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Morphological characterization of indigenous potato (*Solanum tuberosum*) genotypes

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ABSTRACT

Potato (*Solanum tuberosum* L.) is the most important non-grained food and vegetable crop lauded for its nutritional and health benefits. Identifying any new potato genotype primarily depends on its morphological traits, including vegetative, floral and tuber parameters. The present study was carried out during 2020–21 and 2021–22 at the research farm of ICAR-Central Potato Research Institute, regional station, Modipuram, Uttar Pradesh and at ICAR-Central Potato Research Institute, Kufri-Fagu unit, Himachal Pradesh (for floral traits) to evaluate the potato genotypes for vegetative and tuber traits. The experiment was laid out in a randomized complete block design (RCBD) with three replications. Total of 64 indigenous potato genotypes were characterized for 51 morphological traits for distinctiveness, uniformity and stability (DUS) test guidelines. For all traits, there was a high degree of variability between genotypes. Early maturing varieties are preferred owing to their suitability to fit into the potato-wheat (*Triticum aestivum* L.)-paddy (*Oryza sativa* L.) cropping system. Most genotypes were either early or medium maturing based on foliage senescence. High variability was observed for tuber shape, i.e. genotypes bearing flattened, round, ovoid, oblong, long-oblong and reniform-shaped tubers were available. Tuber skin and flesh colour determining consumer preference depicted variability from whitish cream to dark purple-black skinned tubers. Novel genotypes bearing variegated tuber flesh with a niche market of specific consumer segments were noticed in genotypes Red flesh, Bareilly red, DRR Blue, Badami aloo and Kala aloo. Moreover, the results obtained from the present investigation indicated that the description of 64 indigenous potato genotypes based on notes can be used as a reference for the protection of new varieties under the Protection of Plant Varieties and Farmers Right Act (PPV&FRA) rules as well as a comparison against new candidate varieties.

Keywords: DUS guidelines, Genotypes, *Solanum tuberosum*, Variability

Potato (*Solanum tuberosum* L.) is a popular vegetable crop grown globally and widely grown in 5 continents, Africa; Asia; Europe; Oceania and the Americas (Mora *et al.* 2022). Potato producing top 10 countries are China, India, the Russian Federation, Ukraine, United States of America (USA), Germany, Bangladesh, Poland, France and Netherlands. China and India produced about one-third of the world's potatoes in 2020 (Potato Production Worldwide 2020, Statista https://www.statista.com). It is important to note that potatoes have been identified as a food security crop by the United Nations, and they play a significant role in agriculture, the economy, food security, and poverty alleviation (Bradshaw and Ramsay 2009, Bradeen and Haynes 2011, Calliope *et al.* 2018). The potato is grown as a major crop in a wide range of climate zones, including subtropical, tropical, and temperate regions, all with very different agro-ecological conditions, lowlands and highlands, and in very different socio-economic conditions.

As a highly nutritious vegetable and a great source of carbohydrates, potatoes also provide dietary fibre, protein, minerals, vitamins, and antioxidants.Therefore, improving potato crop productivity may help meet the nutritional needs of the growing population (Birch *et al*. 2012).The indigenous potato Bareilly red is nutrient-rich and used in potato breeding programmes (Luthra *et al.* 2018). According to Wang *et al*. (2019), potato landraces have been cultivated in China due to their taste preference or adaptability since this crop was introduced in the 16thcentury.

The description and classification of genetic resources begin with morphological characterization (Abebe *et al*. 2013). A DUS test is conducted exclusively to determine whether a newly bred variety differs from other varieties of the same species, whether the characteristics that establish distinctness are expressed uniformly over time and if they do not change over time. In India, DUS testing of potato varieties is carried out by the ICAR-Central Potato Research

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Institute, Shimla, Himachal Pradesh. Presently, 51 DUS potato characters are defined by Central Potato Research Institute and used for distinguishing new varieties.

To identify genetic resources, they must be characterized by morphological and agronomic traits. Collecting, characterising and evaluating remnant local genotypes before they disappear is essential. The present study aimed to generate the data of DUS descriptors for indigenous varieties, which will be helpful for the characterization of candidate varieties and their protection through PPV&FRA.

MATERIALS AND METHODS

An experiment was conducted during 2020–21 and 2021–22 at the research farm of ICAR-Central Potato Research Institute, regional station, Modipuram, Meerut, Uttar Pradesh to determine the morphological diversity of 64 indigenous potato genotypes (Table 1) for 51 morphological traits. The vegetative and tuber characters were recorded at this station, while the floral characters were recorded at ICAR-Central Potato Research Institute, Kufri-Fagu unit, Shimla, Himachal Pradesh. The experiment was laid out in a randomized block design (RBD) with three replications, and the bed size spacing was 4.8 m^2. The numbers of rows were 4 of 2 meters in length. Row-to-row distance of 60 cm and a plant-to-plant distance of 20 cm were maintained. To assess distinctiveness and stability, observations were collected from 10 plants/replication. For the assessment of the uniformity of characteristics on the plot as a whole (visual assessment by a single observation of group of plants or parts of plants), a population standard of 1% with an acceptance probability of 95% was applied. All leaf/leaflet characteristics were observed on a fourth fully developed leaf from the top of the plant. The latest Royal Horticultural Society (RHS) colour chart was used to assess colour characteristics. Total 51 morphological characters were recorded as per the DUS guidelines recommended by

Table 1 Variation in characteristics of different genotypes

Lightsprout predominant colour	Genotypes
White green	1001, Assamia Alu, Bengal Jyoti, Desi Alu, G-4, Jalandhar, Kanpuria Safed, Lah Arpor, Lah Sarkari, VAR 3797, Lah Syntiew, Phulwa Red Splashed, Phulwa white, Australian White, AGR/56, Dhankri, Nainital
Pink	Champaran Lal, Deshla Lal, Dwarf Culture, Kacha Bhutia, Lah Saw, Lah Saw Smith, Lah Tora, Lal Ankh, Lal Lauvkar, Lal Mitti-1, Lal Mitti-2, ON-1645, Phulwa Red
Red purple	1007, Bhura Alu, Burma Special, C-9 Patna, DRR Red, Garlentic, Gulabia, Gulmarg Special, Aamraj Hatti, K-22, KP-PC-292, Lah Polin , Lah Saw Khasi, Lal Gulab, Lal Jyoti, Rangpuria, Dehati Alu, 1591/11, Desi No-2, Sathoo, V2-2912, Desi No-1, Clone-1, Aberchaibi, Beeta, Badami Alu, PSK-76
Purple	Bareilly Red, Red Flesh, DRR Blue, SisaPani, Jeevan Jyoti, PS-4904
Blue	Kala Aloo
Stem predominant colour	*Genotypes*
Green	1001, 1007, Assamia Alu, Bareilly Red, Bengal Jyoti, Bhura Alu, Burma Special, C-9 Patna, Champaran Lal, Desi Alu, Deshla Lal, DRR Blue, SisaPani, DRR Red, Dwarf Culture, G-4, Garlentic, Gulabia, Gulmarg Special, Aamraj Hatti, Jalandhar, Jeevan Jyoti, K-22, Kacha Bhutia, Kanpuria Safed, KP-PC-292, Lah Arpor, Lah Polin , Lah Sarkari, Lah Saw, Lah Saw Khasi ,VAR 3797, PS-4904, Lah Saw Smith, Lah Syntiew, Lah Tora, Lal Ankh, Lal Gulab, Lal Jyoti, Lal Lauvkar, Rangpuria, Lal Mitti-1, Lal Mitti-2, ON-1645, Phulwa Red, Phulwa Red Splashed, Phulwa white, Dehati Alu, 1591/11, Desi No-2, Sathoo,V2-2912, Desi No-1, Clone-1, Australian White, Aberchaibi, Beeta, AGR/56, Badami Alu, Dhankri, Nainital, PSK-76
Red brown	Kala Aloo
Purple	Red Flesh
Dark purple	None
Flower corolla colour	*Genotypes*
White	1001, 1007, Assamia Alu, Bengal Jyoti, Desi Alu, Deshla Lal, DRR Blue, Dwarf Culture, G-4, Gulmarg Special, Jalandhar, Kacha Bhutia, Kanpuria Safed, Lah Polin, Lah Saw, Lah Saw Khasi ,VAR 3797, PS-4904, Lah Saw Smith, Lah Syntiew, Phulwa white, Dehati Alu, Desi No-2, Sathoo, Desi No-1, Clone-1, Australian White, AGR/56, Kala Aloo, PSK-76,
Red violet	Bareilly Red, Bhura Alu, Burma Special, Red Flesh, C-9 Patna, Champaran Lal, SisaPani, DRR Red, Garlentic, Gulabia, Hamraj Hatti, Jeevan Jyoti , K-22, KP-PC-292, Lah Arpor, Lah Sarkari, Lah Tora, Lal Ankh, Lal Gulab, Lal Jyoti, Lal Lauvkar, Rangpuria, Lal Mitti-1, Lal Mitti-2, ON-1645, Phulwa Red, Phulwa Red Splashed, 1591/11, V2-2912, Aberchaibi, Beeta, Badami Alu, Dhankri, Nainital,
Blue violet	None

Contd.

Table 1 *Contd.*

Lightsprout predominant colour	Genotypes
Tuber predominant skin colour	*Genotypes*
Whitish cream	Bengal Jyoti, Burma Special, G-4, Garlentic, Gulmarg Special, K-22, Kacha Bhutia, Lah Arpor, Lah Saw, Lah Saw Khasi, VAR 3797, PS-4904, Lah Saw Smith, Rangpuria, Phulwa white, Dehati Alu, 1591/11, Sathoo, V2-2912, Desi No-1, Clone-1, Beeta, Dhankri, Nainital, PSK-76,
Yellow	1001,Assamia Alu, Desi Alu, Kanpuria Safed, Lah Polin, Lah Syntiew, ON-1645, AGR/56
Orange	1007, Jalandhar , KP-PC-292
Brown	Lah Sarkari, Australian White
Pink	Phulwa Red Splashed, Aberchaibi
Red	Bengal Jyoti, C-9 Patna, Champaran Lal, Deshla Lal, DRR Red, Dwarf Culture, Gulabia, Aamraj Hatti, Jeevan Jyoti, Lah Tora, Lal Ankh, Lal Gulab, Lal Jyoti, Lal Lauvkar, Lal Mitti-1, Lal Mitti-2, Phulwa Red, Desi No-2, Badami Alu
Reddish purple	None
Purple	Bareilly Red, Red Flesh, DRR Blue, SisaPani
Dark purple-black	Kala Aloo
Tuber shape	*Genotypes*
Flattened	Assamia Alu, Lal Gulab, Phulwa white
Round	Bareilly Red, Bhura Alu, Red Flesh, C-9 Patna, Champaran Lal, Desi Alu, Deshla Lal, DRR Blue, SisaPani, DRR Red, Dwarf Culture, Garlentic, Gulabia, Hamraj Hatti, Jalandhar, Jeevan Jyoti, KP-PC-292, Lah Polin, Lah Saw, Lah Saw Khasi, VAR 3797, PS-4904, Lah Saw Smith, Lah Tora, Lal Ankh, Lal Jyoti, Lal Lauvkar, ON-1645, Phulwa Red, Desi No.2, Aberchaibi, Beeta
Ovoid	1001, 1007, Burma Special, K-22, Kacha Bhutia, Lah Arpor, Lah Sarkari, Lah Syntiew, Rangpuria, Lal Mitti-1, Lal Mitti-2, Phulwa Red Splashed, Dehati Alu, Sathoo, V2-2912, Desi No-1, Clone-1, Australian White, AGR/56, Kala Aloo, PSK-76
Oblong	Bengal Jyoti, G-4, Gulmarg Special, Kanpuria Safed, 1591/11, Nainital
Pear shaped	None
Long-oblong	Dhankri
Reniform	Badami Alu
Irregular	None
Tuber predominant colour of flesh	*Genotypes*
White	Assamia Alu, K-22, Kacha Bhutia, KP-PC-292,VAR 3797, PS-4904, Lah Syntiew, Lah Tora, Dehati Alu, V2-2912, Clone-1, Dhankri, PSK-76
Cream	1001, 1007, Bareilly Red, Bhura Alu, Burma Special, Red, Flesh, Champaran Lal, SisaPani, G-4, Gulmarg Special, Aamraj Hatti, Kanpuria Safed, Lah Arpor, Lah Sarkari, Lah Saw, Lah Saw Khasi, Lah Saw Smith, Lal Ankh, Lal Gulab, Lal Lauvkar,ON-1645, 1591/11, Sathoo, Desi No-1, Aberchaibi, Beeta, AGR/56, Badami Alu, Nainital, Kala Aloo
Yellow	Bengal Jyoti, C-9 Patna, Desi Alu, Deshla Lal, DRR Blue, DRR Red, Dwarf Culture, Garlentic, Gulabia, Jalandhar, Jeevan Jyoti, Lah Polin, Lal Jyoti, Rangpuria, Lal Mitti-1, Lal Mitti-2, Phulwa Red, Phulwa Red Splashed, Phulwa white, Desi No.2, Australian White
Reddish purple	None
Dark purple	None

PPV&FRA, GoI, New Delhi. The indigenous varieties for DUS testing were divided into different groups to facilitate the assessment of distinctiveness. The 51 characteristics used for grouping potatoes were lightsprout (6), vegetative (18), flower (18) and tuber (9).

RESULTS AND DISCUSSION

In the present study, there was considerable variation among 64 indigenous potato genotypes for all qualitative and quantitative characters related to vegetative, floral and tuber stages, viz. lightsprout, stem, foliage, flower and tuber characteristics. The aerial parts of the potato plant are less frequently used for characterization compared to tuber traits. The above ground potato plant characteristics are the first to be noticed in genotypes, but they are not well defined in many varieties. Morphological characterization is essential for differentiating varieties (Seijo-rodriguez *et al*. 2017).

The light sprout predominant colour was uniformly

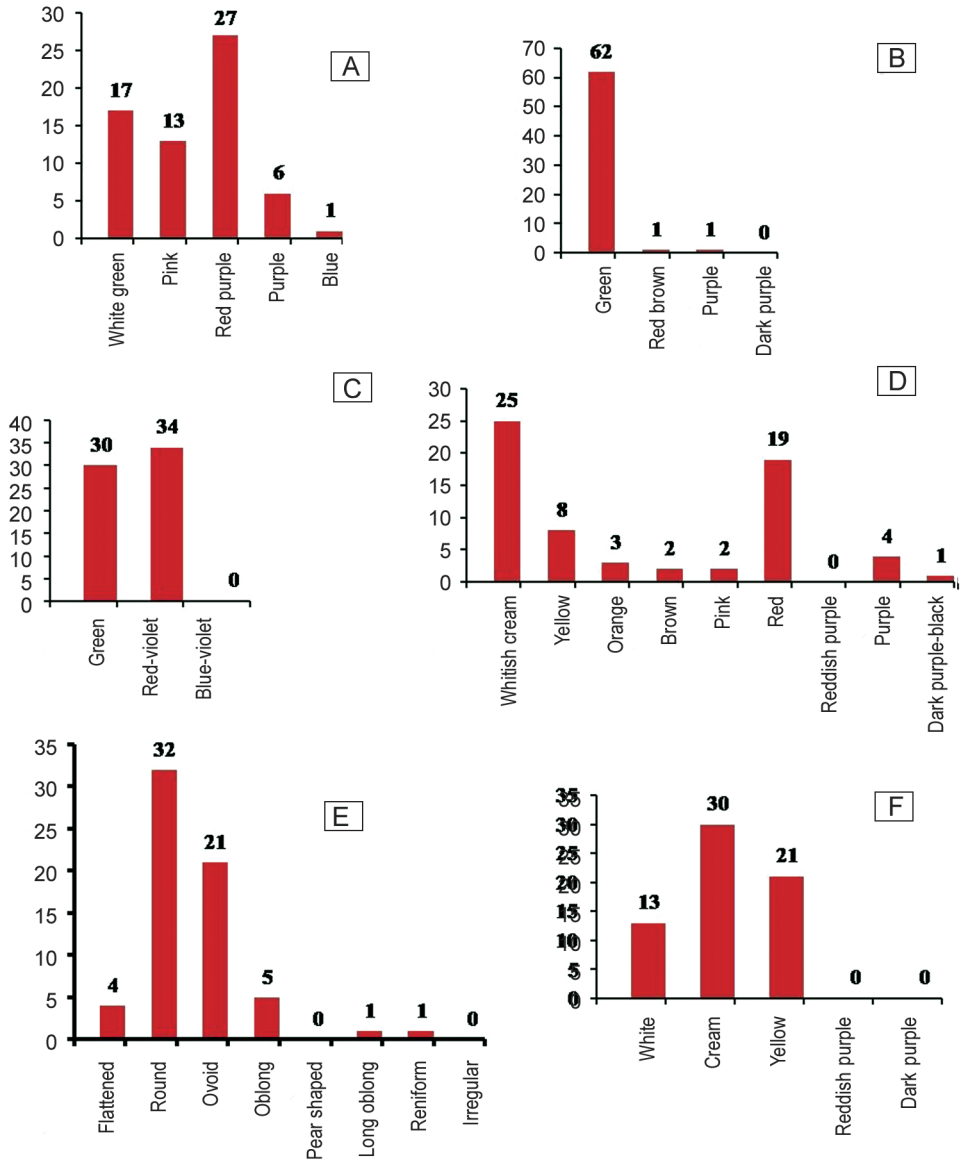

Fig. 1 A, Light sprout: Predominant colour; B, Stem predominant colour; C, Flower: Corolla colour; D, Tuber: Predominant skin colour; E, Tuber: Shape; F: Tuber: Predominant colour of flesh.

distributed among 64 genotypes. 17 genotypes showed white green sprout colour, 13 genotypes had pink colour sprout (Table 1). Red purple sprout colour was observed for 27 genotypes and 6 genotypes showed purple while only a single genotype Kala aloo had blue sprout (Fig. 1A). The colour of lightsprout was found to be a useful trait for the characterization of genotypes. The shape of lightsprout was spherical in 33, conical in 22 and cylindrical in 11 genotypes of potato. About 28 genotypes had light and medium intensity of anthocyanin colouration at base of sprout and 8 were observed with dark anthocyanin colouration at the base of sprout. However, majority of genotypes (50) observed with light intensity of anthocyanin colouration at sprout tip, ten medium and others recorded dark coloured tip. Pubescence at base of lightsprout was absent in 6 genotypes. Others were having either weak or strong pubescence at the base. The length of apical sprouts was small in 51 genotypes, 10 were medium and the rest 3 were with long apical sprouts.

In explaining the foliage parameters, 20 genotypes had compact canopy, 32 were semi-compact and others had open-type canopies. Out of 64 genotypes, 20 were solid stemmed and 44 were hollow. In the dimorphic trait, stem cross-section was round in 50 genotypes and remaining were angular.12 genotypes were small with less than 50 cm plant height, 47 were medium and only 5 were tall. However, weather parameters influence both foliar and floral traits, low temperature and high rainfall lead to more tall plants and also the highest degree of flowering (Escuredo *et al*. 2020)

Concerning predominant stem colour, there were distinct variations in potato genotypes starting from green to dark purple. The majority of genotypes recorded green predominant stem colour with exception of only 2 genotypes (Table 1) (Fig. 1B). Red-brown (47) was the most distributed secondary colouration on stem. Only one genotype had green secondary colouration and absent in 16 genotypes. Distribution of secondary colour was found absent in 16, only at base in 18, only at lower node in 20, throughout lightly scattered in 4 and throughout highly scattered in 5 genotypes. Plant wings were poorly developed in 27 genotypes and highly developed in 37 genotypes of which 30 genotypes had straight wings and remaining were wavy winged. The leaves were open type in 20 genotypes, intermediate in 36 and close leaves were marked in 8 genotypes. Anthocyanin colouration of rachis was absent in 40 while anthocyanin colouration of midrib was absent in 57 genotypes. In case of leaf length, it was large in 47 genotypes, medium in 15 and 2 were small while width was recorded narrow in 5, medium in 58 and broad in single genotype.The distribution of lateral leaflet shape was narrow lanceolate in nine genotypes, lanceolate in one, ovate lanceolate in 45, ovate in 7 and oval in two genotypes.Waviness of margin of the leaflet was weak in 30, medium in 30 and strong in 4 genotypes. 16 genotypes

had strong shining leaflets while glossiness of upper side observed weak in 16 and medium in remaining genotypes. Pubescence of blade at apical rosette was found to be monomorphic character as all the genotypes recorded this character.

One of the most effective visual discrimination between genotypes is by floral traits. Anthocyanin colouration of bud was present in 43 genotypes only while that in floral stalk varied from absent in 18, weak in 23 and medium in 23 genotypes. Anthocyanin colouration of pedicel articulation was present in 39 genotypes and remaining had no colouration. None of the genotype had below the middle pedicel articulation position. Middle was recorded for 17 and above the middle for 47 genotypes. Corolla colour, one of the grouping characters was divided as white coloured in thirty genotypes (Table 1) and 34 genotypes recorded red violet colour. No accessions had blue-violet corolla (Fig. 1C). 12 genotypes had small flowers i.e. small corolla size while 19 genotypes bore large flowers. Inflorescence size was large for 12 genotypes with >20 flowers/inflorescence and 22 genotypes marked for small i.e. <10 flowers. Remaining genotypes had medium-sized inflorescence. Anthocyanin colouration of outer side in white flowers was absent in 25 and present in 5 genotypes while intensity of anthocyanin colouration of corolla on inner side was absent in 30, weak in 13, medium 20 and strong in a single genotype.

The colour of anthers determines its fertility. Anthers produced on male sterile plants are generally light yellow or yellow-green (Muthoni *et al*. 2012). None of the genotypes recorded greenish-yellow anthers signifying all genotypes in the present evaluations are male fertile. 49 genotypes had yellow while others had orange anthers. The anther cone was normal in 56 genotypes while pistil was normal in 62 genotypes. Stylar length was recorded as equal for 10 and longer for 54 genotypes. Stigma shape was round and unilobed in 13 and the remaining genotypes were either bilobed or trilobed.

A high altitude provides conducive conditions for flowering and fruiting in potato (>1500 m asl) (Gopal 1994). Premature bud dropping is one of the major cause of sterility in potato plant. Flowering data at Kufri conditions recorded 14 genotypes had premature bud dropping affecting their successful usage as parental lines in hybridisation activities. However, all the genotypes bear flower. Sparse flowering was observed in 22 genotypes, 28 were medium blooming and profuse in 14 genotypes.

The time to maturity varied among the genotypes under study. Early maturing potato genotypes have advantages of fetching premium prices, mitigate the rise in temperature at harvesting time and also fit into different cropping system. 22 genotypes were early with the maturity duration of less than 80 days. Medium maturation of 80–100 days recorded for 34 genotypes. Remaining genotypes were found to be late with more than 100 days.

Tuber skin colour had direct influence on consumer preferences. Whitish cream and yellow tubers has pan-India acceptance. On the other hand pink and/or red skinned tubers are liked in eastern parts of the country while reddish purple, purple and dark purple-black novel genotypes have several health benefits. 25 genotypes were with white cream skin (Table 1). Yellow colour of tubers was observed in 8 genotypes, 3 genotypes with orange tubers. Brown and pink predominant skin colours were observed in two genotypes each while 19 genotypes were recorded for red skin colour. 4 genotypes showed purple skin colour and only Kala Aloo had dark purple black tuber skin colour (Fig. 1D). Secondary tuber skin colour was absent in 55 genotypes i.e. uniformly coloured, 6 were with whitish cream, 1 was yellow and 2 genotypes were found to have red secondary tuber skin colouration. The secondary skin colouration was present on eyebrow only in 4, spectacled (only around eyes) in one and stippled in 4 genotypes. Most of the genotypes had smooth skin (61) and rough skin was observed in Lal Lauvkar, Desi no. 2 and Australian White.

CIP gene bank uses 9 basic categories for tuber shape i.e. compressed, round, ovoid, obovoid or oval, oblong, long-oblong, elliptic, elongated and unusual shapes (for example pawlike) (Ortiz and Huaman 1994) while tuber shape in Indian potato DUS descriptor is defined into 8 categories i.e. flattened, round, ovoid, pear-shaped, oblong, long-oblong, reniform and irregular. Round to ovoid tubers are suitable for processing into chips while for fries, oblong to long-oblong-shaped tubers are preferred. Tubers of any shape except irregular are suitable for table/fresh consumption varieties. Assamia alu, Gulmarg special, Lal Gulab and Phulwa white had flattened tuber shape while 32 genotypes recorded round tuber shape (Table 1). 21 genotypes were found with ovoid tubers. 5 genotypes were noticed with oblong shape of tubers. Dhankri had long-oblong while Badami aloo recorded reniform tuber shape (Fig. 1E).Tuber eye depth is an important economic trait correlated with peeling losses.Shallow eyes are a quality attribute for a variety suitable for processing. Majority of the genotypes had either shallow (39) or medium deep (16) eyes. Protruding eyes were observed in 3 genotypes while 6 genotypes had deep eyes. Novel appearances of tuber flesh colours have benefits of higher antioxidant content. Red and purple flesh colour results due to accumulation of flavonoids (anthocyanins) while yellow to orange colour is imparted by xanthophylls (group of carotenoids).The white flesh colour was recorded for 13 genotypes and 30 genotypes were found with cream predominant colour of flesh (Table 1, Fig. 1F). Other 21 genotypes had yellow flesh defining high carotenoids content. None of the genotype had either reddish purple or purple predominant flesh colour (Fig. 1F). Dalamu *et al*. 2014 also pointed out wide variations in tuber skin and flesh colour in indigenous potato genotypes that have health promoting compounds, viz. anthocyanins, total carotenoids and total phenolic content. Secondary colouration of flesh was absent in 59 genotypes while reddish purple and dark purple colouration was observed in 3 and 2 genotypes, respectively that were distributed in inner cortex in Red flesh, vascular ring in Bareilly red, DRR Blue and Badami aloo, mottled in Kala aloo and remaining

genotypes had no distribution as secondary colouration itself was absent.

The present study revealed high levels of genetic variations for 51 morphological and agronomic characters among the 64 indigenous potato genotypes. Of 51 characters studied, only one character i.e. pubescence of blade at apical rosette was monomorphic, 13 characters were dimorphic and 37 characters were polymorphic, all of which could be used to identify genotypes. The characteristics of local potato genotypes grown in India were elaborated, which were first introduced and have not been characterized so far. The genotypes with desirable characteristics could be selected and identified for inclusion in potato breeding programme. The information obtained through this type of investigation is useful for the generation of an indigenous potato database that can be compared with new candidate varieties applied for protection under PPV&FRA legislation.

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