber number and average tuber weight (Table 3). T × A progenies exhibited more overall heterobetiosis compared to intra-Tuberosum progenies for tuber number and yield, while reverse was true for average tuber weight and % dry matter. However, differences in heterobeltiosis between two types of progenies were significant only for tuber number.

Combining ability differences due to female, male and female × male interaction were significant for tuber number, average tuber weight, yield, % dry matter and specific gravity except due to female for average tuber weight and due to male for yield (data not shown). The interactions female × clonal generation, male × clonal generation and female × male × clonal generation were non-significant for all the five characters. The ratios of variance due to general combining ability and total genetic variance due to general and specific combining ability for tuber number, average tuber weight, yield, % dry matter and specific gravity

Table 2. Heterosis (%) in Tuberosum × Tuberosum (T × T) and Tuberosum × Andigena (T × A) families

Character	T × T			T × A			Difference in means
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	(T × A) − (T × T)
Tuber number/ plot	75.15	−24.87	21.50	60.91	5.84	42.83	21.33*
Average tuber weight	0.70	−49.74	−25.15	2.14	−40.58	−11.97	13.18
Yield/plot	9.25	−48.11	−9.87	52.23	−22.57	13.68	23.56*
% dry matter	1.26	−9.09	−5.48	3.59	−11.46	−2.88	2.60
Specific gravity	0.11	−1.74	−0.76	0.49	−1.27	−0.66	0.10

*Significant at $p < 0.05$.

Table 3. Heterobeltiosis (%) in Tuberosum × Tuberosum (T × T) and Tuberosum × Andigena (T × A) families

Character	T × T			T × A			Difference in means
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	(T × A) − (T × T)
Tuber number/ plot	42.54	−30.88	10.81	47.99	2.55	33.50	22.68*
Average tuber weight	−2.59	−57.28	−30.94	−16.50	−55.11	−38.08	−7.14
Yield/plot	7.56	−27.45	−13.95	20.92	−33.69	−10.75	3.20
% dry matter	−0.31	−13.62	−7.98	2.59	−19.88	−9.49	−1.50
Specific gravity	−0.50	−2.08	−1.10	0.40	−2.34	−1.10	−0.002

[a]Significant at $p < 0.05$.

were 0.239, 0.105, 0.096, 0.495 and 0.283, respectively (Table 4).

Canonical analysis, used to study genetic relationships between different groups of materials, showed that 75 % of the total variation was explained by first two canonical variates and 87.5 by first three canonical variates. For identifying promising families, two arbitrary breeding targets B10 and B15 were defined with 10% and 15% yield gain over best parent JN 2207, respectively. Among the parents, *per se* performance of JN 2207 for yield in 75 day crop was best. It performed slightly better than best early bulking cultivar Kufri Ashoka. The yield increase in these breeding targets resulted from equal per cent increase in two yield components viz., tuber number per plot and average tuber weight. B10 represented 3.162% increase in tuber number per plot and average tuber weight over best parental genotype JN 2207 without any change in % dry matter and specific gravity from JN 2207. Similarly B15 represented 3.873% increase in tuber number and average tuber weight over JN 2207. Canonical diagrams separate two parental groups and shows distinct areas for T × T and T × A families (Figure 1a,b). The canonical diagram using the first and second canonical variate showed a considerable overlap of intra-Tuberosum and T × A distribution areas with Tuberosum parents (Figure 1a). T × A area was more widely distributed than T × T area. The distribution area of the Andigena parents was distinct and to the right of other 3 groups. There was considerable overlapping of intra-Tuberosum and T × A distribution areas. Compared to intra-Tuberosum area overlapping of T × A distribution area with Tuberosum parent's area was somewhat more. Similar results can be drawn from the canonical diagram using the first and third canonical variate (Figure 1b). The families of various parents were widely distributed from their parents.

Among the three female parents the progenies of the parents Kufri Ashoka were most closely distributed to the targets (Figure 2a). Tuberosum male parent MS/82–797 progenies were closely distributed to targets compared to progenies of other three Tuberosum male parents (Figure 2b). Among the three Andigena male parents, progenies of EX/A 680-16

Table 4. Estimates of variance components pooled over two clonal generations

Estimates	Tuber number/ plot	Average tuber weight	Yield (kg/plot)	% Dry matter	Specific gravity
σ^2gca(females)	360.5	−1.53	0.92	0.18	0.00000938
σ^2gca(males)	588.8	41.14	−0.20	0.89	0.00001635
σ^2gca(pooled)	429.0	11.27	0.60	0.39	0.00001147
σ^2sca	1364.7	96.23	5.64	0.40	0.00002908
σ^2gca/ (σ^2gca + σ^2sca)	0.239	0.105	0.096	0.495	0.283

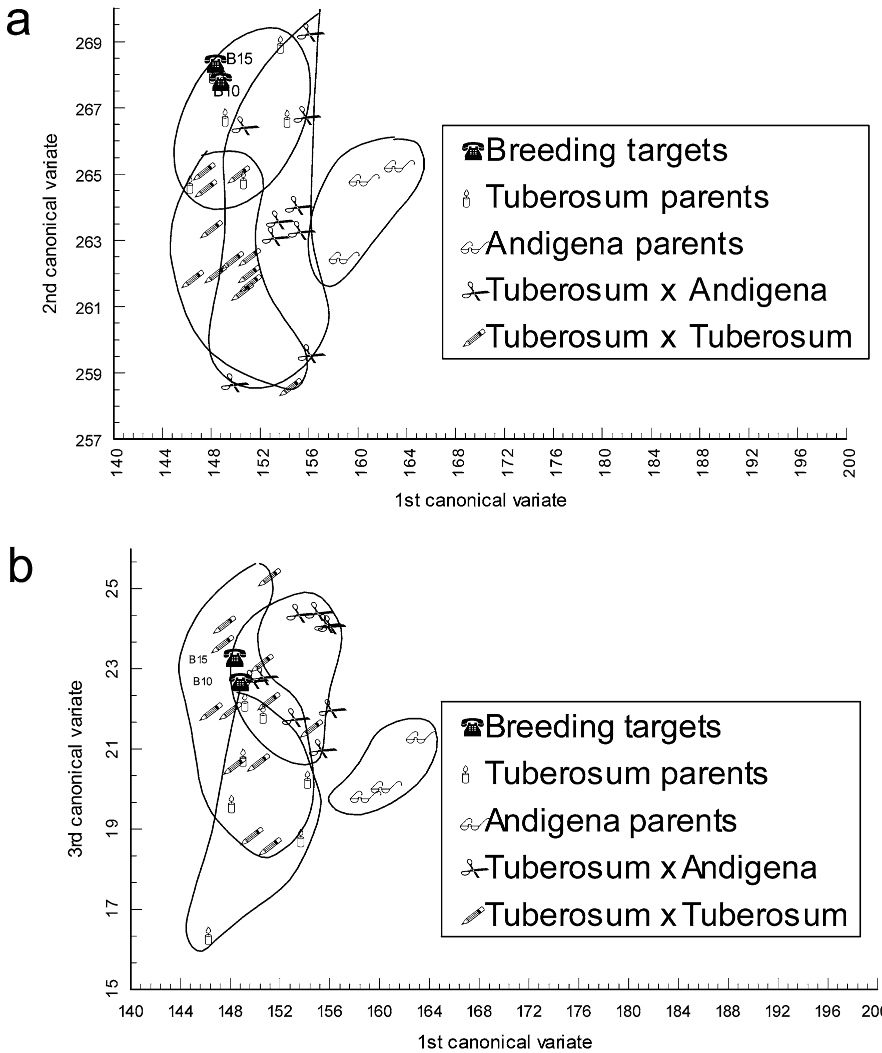

Figure 1. Distribution of progenies and parents on (a) first and second canonical variates and (b) first and third canonical variants.

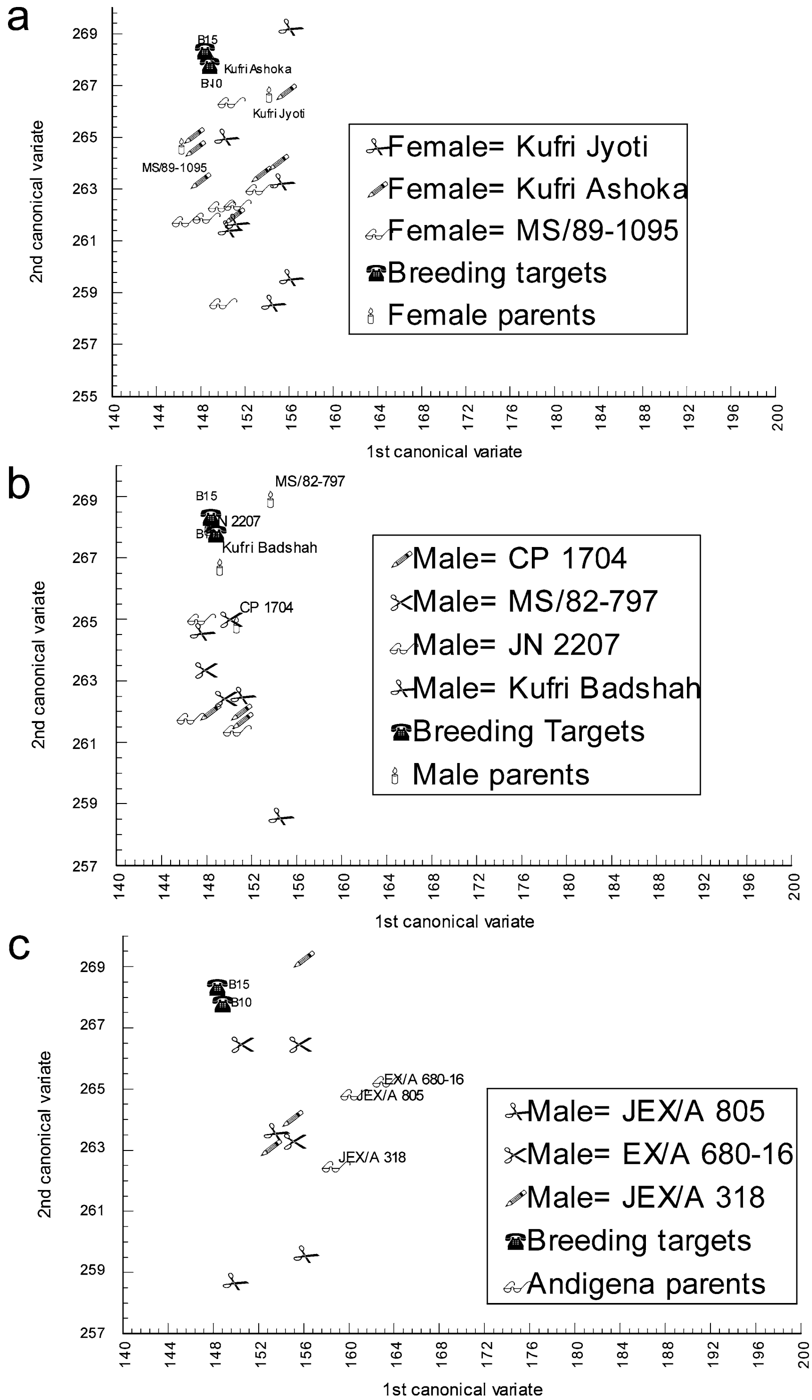

Figure 2. Distribution of progenies on first and second cannonical variate of (a) 3 Tuberosum female, (b) 4 Tuberosum male and (c) 3 Andigena male parents.

Table 5. *Per se* performance, heterosis and heterobeltiosis for tuber yield in promising Tuberosum × Tuberosum (T × T) and Tuberosum × Andigena (T × A) cross combinations identified by canonical analysis

Family	Cross combinations	*per se* performance (kg/plot)	Mid parent heterosis (%)	Heterobeltiosis (%)
T × A	MS/89-1095 × EX/A 680-16	11.84	43.43**	10.94**
	Kufri Ashoka × EX/A 680-16	10.36	19.62**	9.86**
	Kufri Jyoti × JEX/A 318	11.36	52.23**	20.92**
T × T	Kufri Ashoka × JN 2207	12.64	7.82**	5.87**
	Kufri Jyoti × MS/82-797	10.44	9.25**	7.56**
	Kufri Ashoka × Kufri Badshah	12.30	5.58**	4.24**

* and ** : significant at $p < 0.05$ and $p < 0.01$, respectively.

were most closely distributed to the targets (Figure 2c). T × A family MS/89-1095 × EX/A 680-16 was closest to breeding targets among all the families (Figures 1; 2a,c). Two other T × A families viz., Kufri Ashoka × EX/A 680-16 and Kufri Jyoti × JEX/A 318 were close to the breeding targets. Among intra-Tuberosum families, Kufri Ashoka × JN 2207 was the closest to breeding targets followed by families Kufri Jyoti × MS/82-797 and Kufri Ashoka × Kufri Badshah (Figures 1; 2a,b). The promising T × A families had very high mid-parent heterosis and heterobeltiosis; while mid-parent heterosis and heterobeltiosis were comparatively lower in promising intra-Tuberosum families (Table 5).

Discussion

There are reports of reciprocal cross differences in inter-group families between group Tuberosum and Group Andigena (Hoopes et al., 1980; Maris, 1989). According to these reports the progenies with Tuberosum cytoplasm were high yielding. Keeping this in view, inter-group hybrids in the present study were produced using Tuberosum genotypes as female parents. The low yield and average tuber weight of Andigena genotypes compared to Tuberosum is in agreement with earlier studies (Tarn & Tai, 1977, 1983; Furumoto et al., 1991). The low yield of T × T families as compared to their parents resulted from production of large number of smaller tubers. These results confirm earlier findings (Tarn, 1980; Tarn & Tai, 1983). In the present study average tuber weight, tuber number and yield did not differ significantly in T × T and T × A families. Superiority of T × A families over T × T families for yield as well as its components tuber number and average tuber weight was reported (Cubillos & Plaisted, 1976; Gopal et al., 2000) meaning thereby that better yield of T × A families in their studies were due to multiplicative interaction resulting from union of more tuber number and large tuber size. Tarn and Tai (1983) reported that T × A families were superior to T × T families for yield and tuber number but possessed reduced tuber size. In our study on an early (75 day) harvested crop grown under subtropical conditions, the improvement of yield and yield related characters in T × A families over T × T families was not significant. The reason for disagreement may be the experimental material used or the crop duration. Most of the intra-Tuberosum families involved in this study are among the most promising families identified under our breeding program which is aimed at developing early bulking varieties. A similar performance of T × A and intra-Tuberosum families for yield indicates that Andigena parent can be used in crosses to develop high yielding genotypes.

As compared to intra-Tuberosum crosses, more deviation of T × A families above mid-parental value for tuber number and less deviation below mid-parental value for average tuber weight, % dry matter and specific gravity was observed. In contrast to intra-Tuberosum crosses, T × A families also exhibited a positive overall heterosis for tuber yield. The behaviors of two yield components, tuber number and average tuber weight, throws light on the heterosis expressed in inter-Group hybrid populations. As compared to intra-Tuberosum families, there was less negative deviation for average tuber weight and more positive deviation for tuber number in T × A progenies. This might have resulted in negative deviation from mid-parental value for tuber yield in intra-Tuberosum crosses and positive deviation for tuber yield in T × A families. More overall heterosis and heterobeltiosis for tuber yield was observed in the present study in T × A families compared to intra-Tuberosum families. This is in agreement with earlier studies (Glendenning, 1969, 1975; Cubillos & Plaisted, 1976; Tarn & Tai, 1977, 1983; Gopal et al., 2000). Significantly high heterosis for tuber number is in agreement with earlier studies (Tarn & Tai, 1977; Gopal et al., 2000). For average tuber weight heterosis in T × A families was not significantly better than that of T × T families. Gopal et al. (2000) reported significantly high heterosis for average tuber weight in T × A families as compared to intra-Tuberosum families in first clonal generation, while it was not significantly higher in second clonal generation.

Combining ability analysis showed the predominance of non-additive effects for all the characters except % dry matter. Non-additive gene action is known to be important in inheritance of various characters in Potato (Tai & Tarn, 1980; Tarn & Tai, 1983; Kumar & Kang, 2001). For % dry matter, there was almost equal contribution of both additive and non-additive components. Comparatively better proportion of σ^2gca to total genetic variance for % dry matter compared to other characters was also found in our earlier study (Kumar & Kang, 2001). Evaluation of crosses based on parental performance would be considerably less reliable than evaluating progenies performance because of such non-additive effects.

Canonical diagrams separated parental groups and inter group families in different area with some overlapping. The distribution of various groups based on canonical diagram using the first and second canonical variate were similar to that based on first and third canonical variate. T × A area was more widely distributed than T × T area. The wider distribution of T × A families may be due to wider variation among families from crosses involving divergent inter-group parents. The distinct distribution area of the Andigena parents shows that they are different from the Tuberosum parents. Overlapping of T × A area with Tuberosum parents area and proximity of T × A area to breeding goals shows the usefulness of such families in achieving the breeding goals. From the canonical diagram, parental effects on distribution of their families can be known. Lack of association between families and their parents in canonical diagram served as an indirect evidence for the presence of specific combining ability. Present study led to the identification of useful parents viz., EX/A 680-16, Kufri Ashoka and MS/82-797; useful T × A families viz., MS/89-1095 × EX/A 680-16, Kufri Ashoka × EX/A 680-16 and Kufri Jyoti × JEX/A 318; and useful intra-Tuberosum families viz., Kufri Ashoka × JN 2207, Kufri Jyoti × MS/82-797 and Kufri Ashoka × Kufri Badshah. T × A family MS/89-1095 × EX/A 680-16 was closest to breeding targets among all the families. Comparatively very high mid-parent heterosis and heterobeltiosis in promising T × A families compared to promising intra-Tuberosum families emphasizes the value of Andigena parents in developing early bulking potato varieties. Good performance of T × A families in our study was due to high heterosis for tuber number and yield. Further improvement in T × A families can be expected by using improved Andigena accessions in such crosses (Furumoto et al., 1991). Canonical analysis facilitated the identification of superior hybrids and parents based on not only the yield but also the yield components viz., as average tuber weight and tuber number; and quality characters such as % dry matter and specific gravity. Multivariate techniques such as canonical analysis can consider all the agronomic and tuber quality traits objectively and simultaneously. This approach provides an overall evaluation of additive and non-additive genetic effects and the relationship of progenies to their parents. In potato breeding a large number of traits are evaluated when selections are made. This approach provides a practical assistance to a breeder. The multivariate data give an improved evaluation of families and ability to identify superior families. They also permit a measure of progress made towards reaching a breeding goal. Canonical analysis is well suited to developing breeding strategy that lead to creation of populations with the best chances of containing desired new segregants (Tai & De Jong, 1980; Tai & Tarn, 1980). This is particularly important when introducing into potato breeding programs new germplasm such as tetraploid-diploid and T × A hybrid families where segregation patterns are not yet well clear.

The combination of cross evaluated and canonical analysis used here provides a mean of identifying superior Andigena parents. The results of present study shows usefulness of T × A crosses due to high heterosis expressed in such crosses. The results indicate that poor yielding and late maturing Andigena accessions can be used in their crosses with Tuberosum accessions for breeding early bulking potato cultivars for sub-tropical plains.

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