# Characterization of Potato (*Solanum tuberosum* ssp. *tuberosum*) Germplasm Based on Genetic Divergence and Processing Attributes

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Non-hierarchical Euclidean cluster analysis based on principal component scores of yield and processing traits was used for characterization of 108 potato germplasm accessions of world collection under short day (9.75-11.5 h photoperiod) conditions in the North Indian plains. Moderate to high coefficient of variability was observed for tuber yield, average tuber number, average tuber weight, reducing sugars, sucrose, total phenols, free amino acids and chip colour score, which could be harnessed in future improvement programmes. Based on genetic divergence, determined by Euclidean distances, the accessions were classified into six well-characterized clusters with variable number of genotypes. Each cluster has germplasm accessions of heterogeneous origin, suggesting that geographical distribution has no significant bearing on genetic divergence. Inter-cluster distances were higher than the intra-cluster distances, indicating high diversity among clusters. Based on mean performance for processing attributes, six germplasm accessions, namely 316.1 (CP 1798), B 6532-3 (CP 1907), K 85-6 (CP 1940) and K 194-3 (CP 1945) obtained from USA, Tombola (CP 1780) from the Netherlands and Tunika (CP 1806) from Germany are recommended as parents in developing varieties suitable for processing. Adaptability evaluation for yield traits led to the identification of five high yielding accessions, namely, B 4829-7 (CP 1564) from USA and HYB. No. 20089 (CP 1813), 62.66/1 (CP 1824), 57.1775.110 (CP 1826) and Giewont (CP 1868) from Germany. The tuber traits of these accessions ranged from round to oblong shape, shallow to low deep eyes, white to yellow skin color and white to yellow cream tuber flesh color. This classification should aid the utilization of potato germplasm to develop cultivars with specific adaptation features.

**Key words : Cluster Analysis, Intra and Inter-Cluster Distances, Processing Characteristics, *Solanum tuberosum***

Potato is a crop of great importance in the world food production and is the most extensively grown horticultural crop in India (Sikka, 1996; Rao, 1998). It is one of the most productive crop which can play a significant role in ensuring food security and is a versatile food which can be cooked in many ways, can be processed into a number of products and can fit in any meal. On an industrial scale, potato processing is largely confined to the developed countries, but fast growth in processing is also expected in developing countries. In India, there is a spurt in processing activity due to increased urbanization growth, preference of new generation for fast foods, rise in per capita income, increase in number of working women preferring ready-cooked foods and expanding tourist trade (Marwaha, 1997). Recently, a large number of companies including multinationals have stepped into the field of potato processing. These processing industries need varieties with above 20% tuber dry matter and low reducing sugars and total phenols (Gaur *et al.*, 1999). The north-western plains is a major potato producing zone of India where the crop is grown during winter season under short day conditions, planted mainly in October and harvested in January/February. During maturity period, the crop is exposed to average minimum temperature of 4.5$^0$C or even lower leading to the accumulation of low dry matter and high content of reducing sugars in potatoes which make this zone unsuitable for producing potatoes for processing (Ezekiel *et al.*, 1999). Conversely, the major potato processing industries are located in the north-western plains of India, which procure potato from Central plains of Uttar Pradesh and Malwa region of Madhya Pradesh. The cost of the raw material arriving at the factory premises becomes very high due to heavy transportation charges. Thus, there is an urgent need to breed suitable processing varieties for this region. Although, two processing varieties, Kufir Chipsona-1 and Kufri Chipsona-2, have been released for commercial cultivation for the Indo-gangetic plains during 1998 (Gaur *et* al., 1998; Gaur *et al.*, 1999), there is still a need to develop more processing varieties to meet the increasing demand of processing industries and to provide wider choice to the growers. The germplasm is the reservoir of genetic diversity which is often exploited to meet the changing needs for developing improved varieties of a crop. While formulating any breeding programme, understanding about the nature and the degree of genetic divergence for desirable traits available in the germplasm plays a pivotal role as it helps in judicious selection of parents to generate superior and desirable recombinants. The present investigation was, therefore, undertaken to determine the magnitude of variability among genotypes for yield and processing traits; to determine the distribution pattern of genotypes in diverse clusters and, to identify genetically diverse and processing superior germplasm accessions for use as parents in developing potato varieties suitable for processing.

## Materials and Methods

### *Germplasm material*

The material comprised 108 potato germplasm accessions (*Solanum tuberosum* ssp. *tuberosum)* along with two Indian varieties viz., Kufri Chandramukhi and Kufri Jyoti and three processing popular exotic cultivars, viz., Atlantic, FL 1533 and FL 1625 taken as controls. The germplasm material has been collected from nine different countries and was being maintained vegetatively under field conditions. The germplasm accessions along with controls were evaluated for yield and important processing attributes viz., dry matter content, reducing sugars, free amino acids, total phenols and chip colour under short day conditions at the Central Potato Research Stations Jalandhar, located in the north-western plains (30$^0$N 75$^0$E; 237 m above msl). The trial was laid during 1998-1999 and 1999-2000 in two replications. Twelve plants of each genotype in a single row planted at inter and intra-row distances fo 60 cm and 20 cm, respectively, represented each replication. All the recommended agronomical practices were followed. The crop was dehaulmed on 90 days after planting and the tubers were cured for 20 days before harvest. The characters studied were tuber yield per plant (TY), average tuber number per plant (ATN), and average tuber weight (ATW). Important physico-chemcial characters of tubers were studied simultaneously in uniform size tubers (70-80g) of each culture. For the determination of dry matter (DM), tubers were cut into small pieces and over dried at 70$^0$C to a constant weight. The reducing sugars (RS) were detemined by the Nelson-Somogyi method (Pearson, 1976), while sucrose (S) was estimated by the method of Van Handel (1968). Free amino acids (FAA) and total phenols (TP) were determined by the methods of Moore (1968) and Swain and Hills (1959), respectively. The fresh chips were subjectively scored for colour and assigned a value from 1 to 10 (lower number-better colour). Chip colour score (CCS) up to 3 was acceptable.

### *Analytical procedures*

The mean, range, phenotypic coefficient of variation (PVC) and correlation coefficient were calculated. Mean values were used for principal component analysis to transfer the inter dependent variables into a set of independent variables (Mardia, 1971). Different clusters were generated through a non-hierarchical method of cluster analysis using the principal component analysis as proposed by Singh and Roy (1997).

## Results and Discussion

The results of present investigation showed considerable diversity in the germplasm as exhibited by wide ranges and moderate to high variability for all the traits. The data presented in Table 1 shows that the relative contribution of reducing sugars towards variability was very high. This was followed by average number, sucrose, average tuber weight and tuber yield. Moderate coefficient of variation was observed for total phenols, free amino acids and chip colour score, while dry matter content exhibited the lowest coefficient of variability. Since chip colour is the most important visual criterion to assess the consumer acceptability of the finished product, its relationship with other traits was worked out (Table 1).

**Table 1. Estimates of variability parameters for important traits**

| Parameter | Mean | Range | Coefficient of Variability (%) | Correlation coefficient (r) of chip colour score with other traits |
|---|---|---|---|---|
| Yield/plant (g) | 369 | 130-654 | 30.9 | NS |
| Tuber weight (g) | 48.0 | 19.0-96.5 | 31.3 | NS |
| Tuber number/plant | 8.19 | 4.0-18.2 | 33.2 | NS |
| Dry matter (%) | 30.11 | 16.0-24.0 | 8.9 | NS |
| Reducing sugar (mg/100g fresh wt) | 231 | 30-811 | 66.8 | 0.505* |
| Sucrose (mg/100g fresh wt) | 132 | 51-263 | 31.9 | NS |
| Total phenol (mg/100g fresh wt) | 47.0 | 17-92 | 29.9 | NS |
| Free amino acid (mg/100g fresh wt) | 59.0 | 24-104 | 27.9 | NS |
| Chip colour score | 6.35 | 1-10 | 25.8 | – |

Correlation matrix was used to transform all the metric traits into a single index of similarity in the form of principal components, which yielded nine eigen vectors and eigen roots. Only eight vectors were used for further analysis as these accounted for 99.44 per cent of the variation (per cent variation explained by these roots, was 24.04, 18.35, 15.0, 11.35, 10.58, 8.76, 6.68 and 4.59 respectively). The first component was a measure of tuber yield(g); the second component of average tuber weight and the third component was measure of chip colour score as the coefficients associated with these traits have the largest magnitude. Similarly, the dry matter and sucrose were presented by fourth; free amino acids by fifth, reducing sugar content by sixth, average tuber number by seventh and total phenol by eighth component.

Non-hierarchical Euclidean cluster analysis based on these eight principal components grouped 108 germplasm accessions and five controls into six well characterised groups (Table 2), suggesting the presence of considerable genetic diversity in the germplasm. The genotypes were distributed as 29 in cluster I, 13 in II, 23 in III, 11 in IV, 21 in V and 11 in VI (Table 2). The five controls were grouped into cluster V. The intra-cluster distance in cluster VI was the highest (2.595) follwed in the descending order by V, II, IV, I and II (Table 3). The inter-cluster distance between IV and V was 4.019 followed by II and VI (3.702) indicating that the genotypes of these clusters were highly diverse from those in other clusters. The cluster wise mean values are given in (Table 4). The data on inter-cluster distances and the mean performance of genotypes were used to select genetically diverse and superior accessions out of 108 accessions. The cluster III, having 23 genotypes, with the highest mean DM (21.2%), the lowest mean RS (149.69mg/100 g fresh wt) and the lowest and acceptable chip colour score (4.42) was considered desirable group for processing. Similarly, 26 genotypes of cluster V possessed reasonably good processing qu 'ity having 20.4% DM, 167.94 mg/100 g fresh wt RS and 5.09 CCS. The genotypes of cluster IV had high ATN (11.52), the highest RS content (519mg/100 g fresh wt) and high CCS (8.18), and were considered unsuitable for processing (Table 4). The cluster VI comprised of genotypes producing high tuber yield (516 g/plant) and high ATW (74.2 g) with moderate

**Table 2. Cluster-wise distribution of 108 germplasm accessions and five controls**

| Cluster No. | No. of genotypes | Accession number |
|---|---|---|
| I | 29 | CP 1151, 1157, 1197, 1783, 1810, 1884, 1854, 1859, 1871, 1873, 1875, 1876, 1879, 1881, 1890, 1891, 1896, 1911, 1915, 1917, 1918, 1933, 1936, 1945, 1945, 3194, 3195, 3196. |
| II | 13 | CP 1779, 1817, 1846, 1850, 1889, 1893, 1895, 1897, 1906, 1922, 1923, 1927, 1937. |
| III | 23 | CP 1175, 1178 1214, 1401, 1424, 1428, 1493, 1770, 1771, 1776, 1780, 1782, 1785, 1788, 1798, 1802, 1806, 1809, 1812, 1815, 1818, 1880, 1912. |
| IV | 11 | CP 1787, 1835, 1835, 1836, 1843, 1857, 1860, 1868, 1869, 1878, 1919, 1931. |
| V | 26 | CP 1523, 1524, 1771, 1775, 1777, 1778, 1781, 1796, 1800, 1804, 1811, 1825, 1907, 1908, 1914, 1921, 1924, 1935, 1940, 2184, 2271, Atlantic, FL 1533, FL 1625, Kufri Jyoti, Kufri Chandramukhi. |
| VI | 11 | CP 1143, 1207, 1231, 1564, 1784, 1813, 1822, 1824, 1826, 1827, 1832. |

**Table 3. Estimates of average intra and inter cluster distances based on non-hierarchical Euclidean cluster analysis**

| Cluster Number | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| I | **2.124** | 2.372 | 2.476 | 3.639 | 2.149 | 3.471 |
| II | | **2.094** | 2.462 | 2.545 | 2.682 | 2.275 |
| III | | | **2.368** | 3.459 | 2.485 | 3.702 |
| IV | | | | **2.364** | 4.019 | 3.477 |
| V | | | | | **2.468** | 2.685 |
| VI | | | | | | **2.595** |

Diagonal (bold face) values are average intra-cluster distances, and underlined values are the highest (4.019) and the lowest (2.149) inter-cluster distances.

**Table 4. Cluster wise mean values for yield and processing traits**

| Cluster No. | Chip colour Score | Reducing sugar (mg/100 g Fresh wt) | Dry matter (%) | Total phenol (mg/100 g fresh wt) | Free amino acid (mg N/100 g Fresh wt) | Tuber yield/ plant (g) | Average tuber weight (g) | Average tuber number/ plant |
|---|---|---|---|---|---|---|---|---|
| I | 6.04 | 187.63 | 20.24 | 29.55 | 42.76 | 272.75 | 41.91 | 6.86 |
| II | 6.92 | 351.31 | 18.57 | 42.54 | 43.34 | 430.95 | 57.11 | 7.74 |
| III | 4.42 | 149.69 | 3\21.20 | 55.03 | 63.08 | 336.67 | 33.62 | 10.35 |
| IV | 8.18 | 519.95 | 18.99 | 43.65 | 48.17 | 453.57 | 40.33 | 11.52 |
| V | 5.09 | 167.94 | 20.40 | 53.35 | 69.82 | 377.80 | 55.56 | 7.03 |
| VI | 7.82 | 230.15 | 19.80 | 48.23 | 54.74 | 515.83 | 74.18 | 7.06 |
| CD (0.05) | 0.56 | 19.5 | 0.12 | 0.98 | 0.27 | 37.8 | 1.93 | 0.02 |

DM (19.8%) and high reducing sugars (230 mg/100 g fresh wt). The genotypes grouped in cluster, I, II, IV and VI were not suitable for processing on the basis of their cluster mean values, whereas cluster III followed by Cluster V were deemed good for selecting genetically diverse and processing superior genotypes.

In this study, some genotypes which performed exceptionally good in respect to one and/or more yield and quality traits in comparison to the controls, were selected on the basis of individual genotypic performance out of 108 accessions (Table 5). Irrespective of the clustering, seventeen accessions were identified, which had reducing sugars <0.1% on fresh wt basis, an acceptable limit for producing good quality fired chips, Colour, the most important visual criterion for evaluating the quality of fried products, was mainly dependent upon Maillard reaction between reducing sugars and amino acids present in the tubers (Roe *et al.,* 1990; Marwaha, 1999). The presence of high reducing sugars make fried potato products unacceptable for consumers due to excessive darkening and development of off-flavours (Pritchard and Adam, 1994).

Six accessions were identified for having chip colour score up to 3 (acceptable). Out of these 6, four were such which also converged in the class of genetypes having low reducing sugar content (<0.1% on fresh wt basis), indicating the key role of reducing sugars in determining the colour of processed product. The correlation studies also revealed that chip colour was mainly dependent upon reducing sugar content of tuber (r=0.555**). Similar observations were also reported by Mizza (1983).

Six accessions were identified for having very high dry matter content (23.1-24.1%). Since, high dry

**Table 5. Elite accession with desirable processing quality traits selected from each cluster**

| Cluster No. | Chip colour Score (≤3) | Reducing sugar (<100 mg/100 g fresh wt) | Dry matter (>23%) | Total phenol (<24 mg/100 g fresh wt) | Free amino acid (<30 mg N/100 g fresh | Sucrose content (≤ 60 mg/100 g fresh wt) | Tuber yield/ Plant (>600g) | Average tuber weight (>70g) | Average tuber number (>15) |
|---|---|---|---|---|---|---|---|---|---|
| I | 1945 (3) | 1810(62.9) | 1873 (24.1) | 1891 (22.) | 1873 (24.0) | 1859(54) | | 1850 (71.6) | |
| | | 1896(69.0) | | | | 1918 (29.0) | | | |
| | | 1945 (78.0) | | | | | | | 1175 (15.4) |
| | | | | | | | | | 1780 (16.9) |
| | | | | | | | | | 1912 (18.2) |
| II | | | | 1817 (17.6) | 1937 (29.0) | | | | |
| III | 1780 (3) | 1175 (86.3) | 1178 (23.3) | | | 1175 (56) | | | |
| | 1798 (3) | 1214 (49.8) | 1776 (23.4) | | | | | | |
| | 1806 (3) | 1770 (68.3) | 1785 (23.1) | | | | | | |
| | | 1798 (29.0) | | | | | | | |
| | | 1806 (78.0) | | | | | | | 1868 (18.0) |
| | | 1818 (72.1) | | | | | | | |
| | | 1880 (58.0) | | | | | | 1924 (73.4) | |
| IV | | 1843 (69.2) | | 1868 (21.1) | | 1860 (57) | 1868 (620) | | |
| | | | | 1878 (23.1) | | 1868 (51) | | | |
| | | | | | | 1869 (60) | | 1143 (75.0) | |
| V | 1907 (3) | 1800 (80.9) | 1777 (24.0) | | | | | 1207 (79.2) | |
| | 1940 (1) | 1921 (88.0) | 1940 (23.1) | | | | | 1813 (80.5) | |
| | | 1940 (67.0) | | | | | | 1822 (76.8) | |
| | | | | | | | | 1826 (70.0) | |
| VI | | 1143 (69.3) | | | | 1207 (55) | 1564 (623) | 1832 (96.5) | |
| | | 1813 (71.2) | | | | 1564 (56) | 1813 (686) | | |
| | | 1873 (71.2) | | | | | 1824 (654) | | |
| | | | | | | | 1826 (650) | | |
| Control | | | | | | | | | |
| KCM | 5 | 112.0 | 17.8 | 32.4 | 101.3 | 197 | 329 | 48.9 | 9.7 |
| K. Jyoti | 5 | 101.7 | 19.9 | 40.2 | 104.1 | 193 | 472 | 37.8 | 8.7 |
| Atlantic | 3 | 82.0 | 21.2 | 17.4 | 76.4 | 263 | 425 | 60.2 | 7.1 |
| FL 1533 | 3 | 77.5 | 19.6 | 25.4 | 81.3 | 176 | 385 | 50.3 | 7.7 |
| FL 1625 | 3 | 33.0 | 21.6 | 23.4 | 92.1 | 170 | 334 | 48.7 | 6.8 |
| CD (5%) | 0.2 | 8.1 | 1.1 | 2.6 | 4.7 | 11.3 | 18.9 | 3.6 | 1.8 |

matter was associated with low oil absorption, high product yield and better process efficiency (Storey and Davis, 1992), these accessions were acclaimed suitable for processing. A wide variation in the sucrose content (51-263 mg/100 g fresh wt) was observed in the germplasm, but this parameter showed no specific influence on the processing quality of fried products as reported earlier (Marwaha, 1998).

Potatoes used for different forms of processing have stringent size and shape requirement (Krikman, 1986). Large size tubers are preferred for processing into fried and dehydrated products, as the peeling loss is proportionally greater for small tubers (Marwaha, 1997). In the present investigation, eight genotypes, viz., CP 1143, 1207, 1822, 1826, 1832, 1850, 1873 and 1924 were identified for having large tuber size (>70g) and were considered most suitable, as these will show less peeling losses ultimately leading to high product yield. Four accessions namely, CP 1175, 1780, 1832 and 1912 produced small sized tubers (19.1-28.7 g), but in large numbers (ATN>15) and were designated ideal for canning which required small size tubers with low dry matter content (Kadam *et al.*, 1991). CP 1832 with high ATN (18.3) and low dry matter (17.0%) was found to be most suitable for canning.

Five high yielding accessions viz., CP 1564, 1813, 1824, 1826 and 1868 were identified having dry matter content between 16.0 to 21.3 per cent, Since, the yield recovery of processed products was directly related to the tuber dry mater content and tuber yield per unit area of a particular genotype (Marwaha and Kang, 1994), these accessions were expected to give high product yield. CP 1813, an accession, besides producing high yield (686g/plant), also possessed high ATW (80.4 g), high dry matter content (21.0%), low free amino acids (33.7 mg N/100g fresh wt), low total phenols (32.2mg/100g fresh wt) and low reducing sugars (71.2mg/100g fresh wt). This high yielding accession with desirable processing attributes can be successfully exploited to generate useful segregates in breeding programme for processing quality.

Three accessions, viz., CP 1873, 1918 and 1937 were found to have low FAA content (<30 mg N/100g fresh wt). Free amino acids have been reported to participate in the development of colour of the fried products (Cobb *et al.*, 1990), however in the present study no such relationship was observed (r=-0.136). This was in confirmation with the findings reported by several workers (Herrman *et al.*, 1996; Marwaha, 1999).

Phenolic compounds have been associated with enzyme discoloration (Marwaha, 2001) and cooking quality of potato (Mondy and Munshi, 1988). Four accessions, viz., CP 1817, 1868, 1878 and 1891 contained low total phenol content (<24mg/100 g fresh wt) and were expected to show better cooking quality.

On simultaneous consideration of all the factors, an accession CP 1940 from USA, was marked excellent for having the best chip colour (chip colour score 1), low reducing sugars (<0.1%), high dry matter (23.1%) and low total phenol (26.0 mg/100 g fresh wt). It has oval shaped tubers having shallow eyes with a good average tuber weight (63.9 g). Six germplasm accessions, viz. CP 1780, 1898, 1806, 1907, 1940 and 1945 were found to possess all the desirable processing traits. These accessions can serve as parents to generate desirable segregates in breeding programmes aimed to develop potato varieties suitable for processing in the north-western plains of India.

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