

Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes

*A Thesis submitted to the
Odisha University of Agriculture and Technology
in partial fulfillment of the requirement for the degree of
Master of Science in Agriculture
(Plant Breeding and Genetics)*

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This is to certify that the thesis entitled “Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes” submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF SCIENCE IN AGRICULTURE (Plant Breeding and Genetics)** of the **Odisha University of Agriculture and Technology, Bhubaneswar**, is a faithful record of bonafide research work carried out by **SUPRIJA KANHAR, Adm. No. 201222111** under my guidance and supervision. No part of the thesis has been submitted to any other degree or diploma.

It is further certified that the assistance and help availed by her from various sources during the course of investigation have been duly acknowledged.


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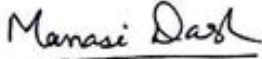
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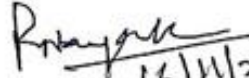

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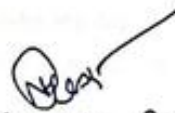
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ABSTRACT

The present investigation entitled “**Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes**” was carried out in AICRP on potato, Bhubaneswar during Rabi 2021-2022 to study the genetic variability among twenty five heat tolerant potato genotypes with respect to morphological and biochemical traits, and the association of different characters with tuber yield. The experiment was carried out in randomized complete block design with three replications. Statistical analyses of 20 morphological and 10 biochemical characters were done for variability, heritability, genetic advance, correlation, path coefficient analysis and D^2 analysis. The analysis of data revealed that there exists a wide range of variation for almost all the characters studied with particular reference to plant height, number of shoots per plant, number of leaves per plant, number of leaflets per leaf, top most leaf length and breadth, yield per plot, etc. In general, the values for phenotypic coefficient of variation were higher than the respective genotypic coefficient of variation values for all the characters under study. The values of phenotypic coefficient of variation and genotypic coefficient of variation were highest for non-marketable tuber yield and lowest for leaves per plant at both 40 days and 50 days after planting. Genetic advance was the highest for total tuber yield (t/ha) and the lowest for leaflets/ leaf at 30 days after planting. Highest heritability was observed for marketable tuber yield (t/ha) and lowest for top most leaf length at 40 days after planting. GA as % over mean was the highest for non-marketable tuber yield and lowest for leaves per plant at both 40 days and 50 days after planting. Path coefficient analysis revealed that marketable tuber yield had the highest direct positive effect on total tuber yield while highest direct negative effect on tuber yield was exerted by plant height at 50 days after planting. Similarly top most leaf length exhibited highest positive indirect effect on tuber yield and leaflet per plant at 30 days after planting. Based on D^2 statistics, twenty five varieties were grouped into 11 clusters for morphological characters and 10 clusters for biochemical characters. For morphological traits, the cluster I included maximum number of 15 genotypes. Cluster III and cluster VII were found to be the most divergent from each other having inter-cluster distance of 57.26 while cluster II and cluster V were least divergent from each other having inter-cluster distance of 7.93. For biochemical traits, the cluster I and cluster II included maximum number of 8 genotypes each. From the multivariate analysis, it has been seen that cluster IV and cluster IX were most divergent from each other having inter-cluster distance of 81.54. In contrast, cluster V and cluster VIII were least divergent from each other having inter-cluster distance of 8.12.

INTRODUCTION

Potato (*Solanum tuberosum L.*) belongs to family Solanaceae having chromosome no. $2n=4x=48$. It is the world's third most significant food crop after wheat and rice. In many developing nations around the world, potato is regarded as an essential crop due to its nutritional content. In general, potato provides more calories and protein per unit area with much less amount of time and water than the majority of other food crops (Upadhyaya, 1989).

The potato is an Andean tuber crop that was first domesticated in South America. It began to spread throughout the world after Columbus' expeditions. It was introduced into Europe in the 16th century. It was brought to India in the early Seventeenth century and over time developed into the most significant and commonly grown vegetable crop in the eastern Gangetic plains of India.

Potatoes, in reality, have a well-balanced nutritional composition, with less calories and a significant amount of high-quality protein, vitamins, minerals and trace elements. Potatoes are nutritionally superior to most other cereals and root crops because of their greater protein to calorie ratio. Vitamin C is found in small amounts in other staple foods such as rice, wheat and maize. In contrast, potato contains half of the daily adult requirement of vitamin C. Gopalan *et al.* (1972) determined that 100g of fresh potato tubers contains carbohydrates (22.6 g), proteins (1.6 g), calcium (10 mg), minerals (0.60 g), carotene (24 mg), iron (0.70 mg), fibre (0.40 g), phosphorus (40 mg), thiamine (0.10 mg), riboflavin (0.01 mg), niacin (1.20 mg) and vitamin-C (17 mg). Antioxidants found in the carotenoids and anthocyanins are available in potatoes. The body can easily absorb the iron found in potatoes. When it comes to fibre, it satisfies the daily recommendation by 10%. Because of its extensive utility, the potato is regarded as the "**king of vegetables**" and holds a dominant position among other crops.

Odisha has a diverse geography and a variety of climate conditions. As a result, it has been divided into ten agroclimatic zones under four physiographic divisions, namely the Coastal Plain, Eastern Ghats, Central Tableland, and Northern Plateau, which are mostly characterized by tropical, moist, humid to sub humid climate with summer temperatures reaching up to 35-45 degree Celsius and winter temperatures from 9 to 11.5 degree Celsius, and are characterized by deltaic alluvial sandy loam to clay loam soil. One of the greatest

impediments to achieving the potential yield in Odisha state is the short winter time in practically all agro climatic zones. Potatoes may be cultivated in Odisha during the kharif season, which runs from June to October in the undivided districts of Kandhamal and Koraput, and from November to February in the rest part of the state. When the night temperature during tuberization remains between 12 and 18 degree Celsius, the potato crop's growth and economic returns can be attained. Potatoes respond effectively to residual fertilizer applications in the rabi season, and this contributes to great returns. Potash, phosphorus and nitrogen residues of potato crop cut the subsequent grain crop's nutritional requirements by half. Potato planting, harvesting, post-harvest handling, and processing all provide significant job opportunities. The main causes of such a low yield of potatoes in India, particularly in Odisha, are due to the use of improper planting materials, unbalanced application of fertilizers and manures and the use of conventional farming techniques.

Among all major food crops, potatoes yield the most dry matter, edible energy and proteins per unit area per unit time. Potato production is migrating from Europe to Asia and other countries of the developing globe where population density is high, owing to the crop's capacity to feed an ever-increasing population. Today, developing countries produce 37 percent of the world's potatoes (Shekhawat and Naik 1999). Potato yields are low in these places because of the high day and night temperatures. Imparting potatoes with heat resistance will help them establish as a major food crop in these places.

High night time temperatures are considerably more harmful to potato tuber development than high day time temperatures. Potatoes may provide a reasonable yield even with 30-35°C in day time but the night time temperature remaining below 18°C. Tuberisation is negligible even if the day temperature is 25-27 degree celcius and the overnight temperature is above 22°C. So, when it comes to potato heat tolerance, the lowest night temperature is more important than the highest day temperature (Burton, 1996).

To increase the effectiveness of the selection process for tolerable variations, it is essential to observe the morphological and physiological features that contribute to the heat tolerance of potato genotype. The goal of this study was to determine whether it was possible to select heat-tolerant potato genotypes with good yields in hot field circumstances just by studying some vegetative growth and physiological parameters. The protein level of potatoes is quite high compared to cereals on a dry weight basis. Potato is low in fat and high in numerous micronutrients and vitamins (Lutaladio and Castaldi, 2009) especially Vitamin C

when consumed with skin. The valuable amino acid content of potatoes results in good protein quality. It provides the essential daily needs of several chemicals, including macro and microelements. However, the development and introduction of heat tolerant potatoes will benefit farmers of tropical areas considerably.

Keeping these in view, the present investigation entitled “Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes” was initiated with the following objectives:

- To estimate variation in growth attributes and yield of heat tolerant potato genotypes.
- To elucidate the difference in quality parameters and other biochemical and physiological traits among test entries.
- To study the correlation among morphological, physiological and biochemical traits.

REVIEW OF LITERATURE

Potato is the most important vegetable and is consumed every day by the whole global population. It is a well-balanced diet with high protein content, superior nutritional value and necessary vitamins and minerals. In addition to direct consumption, the processing sector is increasingly using potato as a raw material. However, rising temperatures are challenging agriculture worldwide, especially in the northern hemisphere where most cultivated plants like potato are not adapted to such conditions (George *et al.*, 2017, Hastilestari *et al.*, 2018 and Trapero-Mozos *et al.*, 2018). Elevated temperatures result in down-regulation of SP6A (SELF-PRUNING 6A) expression, which correlates with decreased tuber yield (Hancock *et al.*, 2014; Hastilestari *et al.*, 2018; Lehretz *et al.*, 2019). Drought is often linked with heat and both together strongly decrease tuber yield (Schafleitner *et al.*, 2007). Co-expression of hexokinase 1 from *Arabidopsis thaliana* (AtHXK1) in guard cells and SELF-PRUNING 6A (SP6A) using the leaf/stem-specific StLS1 promoter could help to increase water use efficiency as well as tuberization under drought and heat stress (Lehretz *et al.*, 2021).

Knowledge of genetic variability and genetic diversity for economic features in breeding material, particularly their magnitude, is crucial for developing a successful breeding programme. Additionally, yield is a complicated trait with polygenic control and is also controlled by environmental factors. Therefore, it's critical to determine the coefficient of variation, correlations, and direct and indirect effects of yield-contributing factors on potato yield and quality. Potato breeders have done a lot of research on these aspects.

This chapter provides a quick summary of research on potato improvement done by various researchers under the following headings:

- 2.1. Genetic variability
- 2.2. Heritability and genetic advance
- 2.3. Association of characters and path analysis
- 2.4. Analysis of genetic divergence

2.1 Genetic variability

Genetic variability and the degree to which it is present in a population play a major role in the planning and success of any crop improvement programme. It helps to examine yield variation caused by a variety of factors, each of which may be influenced by both genotypic and environmental reasons, when assessing the effects of genotype on yield variability. Thus, variability is a crucial pre-condition for ongoing genetic advancement in all crop plants. So, here is an overview of the genetic variation in potatoes that has been documented by various workers.

Maris (1990) found that the coefficient of variation and response to selection were high for the number of days to plant emergence, height of the plant, maturity duration, number of main stems, number of tubers, yield, mean tuber weight, days to flowering, yield of dry matter, specific gravity, shape of the tubers and the colour of flesh.

Garg and Bhutani (1991) observed significant genotypic and phenotypic coefficient of variation for the number of tubers per plant, average tuber weight and tuber yield.

Chandra *et al.* (1992) conducted an experiment by using 55 exotic genotypes of potatoes to evaluate genetic variability for micro tuber production in vitro. They reported a wide range of genetic variability for the weight of micro tubers in the form of phenotypic coefficient of variation.

Rasul *et al.* (1995) reported high variability for days to maturity, foliage coverage and plant height. Additionally, they discovered that the genotypic coefficient of variation was high for tuber yield per hectare (37%) whereas moderate for plant height (19.4%).

Desai and Jaimini (1997) investigated 36 potato genotypes for 14 traits in 16 different habitats and found that, regardless of environment, high genotypic coefficients of variation were present for number of tubers, tuber yield, protein content and average tuber weight.

Sandhu and Kang (1998) studied 286 genotypes of andigena potato and found that there was a lot of variation in inter-nodal length, leaflet index, number of shoots, shoot height and tuber yield. For shoot height, shoot number, tuber yield and leaflet index, high values of the coefficient of variation were also reported.

Biswas *et al.* (2005) examined the genetic variability of seven parents and their ten hybrids for eight quantitative variables at 60 and 90 days after planting. They found that the maximum variability was observed for tuber weight per plant and number of tubers per plant at 60 DAP.

Ummayyah *et al.* (2010) studied the genetic variability analysis on 26 genotypes of potatoes for 17 yield and quality traits and found that the leaf area, tuber yield per plant, stolon length, number of stolons, average tuber weight, tuber yield per hectare, total soluble solids (TSS) and number of tubers per plant, all showed high heritability with high genetic gain, indicating that these characters could be used as trustworthy tools for breeding.

Patel *et al.* (2013) examined the genetic diversity of 24 different potato genotypes grown for table use with two different harvest dates (75 days and 90 days after sowing) and they observed that plant height, number of tubers per plant, average weight of the tubers, reducing sugar, chip colour and dry matter content of tubers- all showed high levels of phenotypic heterogeneity. Reducing sugar, number of stems per plant, marketable tuber yield, chip colour, tubers per plant, and total yield of tubers- all showed high GCV (%) and PCV (%). High heritability and genetic advance as a proportion of mean values were noted for reducing sugar. At both phenotypic and genotypic levels, the marketable tuber yield showed a substantial and positive association with the number of stems per plant, number of tubers per plant and the total yield of tubers. Higher positive direct effects on total tuber yield for marketable yield were found after the path coefficient analysis which revealed that the genotypes under investigation have a appreciable amount of genetic diversity.

Santosh *et al.* (2014) examined the genetic diversity among eleven early maturing potato hybrids. The genotypes displayed significant genotypic and phenotypic coefficient of variation in yield and yield components. Characters like number of tubers per plant, plant height, total tuber yield, marketable tuber yield, tuber diameter and non-reducing sugars showed high genetic advance (% of mean) values as well as high heritability. However, estimations for the number of leaves, tuber dry matter, reducing sugars and total sugars were minimal. Through simple selection techniques, these attributes could be improved.

2.2 Heritability and genetic advance

Ikbal and Khan (2003) investigated on phenotypic and genotypic variability, heritability, coheritability and genetic advance in fifteen potato cultivars of exotic and indigenous origin. They reported strong genetic advance together with high heritability (in the broad sense) for plant height and the number of stems per plant.

Joseph *et al.* (2005) observed that all characters had heritability values ranging from moderate to high, with the exception of the number of potato leaves. Basavaraj *et al.* (2005) likewise noted moderate to high heritability together with substantial genetic advance for the traits evaluated in the potato. Similar results were observed by Luthra *et al.* (2005) for the tuber number, tuber yield and average tuber weight.

Biswas *et al.* (2005) showed high heritability for tuber weight, potato plant weight and number of tubers per plant.

Roy and Singh (2006) reported high heritability for emergence percentage, dry matter percentage, total tuber yield, total sugar, harvest index and total starch %.

Chandrakar (2007) in a study of potato clonal populations, found that tuber weight per plant and the number of tubers were highly heritable, whereas number of shoots, number of compound leaves per plant, plant height, marketable and unmarketable tuber yield per plot, harvest index as well as the dry matter content of tubers and shoots were moderately heritable. Both weight of tuber and number of tubers per plant had strong genetic advance expressed as a percentage of the mean

Sharma *et al.* (2007) reported high heritability and high genetic advance for the fresh weight of tubers, percentage of dry weight of tubers, number of roots per plant and number of shoots per plant.

Singh (2008) observed that there is high heritability for plant height, number of leaves per plant, total tuber weight, marketable tuber weight, weight of tubes per plant, number of tubers per plant, dry matter content of the tuber, total tuber weight per plant, marketable tuber weight per plant, number of tubers per plant and leaves per plant. Strong heritability estimation was seen coupled with high genetic advance.

Ozturk *et al.* (2014) examined the broad sense heritability values of a few quantitative variables in a study of 21 potato genotypes. They concluded that plant height, leaf length, leaf breadth, tuber weight and starch output- all exhibit moderate to high levels of heredity.

Hajam *et al.* (2018) studied 38 genotypes of potato for genetic variability, heritability and genetic advance for various qualitative traits of potato. The study revealed that the phenotypic coefficient of variation were slightly higher than genotypic coefficient of variation for most quality control attributes which indicate minor effect of environment in the expression of traits.

2.3.1 Correlation coefficient

The evaluation of genetic correlation aids in the investigation of the relationships between different plant traits, identifying the constituent characters from which selections can be made to increase yield and quality metrics. The inherently connected relationship between the two variables is known as genotypic correlation. It might be brought on by linkage or the pleiotropic effects of genes. If the association between yield and a character is caused by the character's direct influence, this indicates that the relationship between them is real, and selecting such characters can help to increase yield. However, the breeder must choose the trait via which the indirect influence is anticipated if the connection is mostly caused by the character's indirect effect on other component traits. When the character for which indirect selection is used has a high heritability and a positive connection with yield, a good yield response is obtained. Various researchers have studied the genotypic and phenotypic relationships between different yield attributing traits which are reviewed here.

Resul *et al.* (1995) reported that tuber production per hill, foliage covering and plant vigour all are positively and significantly correlated with potato tuber yield per hectare.

Desai and Jaimini (1998) reported that all the features under study except the protein and sugar content had a significant positive relationship with plant height, days to maturity and tuber production.

Halwai (2000) reported that there was a positive and significant correlation between the total tuber yield with the number of stolons per plant, number of shoots per plant, fresh weight of the shoots and roots per plant and dry weight of the tubers per plant.

Ramanjit *et al.* (2001) reported that dry matter production of roots, leaves and tubers are highly significant and show positive correlation with tuber yield, tuber weight, number of tuber and leaf area index at both 60 and 90 days of crop duration.

Robert *et al.* (2002) found that the chip colour had the strongest correlation with the amount of reducing sugar present. Multiple analyses showed that each parameters of chip colour varied significantly between cultivars and seasons.

Patel *et al.* (2003) from a study on 20 potato genotypes, found that there was a significant correlation of tuber yield with number of stems per plant, fresh weight of the tuber per plant and the plant height. On the other hand, the average weight of the tubers was negatively associated with the number of tubers per plant.

Luthra and Gopal (2005) reported that tuber yield is significantly and positively correlated with average tuber weight and tuber counts.

Roy and Singh (2006) reported that there is a significant positive correlation of total tuber yield with the tuber yield per plant and number of tubers per plant.

Sharma *et al.* (2007) found that tuber yield was negatively correlated with percent dry weight of shoots but positively correlated with number of tubers per plant, fresh weight of roots, dry weight of roots.

Kamal *et al.* (2007) reported that both at the genotypic and phenotypic levels, there is significant and positive correlation of tuber yield with quantity of tubers per hill, average tuber weight. Shoot girth, however, showed a significant and negative association with tuber yield.

Arslan (2007) conducted an experiment using correlations and path analysis to ascertain the relationships between tuber production and some traits of potato. The average tuber weight, plant height, stems /plant, and tuber output were all shown to be strongly positively correlated with tuber yield.

Singh *et al.* (2008) reported that there is a significant and positive correlation of the marketable tuber yield per plant with the weight of the tubers per plant, number of leaves per plant, number of tubers per plant, the total weight of the tubers per plant, the number of marketable tubers per plant, and the number of unmarketable tubers per plant.

Yenagi *et al.* (2008) reported that there is a positive and significant association between plant height, tuber yield and total dry matter production per plant, but a negative and significant correlation between dry matter production of tubers per plant.

Mishra *et al.* (2017) conducted an experiment to assess the degree of correlation between the factors that affect yield and those that affect tuber production. They found that there was a significant and positive correlation of total tuber yield with the number of leaves per plant, dry weight of the tuber, number of tubers per plant and the harvest index.

2.3.2 Path Coefficient analysis

It is very much important to have knowledge of the degree of correlation between the yield and other yield contributing traits to bring simultaneous improvement in yield

contributing traits. Path coefficient analysis is the approach to identify the ideal characters directly or indirectly contributing to the dependent variable in such scenarios because the relationship becomes more complex as the number of component characters increase.

Measuring the contribution of individual factors to the observed correlation becomes both necessary and deceptive as the number of variables increases. So, in order to characterize more complicated qualities like yield, the observed correlation coefficients are divided into components of direct and indirect influences (Baloch *et al.*, 1992). Under such circumstances, the "path coefficient analysis" is used to divide the correlation coefficients exactly into their direct and indirect impacts in order to identify the traits that will have the greatest influence on potato breeding programme. As a result of the widespread use of path coefficient analysis in the genetic improvement of yield, studies conducted by various researchers to evaluate the effects of yield attributing and quality characters on their direct effect are reviewed here.

Kumar and Kang (2000) conducted an experiment with andigena potatoes in three distinct sites and found that the number of tubers per plant and mean tuber weight had a significant and favourable direct impact on tuber yield. Additionally, they stated that the number of tubers had a significant and negative indirect impact on tuber yield via average tuber weight

Ozkaynak *et al.* (2003) conducted a study to identify the direct and indirect effect on tuber yield, they found that the average tuber weight and number of tubers were the most significant factors.

Roy and Singh (2006) reported that the tuber yield per plant exhibited high direct effect towards percentage of marketable tuber production.

Patel *et al.* (2003) reported that the tuber yield exhibit a significant positive direct impact on number of tubers per plant and average tuber weight while number of tubers per plant exhibit a significant but negative direct impact on the average tuber weight. The number of tubers per plant had a higher indirect effect on yield but plant height, fresh weight of tubers per plant and the number of leaves per plant- all had lower positive direct effects on yield. Dry matter content had a favourable direct impact on tuber output and a highly positive indirect impact via the quantity of tubers produced per plant.

Roy and Singh (2006) reported that number of tubers per plant, number of branches per plant and percentage of marketable output all had a significant direct impact on overall tuber production.

Kamal *et al.* (2007) found that the plant height, number of tuber hills per plant, tuber weight, number of leaves per haulm, number of haulms per hill and number of stolons per hill have positive effect on potato tuber yield

Singh (2008) reported that there is a strong positive correlation of marketable tuber weight with plant emergence, plant height, the number of leaves per plant, the number of leaflets per leaf, number of marketable tubers per plant and the number of unmarketable tubers per plant.

Yenagi *et al.* (2008) reported that there is a positive and statistically significant correlation between tuber yield and growth characteristics such as plant height and total dry matter production per plant, but a negative and statistically significant correlation between dry matter production in tubers per plant. Weight and quantity of tubers per plant were significant and positively linked with tuber production.

Patel *et al.* (2018) tested 42 different potato genotypes (*Solanum tuberosum* L.) for a variety of quantitative and qualitative parameters to ascertain the relationship between yield and its constituent parts. The path coefficient analysis showed that the number of tubers per plant, marketable tuber yield, total soluble solid, and average weight of tubers per plant all had higher positive direct effects than plant height and the number of stems per plant, which were negative and of low magnitude. However, these two characters indirectly contributed to total tuber yield through the number of tubers per plant, marketable tuber yield, total soluble solid, and average weight of tubers per plant.

2.4 Analysis of genetic divergence

The breeders' prime concern is genetic divergence. The likelihood of getting larger heterotic combinations and a wide spectrum of variability in segregating generations increases with parental diversity within the general limitations of fitness. The Mahalanobis D^2 statistic can be used to determine genetic divergence between populations as well as the relative contributions of various yield components to overall genetic variation. It has been used by the several researchers to evaluate the genetic diversity of potato and is reviewed here.

Luthra and Gopal (2005) found that although the parental lines were morphologically different, they had a limited genetic base and could be divided into four clusters, and that morphological variety was unrelated to geographical and taxonomic diversities. When it came to tuber yield, however, genetic divergence and heterosis had a positive association.

Haydar *et al.* (2007) examined genetic divergence in 30 potato varieties for tuber production and its components. The amount of tubers per plant contributed the most to diversification. Most of the time, the inter-cluster distance was greater than the intra-cluster distance, showing greater genetic variation between the genotypes of various groups.

Regassa and Basavaraja (2007) evaluated the genetic diversity of 100 potato genotypes grown under rainfed circumstances, reported eight distinct clusters, and came to the conclusion that genetic diversity had no relationship to geographic diversity. The number of main stems per plant and average tuber weight per plant both contributed significantly to overall divergence.

Biswas *et al.* (2008) also reported genetic diversity in potato for six important yield contributing traits in 13 parents and their 30 hybrids. According to diversity analysis, 13 parents were grouped in six clusters and superior male and female parents were distributed in relatively distant clusters. Among the 13 parents, TPS-13, TPS-67, Lalpakri, Patnai and Ausha were selected to produce hybrids with considerable hybrid vigour.

Singh *et al.* (2008) reported that the D^2 values among six distinct clusters recorded for various characteristics implies the presence of considerable genetic variety in the genotypes included in the analysis. Genotypes with superiority for more than three traits, such as Kufri Ashoka, Kufri Chipsona-2, DSP-7, MP/95-1309, Jx374 and J/92-164 may be used as parents in a hybridization programme.

Luthra (2010) studied one hundred ninety-five accessions of the potato tuberosum group that were assessed for nine different characteristics over the course of three successive autumn crop seasons in order to determine the genetic divergence based on Non-hierarchical Euclidean distances for the purpose of identifying genetically diverse and agronomically superior accessions that may produce putative transgressive segregates during hybridization. 195 potato accessions were divided into 8 clearly distinct clusters based on the first five principal components, which included number of tubers, number of stems, plant height, tuber

yield and germination which accounted for 97.67% of the variation. Genetic diversity was unrelated to geographical diversity. Twenty genetically varied and agronomically viable genotypes were found, and they might be used in a crossing programme to produce segregates with traits that are economically desirable for the creation of potato varieties for subtropical plains of india.

Panigrahi *et al.* (2014) used Mahalanobis D-square (D^2) for 19 potato genotypes in West Bengal to analyse genetic diversity for yield and yield attributing traits. Seven clusters were created from these genotypes. Cluster VII had the highest divergence with four genotypes, while cluster IV had the highest divergence with five genotypes. The fact that the inter cluster distance was greater than the intra cluster distance indicated that the accession included a sizable degree of genetic variation. Cluster I with III and Cluster VI with IV were found to have the highest and lowest degrees of divergence, respectively. Dry matter percentage, marketable tuber yield, total tuber yield, harvest index, and polar and equatorial tuber diameter were among the characteristics in Cluster VI that showed high mean values. These characteristics, when combined with plant height, are the main features responsible for genetic divergence between accessions. In order to produce desired transgressive segregants, hybridization programmes can successfully use the genotypes from different clusters because they have the highest degree of divergence. It is anticipated that the greatest level of heterosis will show up in cross combinations involving the parents from the most diverse clusters.

Rangare *et al.* (2017) conducted an experiment with forty-four potato genotypes for studying genetic divergence on the basis of D^2 analysis. The D^2 value recorded for numerous criteria suggested the presence of considerable genetic diversity.

Prabha *et al.* (2018) conducted an experiment with 39 F_1C_1 clonal progenies of potato under AICRP –potato research farm. 39 progenies were grouped into 5 clusters depending upon the similarity of their D^2 value. The progenies developed from the selected genotypes within the limits of compatibility of these clusters, may produce high magnitude of heterosis of desirable transgressive segregants, which would be rewarding in a breeding programme.

MATERIALS AND METHODS

The current study entitled “**Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes**” was carried out during *Rabi* season of 2021-2022 at experimental research farm of AICRP on Potato, OUAT, Bhubaneswar, Odisha, India. A detailed account of the materials used, procedure followed in field experiments, recordings of observations, analysis of soil and plant samples, biochemical analysis of potato tubers and statistical tools used are described below.

3.1 Geographical location of the experimental site

The experimental site of AICRP on Potato, OUAT, Bhubaneswar, Odisha is situated at 20° 15' N latitude and 85° 52' E longitude. The site is about 62 km away from Bay of Bengal at an elevation of 25.5 m above sea level. The site is at a distance of 5 km from the College of Agriculture, OUAT, Bhubaneswar.

It is situated along the axis of the Eastern Ghat mountain in the eastern coastal lowlands. Averaging 45 metres (148 feet) above mean sea level, the city is situated at 20°16'25" North latitude and 85°47'19" East longitude.

3.2 Climate

The experimental site comes under the eighteenth agro-climatic region of the country known as Eastern Coastal plain. The climate of Bhubaneswar is humid-sub tropic and it experiences moist and warm climate with hot and humid summer and mild winter.

Daily weather data during whole cropping season from planting to harvesting was recorded at Meteorological observatory of Odisha University of Agriculture and Technology, Bhubaneswar.

Table 3.1: Weekly Meteorological Data at the Experimental Location

Month	Standard Meteorological Week	Week period	Temperature (°C)		RH (%)		Rainfall (mm)
			Min.	Max.	Min.	Max.	
Dec. 2021	49	3-9 Dec.	19.84	26.19	82.43	93.86	70.80
	50	10-16 Dec.	15.46	27.49	59.29	86.43	1.00
	51	17-23 Dec.	10.03	25.71	63.86	87.29	0.00
	52	24-31 Dec.	15.36	27.26	79.13	93.13	0.80
		Monthly Average	15.17	26.66	71.17	90.17	72.60
Jan. 2022	1	1-7 Jan.	12.83	26.43	77.14	91.57	0.00
	2	8-14 Jan.	15.70	26.69	39.41	94.86	16.50
	3	15-21 Jan.	14.63	25.73	25.73	94.71	0.00
	4	22-28 Jan.	16.87	27.53	41.03	95.43	12.60
		Monthly Average	15.01	26.59	45.83	94.14	29.10
Feb. 2022	5	29Jan.-4 Feb.	14.67	28.19	67.71	95.14	0.00
	6	5-11 Feb.	15.81	28.71	66.29	95.29	0.00
	7	12-18 Feb.	15.33	28.89	74.43	95.14	1.10
	8	19-25 Feb.	19.71	31.21	70.00	95.00	40.00
	9	26 Feb.- 4 Mar.	19.97	33.07	69.00	93.86	0.00
		Monthly Average	17.10	30.01	69.49	94.89	41.10
Mar. 2022	10	5-11 Mar.	20.61	34.66	67.43	93.14	0.00
	11	12-18 Mar.	22.27	36.27	68.57	94.57	0.00
	12	19-25 Mar.	23.01	36.26	69.43	94.57	0.00
	13	26 Mar.- 1 April	25.96	35.41	76.57	93.14	0.00
		Monthly Average	22.96	35.65	70.50	93.86	0.0

3.3 Field operations

The general operations carried out in the field are as follows.

Table 3.2: General operations carried out in the field

Date	Operations
20.11.2021	Land preparation
25.11.2021	Layout
30.11.2021	Planting and basal application of fertilizers
25.12.2021	1 st top dressing
22.01.2022	2 nd top dressing
20.02.2022	Harvest





3.4 Experimental Details




- CROP : Potato (*Solanum tuberosum L.*)
- NUMBER OF GENOTYPES : 25
- SEASON : Rabi
- YEAR : 2021-22
- LOCATION OF EXPERIMENT : AICRP on Potato, OUAT, Bhubaneswar

3.4.1 Particulars of field lay out

- EXPERIMENTAL DESIGN : RBD
- REPLICATIONS : 3
- SPACING : 60 cm * 20 cm
- PLOT SIZE : 2.4 m × 2.4 m
- DATE OF PLANTING : 30th Nov 2021
- FERTILISER DOSE : 150-80-100 kg N-P₂O₅-K₂O/ha +
10 ton FYM per ha.
- DATE OF HARVEST : 75 days after planting

3.4.2 Experimental material

GENOTYPES	LEAF IMAGE
HT-21-1	 A photograph of a single, healthy green leaf with a prominent central vein and several smaller veins branching out. The leaf is attached to a short stem and shows no signs of damage or disease.
HT-21-2	 A photograph of a single green leaf with several small, irregular holes and white spots on its surface, indicating insect damage or a fungal infection.
HT-21-3	 A photograph of a single green leaf with several small, circular holes and white spots on its surface, indicating insect damage or a fungal infection.
HT-21-4	 A photograph of a single, healthy green leaf with a prominent central vein and several smaller veins branching out. The leaf is attached to a short stem and shows no signs of damage or disease.

<p>HT-21-5</p>	
<p>HT-21-6</p>	
<p>HT-21-7</p>	

HT-21-8











HT-21-9










HT-21-10



HT-21-11	
HT-21-12	
HT-21-13	
HT-21-15	

HT-21-16	
HT-21-17	
HT-20-3	
HT-20-11	

HT-20-12	
HT-18-7	
HT-18-4	
K.Lima	

K.Khyati	
K.Surya	
K.Pukhraj	

3.4.3 Planting material:

The varieties (genotypes) employed in this study include HT-21-1, HT-21-2, HT-21-3, HT-21-4, HT-21-5, HT-21-6, HT-21-7, HT-21-8, HT-21-9, HT-21-10, HT-21-11, HT-21-12, HT-21-13, HT-21-15, HT-21-16, HT-21-17, HT-20-3, HT-20-11, HT-20-12, HT-18-4, HT-18-7, K. Surya, K. Khyati, K. Lima and K. Pukhraj. Before being placed in cold storage, the tubers were treated with 3% boric acid. Fifteen days before planting, the tubers were taken out of the cold storage.

3.5 Cultural operations

3.5.1 Land preparation

The land was thoroughly cross ploughed and leveled uniformly. The whole plot was divided into three replications. Each replication was again subdivided into twenty five treatment plots. Each treatment plot was 2.4 m long and 2.4 m wide. Then the treatments were allocated randomly to the plots. Furrows and bunds were made for planting of seed tubers and irrigation channels.

3.5.2 Planting of seed tuber

Seed tubers were planted in superficial furrows on well leveled plots with a spacing of 60 cm between rows and 20 cm between plants within a row on 30th November, 2021. Ridges of about 15 cm high were made to cover the tubers and light irrigation was made so that the top one-third of the ridge would remain dry.

3.5.3 Fertilizer application

Recommended fertilizer dose @ 150: 80:100 kg ha⁻¹ N: P₂O₅: K₂O and FYM @ 10t ha⁻¹ were applied uniformly in each plot. The total amount of phosphorous and 50 % each of nitrogen and potash were applied as basal dose before planting. Remaining amount of nitrogen and potash were applied in first top dressing at 25 DAP. Nitrogen and phosphorous were applied in the form of urea and Diammonium phosphate (DAP), respectively and potassium was applied in the form of Muriate of Potash (MOP).

3.5.4 Irrigation scheduling

Based on the cumulative pan evaporation (CPE) of each day, irrigation schedules were made for the crop at about 20 mm CPE. Due to rain during crop growing season, the irrigation timetable for the crop was delayed in some way. Five irrigations were made during crop season. Irrigation was withheld 10-15 days prior to harvesting.

3.5.5 Intercultural operations and weed management

Metribuzin was sprayed as a pre-emergence treatment (0.75 kg/ha) before to the crop's emergence. At 25 days after planting, manual hoeing, weeding, top dressing, and earthing up were completed followed by irrigation. Remaining 50% of Nitrogen and Potassium were applied at top dressing. Another light earthing up was done at 40 days after planting.

3.5.6 Plant protection measures

Mancozeb was sprayed at the rate of 3 g per litre of water twice at an interval of 15 days beginning at 40 days after planting in order to suppress the early blight disease. During the crop-growing season, Imidacloprid @3ml/10 litres of water was treated twice to combat sucking pests.

3.5.7 Haulm cutting

Haulm cutting was done on 5th of February, 2022 around one week before harvesting. Irrigation was stopped around 5 days before haulm cutting.

3.5.8 Harvesting

The potato tubers were harvested on 12th of February, 2022 for 75 days' crop and on 27th of February, 2022 for 90 days' crop. Yield data of each variety was recorded from three replications very meticulously. Harvesting was done with the help of spade. Plot wise total tuber yield, marketable tuber yield and rotten tuber yield were recorded very meticulously. The number of marketable, non- marketable and rotten tubers in each plot were counted and recorded.

3.6 Biometric observations

3.6.1 Sampling Technique

Five representative plants of each treatment in a replication were selected randomly and tagged properly. Observations of various biometric characters of selected plants were recorded. While selecting the sample plants the border plants were excluded to avoid border effect.

The observations on growth parameters like emergence percentage, plant height, number of shoots plant⁻¹, number of leaves plant⁻¹, leaf area, chlorophyll content of leaf, yield and number of tubers ha⁻¹, yield of marketable, non-marketable, rottage and total tubers per plot, specific gravity, tuber dry matter % were recorded during the course of investigation. The emergence percentage was observed to be above 90 percent in all the genotypes.

3.6.2 Morphological observations

3.6.2.1 Plant height (cm)

The height of five sample plants in each plot were measured in cm from the base to tip of the plant. The mean values of five plants were calculated for each treatment and analyzed. Observations were taken at 30, 40 and 50 DAP.

3.6.2.2 Number of shoots per plant

The numbers of shoots arising from the sprouted tuber were counted at 30, 40 and 50 days after planting and were recorded. The averages of five sample plants were calculated to get the number of shoots per plant for each treatment.

3.6.2.3 Number leaves per plant

After 30,40 and 50 days of planting, the number of compound leaves arising from the plant was counted and recorded. To get the number of compound leaves per plant in each treatment the average of five selected plants were calculated.

3.6.2.4 Number of leaflets per leaf

Number of leaflets per leaf was counted from five sample plant at 30, 40 and 50 DAP and the mean value of those five plants were calculated for each treatment and analysed

3.6.2.5 Length and breadth of top-most leaflet at 40 DAP

Length and breadth of top-most leaflet at 40 DAP was measured . The average of five samples was calculated to get the leaf length and breadth in each treatment. It is expressed in cm.

3.6.2.6 Dry matter percentage of tuber

From each treatment, tubers were harvested from five sample plants and the fresh weight was measured with the help of electronic balance. Then the same tubers were sliced and oven dried at a temperature of 60°C for 72 hours till a constant weight was obtained. The weight of the oven dried sample was recorded. The dry matter content of the tuber was calculated by using following formula given by Elfnes *et al.* 2011.

$$\text{Dry matter content (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100$$

3.6.3 Yield and yield attributes

3.6.3.1 Total healthy tuber yield (t. ha⁻¹)

Harvesting was done at 75 days after planting and total healthy tuber yield was recorded. It was expressed in t ha⁻¹.

3.6.3.2 Yield of marketable and non-marketable tubers (t. ha⁻¹)

The tubers weighing < 20g (non-marketable) and > 20g (marketable) were separately weighed and recorded. Yield was expressed in t. ha⁻¹.

3.6.3.3 Number of tubers (No. ha⁻¹)

At the time of final harvest, the tubers were graded into marketable (>20g) and non-marketable (< 20g) in each treatment, counted and expressed in No. ha⁻¹.

3.6.3.4 Yield of rotten tubers (t. ha⁻¹)

During harvesting the rotten tubers were separated from healthy tubers and weight was taken separately in each treatment. It was expressed in t. ha⁻¹. The rottage was due to soft rot, brown rot and other causes.

3.6.3.5 Number of rotten tubers (No. ha⁻¹)

The number of rotten tubers in each treatment was counted and expressed in No. ha⁻¹.

3.6.4 Biochemical analysis

3.6.4.1 Estimation of Chlorophyll a, Chlorophyll b and Total Chlorophyll content of leaf

Total chlorophyll content in the leaves was determined by using the method stated by Arnon (1949). The 3rd leaf from the top was sampled for the analysis. The leaf samples were immediately kept in moist polythene bags to keep them fresh. 0.1g of fresh leaf was taken from the interveinal portion of the leaves leaving the margin and vein and were cut into small pieces. Then the leaf discs were put immediately in 10 ml of 80% v/v acetone solution in falcon tube and closed tightly and kept in dark for 24 hours. Then they were filtered by Whatman No.1 filter paper. The filtrate was used to record the absorbance (OD) at 645 nm and 663 nm by UV-Vis Spectrophotometer after calibrating with blank of 80% acetone solution. The respective pigment content of leaf was calculated using the following formula and expressed as mg/g FW leaf.

$$\text{Chlorophyll a} = [(12.7 \times \text{OD } 663) - (2.69 \times \text{OD } 645)] (V/1000 \times W)$$

$$\text{Chlorophyll b} = [(22.9 \times \text{OD } 645) - (4.68 \times \text{OD } 663)] (V/1000 \times W)$$

$$\text{Total chlorophyll} = [(8.02 \times \text{OD } 663) + (20.20 \times \text{OD } 645)] (V/1000 \times W)$$

Where,

OD 645 = OD value at 645 nm

OD 663 = OD value at 663 nm

V = Volume of the extract (ml)

W = Fresh weight of leaf sample (g)

3.6.4.2 Estimation of reducing sugar

The estimation of reducing sugar was done by Dinitrosalicylic acid method suggested by Sadasivam and Manickam (1992). 1g of the sample was weighed and sugar extracted with

hot 80% ethanol twice (5ml each time). The supernatant was collected and evaporated by keeping it on a water bath at 80°C. 10 ml of water was added to dissolve the sugars. 2 ml of the extract was added in the test tube and the volume was equalized to 4 ml with water in all the tubes. 3 ml of DNS reagent were added to all the tubes. The content was heated in boiling water bath for 5 min. When the contents of the tube were still warm, 1 ml of 40% Rochelle salt solution was added. After cooling, the intensity of the absorbance was recorded at 510 nm using spectrophotometer. 1000 ppm glucose solution was prepared and 0, 0.6, 0.7, 0.8 and 1 ml of it was taken in different test tubes for standard preparation. By adding water in all the test tubes volume was equalized to 6 ml. Then same procedure was followed as in sample. Amount of reducing sugar present in the sample solution was calculated using the standard graph and expressed in mg 100 g⁻¹ FW.

3.6.4.3 Estimation of starch

DNS (3, 5-dinitrosalicylic acid) colourimetric method was used for the determination of starch (Geirwyn, 1995). About 0.1 g of the powdered tuber sample was hydrolysed in 10 ml of 1.5 M H₂SO₄ for 20 min in a boiling water bath (100 °C). 12 ml 10% NaOH was added after cooling and the contents were filtered in 100 ml volumetric flask (hydrolysate) and then volume was made to 100 ml. 2 ml of the extract was added in the test tube and the volume was equalized to 4 ml with water in all the tubes. 3 ml of DNS reagent were added to all the tubes. The content was heated in boiling water bath for 5 min. When the contents of the tube were still warm, 1 ml of 40% Rochelle salt solution was added. After cooling, the intensity of the absorbance was recorded at 510 nm using spectrophotometer. 1000 ppm glucose solution was prepared and 0, 0.6, 0.7, 0.8 and 1 ml of it was taken in different test tubes for standard preparation. By adding water in all the test tubes, volume was equalized to 6 ml. Then same procedure was followed as in sample. Amount of starch present in the sample solution was calculated using the standard graph and expressed in mg 100 g⁻¹DW.

3.7. Statistical analysis

The data recorded for various characters were subjected to statistical analysis based on their sample means (Gomez and Gomez, 1983).

Analysis of variance

The data on different characters of 24 Potato Genotypes were subjected to statistical analysis. The mean, standard error and co-efficient of variation were calculated following

Panase and Sukhatme (1961).

$$\text{General mean} = \sum X/n$$

Where, $\sum X$ = Summation of observations

n = number of observations

$$\text{Variance} = \frac{[\sum X^2 - (\sum X)^2 / n]}{n-1}$$

where, $\sum X^2$ = Sum of squares of all the observations of variance

$\sum X$ = Summation of all the observations of a variate

n = Number of observations of a variate

$$\text{Standard Error (SE)} = SD / \sqrt{n}$$

Critical Difference (CD) = $SE_d \times t_{5\%}$ at error df

$$\text{Co-efficient of variation (CV) \%} = \frac{SD}{\text{Mean}} \times 100$$

The analysis of variance table is as follows

Source	df	SS	MS	F. cal
Replication	r-1	SSr	Mr	Mr/Me
Treatment	t-1	SSt	Mt	Mt/Me
Error	(r-1)(t-1)	SSE	Me	
Total	(rt-1)			

Where, r = number of replications

t = number of genotypes

Mr = replication mean square

Mt = genotype mean square

Me = error mean square

Test of significance was carried out by referring to the 'F' table (Snedecor and Cochran, 1967).

Genotypic and phenotypic variances

The genotypic and phenotypic variances were calculated as suggested by Johnson *etal*(1955).

$$\text{Genotypic variance } (\sigma^2g) = \frac{Mt - Me}{r}$$

Where, Mt = Mean squares for genotypes

Me = Mean squares for error

r = Number of replications

$$\text{Phenotypic variance } (\sigma^2_p) = \sigma^2_g + \sigma^2_e$$

Where, σ^2_g - Genotypic variance

σ^2_e - Error variance

Phenotypic and genotypic co-efficients of variation

The phenotypic co-efficient of variation (PCV) and genotypic co-efficient of variation (GCV) were calculated following procedures described by Burton (1952)

$$\text{PCV} = \frac{\sigma_p \times 100}{\text{Grand mean}}$$

Grand mean

$$\text{GCV} = \frac{\sigma_g \times 100}{\text{Grand mean}}$$

Grand mean

Where, σ_p - Phenotypic standard deviation

σ_g - Genotypic standard deviation

Heritability

Heritability (H^2) in broad sense was calculated according to Johnson *et al* (1955).

$$\text{Heritability (Broad sense) } H^2 = \frac{\sigma^2_g}{\sigma^2_p}$$

where, σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

Genetic advance

Genetic advance was worked out by the method suggested by Johnson *et al* (1955).

$$\text{Genetic advance (GA)} = K H^2 \sigma_p$$

Where, K= Selection differential at 5 per cent selection intensity which is 206

H^2 = Heritability

σ_p = phenotypic standard deviation

Genetic advance as per cent mean

Genetic advance was expressed as percent mean by using the following formula.

$$\text{Genetic advance as per cent of mean} = \frac{\text{GA} \times 100}{\text{GM}}$$

Where, GA - Genetic advance

GM - Grand mean

Association analysis

To estimate the association among different traits observed among the genotypes, phenotypic and genotypic correlation co-efficients were worked out following Panse and Sukhatme (1961) The variance and covariance values were utilized to calculate the correlation coefficients by following formula:

Phenotypic correlation co-efficient

$$r_{xy} (P) = \frac{\text{Cov.}xy (P)}{\sqrt{[V_x(P) V_y(P)]}}$$

Where, Cov.xy (P) - Phenotypic co-variance between characters x and y

$V_x (P)$ - Phenotypic variance of character x

$V_y (P)$ - Phenotypic variance of character y

Genotypic correlation co-efficient

$$r_{xy}(G) = \frac{\text{Cov.}xy (G)}{\sqrt{[V_x(G) V_y (G)]}}$$

Where, Cov. xy(G) - Genotypic co-variance between characters x and y

$V_x (G)$ - Genotypic variance of character x

$V_y (G)$ - Genotypic variance of character y

The correlation co-efficients were tested for significance using the method given by Snedecor and Cochran (1967) at five per cent and one per cent levels

Path co-efficient analysis

The path co-efficients were worked out using the genotypic correlation coefficients as per the methods given by Dewey and Lu (1959). The technique was used to split genotypic correlation co-efficient into measures of direct and indirect effects as dependent variable and independent variables.

$$R = \sqrt{1 - \sum d_i r_{ij}}$$

Where, R= residual effect

d_i = direct effect of the i^{th} character

r_{ij} = correlation co-efficient between the i^{th} character and j^{th} dependent character

direct and indirect effects of different characters on yield and total numbers of tubers per plant were both calculated at both genotypic and phenotypic levels.

Genetic Divergence

A measure of genetic distance based on multiple characters between population using Mahalanobis D^2 statistics (1928). The generalized distance between any two populations is defined as:

$$D^2_p \text{ or } \Delta^2 = \sum_{i=1} \sum_{j=1} (\lambda_{ij}) (\delta_i \delta_j)$$

Where, λ_{ij} = sample estimate of (λ_{ij})

$\delta_i \delta_j$ = sample estimate of $\delta_i \delta_j$

RESULTS

In the present investigation entitled "Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes", the observation on tuber yield and its component characters were recorded. Statistical methods were used to quantitatively assess the mean values of the variables under research to determine their relationship with yield as well as their variability, heritability and genetic gain for selection. The nature and the extent of genetic divergence among 25 genotypes as well as the direct and indirect effects of these variables on tuber yield were also investigated. The results are presented below.

4.1 Analysis of variance

The analysis of variance was carried out for 25 different morphological and 10 biochemical characters and presented in the Table 4.1 and 4.2, respectively. The analysis of variance revealed the existence of highly significant variation among the test genotypes for several characters under study. No significant variation was observed among potato genotypes with respect to leaves/ plant, leaflets/ leaf, and length and breadth of top-most leaf. In potato, similar results were obtained by Petros *et al.* 2013, Gopal *et al.* 1999 and Solomon *et al.* 2015.

The mean sum squares was maximum in case of total tuber yield (21.363) followed by marketable tuber yield (20.903), plant height (1.326) and dry root biomass (1.143). Among biochemical characters, mean sum of square was maximum for Zinc content (120.112) followed by total tuber yield (21.363) and ascorbic acid (11.489).

Table 4.1. ANOVA for morphological characters of 25 potato genotypes

Characters	Time of observation	Source of variation	df	M.S.S.	F-Value
Plant height (cm)	30 DAP	Replication	2	1.014	1.861
		Treatment	24	1.326	2.435
		Error	48	0.545	
	40 DAP	Replication	2	1.338	2.938
		Treatment	24	0.889	1.953
		Error	48	0.455	
	50 DAP	Replication	2	1.314	2.922
		Treatment	24	0.885	1.969
		Error	48	0.450	

Table 4.1. ANOVA for morphological characters of 25 potato genotypes (contd.)

Shoots/plant	30 DAP	Replication	2	0.203	1.789
		Treatment	24	0.621	5.481
		Error	48	0.113	
	40 DAP	Replication	2	0.232	1.940
		Treatment	24	0.509	4.262
		Error	48	0.119	
	50 DAP	Replication	2	0.115	0.824
		Treatment	24	0.517	3.718
		Error	48	0.139	
Leaves/plant	30 DAP	Replication	2	0.505	0.761
		Treatment	24	1.144	1.725
		Error	48	0.663	
	40 DAP	Replication	2	0.073	0.155
		Treatment	24	0.733	1.551
		Error	48	0.473	
	50 DAP	Replication	2	0.073	0.155
		Treatment	24	0.733	1.551
		Error	48	0.473	
Leaflets/leaf	30 DAP	Replication	2	0.008	0.013
		Treatment	24	0.593	1.034
		Error	48	0.573	
	40 DAP	Replication	2	0.029	0.049
		Treatment	24	0.729	1.229
		Error	48	0.593	
	50 DAP	Replication	2	0.027	0.042
		Treatment	24	0.687	1.076
		Error	48	0.639	
Top leaf length (cm)	40 DAP	Replication	2	3.071	3.390
		Treatment	24	0.930	1.027
		Error	48	0.906	
Top leaf breadth (cm)	40 DAP	Replication	2	0.652	1.276
		Treatment	24	0.652	1.276
		Error	48	0.511	
Dry Shoot biomass (g/plant) after harvest	75 DAP	Replication	2	0.330	0.561
		Treatment	24	0.660	1.122
		Error	48	0.588	
Dry Root biomass(g/plant) after harvest	75 DAP	Replication	2	0.278	0.624
		Treatment	24	1.143	2.569
		Error	48	0.445	
Rottage (t/ha)	75 DAP	Replication	2	0.086	0.523
		Treatment	24	0.704	4.295
		Error	48	0.164	
Marketable tuber yield (t/ha)	75 DAP	Replication	2	2.553	2.543
		Treatment	24	20.903	20.818
		Error	48	1.004	
Non-marketable tuber yield (t/ha)	75 DAP	Replication	2	0.013	0.126
		Treatment	24	0.733	7.046
		Error	48	0.104	
Total tuber yield (t/ha)	75 DAP	Replication	2	2.252	2.051
		Treatment	24	21.363	19.456
		Error	48	1.098	

Table 4.2. ANOVA for biochemical characters of 25 Potato genotypes

Character	Source of variation	df	M.S.S.	F- Value
Tuber density (g/cc)	Replication	2	0.000	0.003
	Treatment	24	13*10 ⁻⁶	2.428
	Error	48	5*10 ⁻⁶	
Peel (%) on dry weight basis	Replication	2	5.108	24.920
	Treatment	24	0.373	1.821
	Error	48	0.205	
Tuber Dry matter (%)	Replication	2	1.782	1.589
	Treatment	24	1.343	1.197
	Error	48	1.122	
Starch (%)	Replication	2	2.351	0.219
	Treatment	24	6.650	0.620
	Error	48	10.732	
Ascorbic acid (mg/100g)	Replication	2	13.314	9.081
	Treatment	24	11.489	7.835
	Error	48	1.466	
Red sugar (mg/100g)	Replication	2	3.99*10 ⁻⁶	4.017
	Treatment	24	4.51*10 ⁻⁶	4.548
	Error	48	9.9*10 ⁻⁶	
chlorophyll. a (mg/g)	Replication	2	0.049	7.767
	Treatment	24	0.023	3.617
	Error	48	0.006	
Chlorophyll. b (mg/g)	Replication	2	0.132	51.529
	Treatment	24	0.010	3.875
	Error	48	0.003	
Total chlorophyll (mg/g)	Replication	2	0.346	23.918
	Treatment	24	0.055	3.776
	Error	48	0.014	
Zinc content (ppm)	Replication	2	91.143	14.846
	Treatment	24	120.112	19.565
	Error	48	6.139	
	Treatment	24	21.363	19.456
	Error	48	1.098	

4.2. Morphological Characters

4.2.1. Plant height (cm)

A range of 42.776- 44.756 cm was observed among 25 genotypes for plant height at 40 DAP and the height did not increase at 50 DAP. HT-21-15 recorded maximum height of 44.62 cm at both 40 DAP. However, minimum height of 41.91 was noticed in HT-21-17 (Table 4.4).

4.2.2. Shoots per plant

A range of 4.366 -6.566 was observed for shoots per plant at 30 DAP which increased to 4.766-6.666 at 40 DAP and remained same at 50 DAP. Highest number of shoots per plant was recorded for HT-21-8 at 40 DAP.

4.2.3. Number of leaves per plant

There was prominent variation in number of leaves per plant among genotypes at 30 DAP (41.566 -44.133), 40 DAP (42.316 -44.723) and at 50 DAP (42.316 -44.723) . Highest number of leaves per plant was recorded at 50 DAP in HT-21-3(44.72) followed by HT-21-2(44.30) and HT-21-16(43.87). The minimum number of leaves per plant was observed in HT-21-1 (41.56) at 30 DAP.

4.2.4. Number of leaflets per leaf

There was significant variation among genotypes for number of leaflet per leaf at 30 DAP (4.800-6.333), at 40 DAP (5.333 -6.866) and at 50 DAP (5.333- 6.866). Highest number of leaflets per leaf was recorded in HT-21-10 (6.86) followed by K. Surya (6.73) at both 40 DAP and 50 DAP and lowest was recorded for HT-21-2 (4.80).

4.2.5. Top leaf length and leaf breadth

A significant range of was observed for top leaf length 5.383 -7.483cm and leaf breadth (4.443- 6.440cm). Highest leaf length was recorded for HT-20-12 (7.36) followed by HT-18-4 (6.93) and HT-21-10 (6.64) and lowest was recorded for HT-21-2 (5.38). Leaf breadth was highest for HT-20-12 (6.44) followed by HT-21-8 (5.31) and lowest was recorded for HT-21-17 (4.52).

4.2.6. Shoot weight (g/plant) after harvest

Weight of shoot after harvest varied between 16.863 -19.343g/plant. Highest shoot weight was observed for HT-21-6 (19.343) followed by HT-21-13 (19.047), HT-21-7 (18.947), HT-21-9 (18.907), HT-18-7 (18.893) and HT-20-12 (18.887) and the lowest shoot weight was observed for HT-21-2 (16.863).

4.2.7. Root weight (g/plant) after harvest

Weight of root after harvest varied between 7.286 -10.106g/plant. Highest root weight was observed for HT-21-6 (10.106) followed by HT-21-1 (9.827) and HT-20-12 (9.163). Lowest value for root weight was observed for K. Pukhraj (7.287).

4.2.8. Rottage (t/ha)

A significant range of 0.786 -2.603 t/ha was observed for rottage. Highest rottage was observed in HT-21-8 (2.603) followed by HT-20-12 (2.590), HT-21-7 (2.143) and HT-21-13 (2.083). Lowest value was observed for HT-21-3 (0.787).

4.2.9. Marketable tuber yield (t/ha)

A wide range of 10.040 -20.580 t/ha was observed for Marketable tuber yield. Highest Marketable tuber yield was observed for HT-20-3 (20.580) followed by HT-21-4 (18.193), HT-21-1 (17.970), HT-21-11 (17.333) and lowest was observed for HT-21-13 (10.040).

4.2.10. Non-marketable tuber yield (t/ha)

A significant range of 0.626- 2.996 was observed for non-marketable tuber yield. Highest non-marketable tuber yield was recorded for HT-21-7 (2.997) followed by HT-21-1 (1.987), HT-21-2 (1.600) and lowest value was observed for HT-18-4 (0.627).

4.2.11. Total tuber yield (t/ha)

A significant range of 10.6933- 21.483t/ha was observed for total tuber yield. Highest total yield was recorded for HT-20-3 (21.483) followed by HT-21-1 (19.400), HT-21-4 (18.870) and lowest was for HT-21-13 (11.040).

Table.4.3. Variation in morphological features of 25 heat tolerant potato genotypes

SI No.	Character	Time of observation	Mean	Range	SE(\pm m)	CD (0.05)	CV (%)
1	Plant height (cm)	30 DAP	43.077	41.793-44.293	0.426	1.212	1.713
		40 DAP	43.936	42.776- 44.756	0.390	1.108	1.536
		50 DAP	43.937	42.776- 44.756	0.387	1.101	1.526
2	Shoots/plant	30 DAP	5.385	4.366 -6.566	0.194	0.552	6.248
		40 DAP	5.568	4.766-6.666	0.200	0.567	6.205
		50 DAP	5.631	4.766 -6.700	0.215	0.612	6.621
3	Leaves/plant	30 DAP	42.868	41.566 -44.133	0.470	1.337	1.900
		40 DAP	43.472	42.316 -44.723	0.397	1.129	1.581
		50 DAP	43.472	42.316 -44.723	0.397	1.129	1.581
4	Leaflets/leaf	30 DAP	5.508	4.800-6.333	0.437	1.243	13.742
		40 DAP	6.055	5.333 -6.866	0.445	1.264	12.720
		50 DAP	6.084	5.333- 6.866	0.461	1.312	13.136
5	Top leaf length (cm)	40 DAP	6.246	5.383 -7.483	0.550	1.563	15.240
6	Top leaf Breadth (cm)	40 DAP	5.014	4.443- 6.440	0.413	1.173	14.250
7	Shoot weight (g.) after harvest	75 DAP	18.492	16.863 -19.343	0.443	1.259	4.147
8	Root weight (g.) after harvest	75 DAP	8.467	7.286 -10.106	0.385	1.095	7.879
9	Rottage (t/ha)	75 DAP	1.440	0.786 -2.603	0.234	0.665	28.117
10	Marketable tuber yield (t/ha)	75 DAP	14.674	10.040 -20.580	0.579	1.645	6.829
11	Non-marketable tuber yield (t/ha)	75 DAP	1.191	0.626- 2.996	0.186	0.530	27.072
12	Total tuber yield (t/ha)	75 DAP	15.540	10.693- 21.48	0.605	1.720	6.743

Table 4.4. Mean performance of potato genotypes for morphological traits

Genotype	Plant height (cm)			Shoots/plant			Leaves/plant			Leaflets/leaf			Top leaf length (cm)	Top leaf breadth (cm)
	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	40 DAP	40 DAP
HT-21-1	42.80	44.37	44.37	4.50	4.76	4.76	41.56	42.31	42.31	5.20	5.53	5.53	6.51	5.24
HT-21-2	42.27	44.21	44.21	5.33	5.60	5.60	43.94	44.30	44.30	4.80	5.53	5.53	5.38	4.54
HT-21-3	43.48	44.53	44.53	5.30	5.56	5.60	44.13	44.72	44.72	5.33	5.66	5.66	6.31	4.58
HT-21-4	41.79	44.90	44.90	4.36	5.23	5.23	43.00	43.60	43.60	5.00	5.40	5.40	6.58	5.18
HT-21-6	42.94	43.98	43.98	6.33	6.50	6.50	42.76	43.16	43.16	5.53	6.86	6.86	6.09	4.56
HT-21-7	42.98	43.43	43.43	5.46	5.50	5.50	43.20	43.63	43.63	6.13	6.13	6.13	6.38	5.14
HT-21-8	43.37	44.17	44.17	6.56	6.66	6.70	43.04	43.61	43.61	5.00	5.73	5.73	6.35	5.31
HT-21-9	43.23	43.86	43.86	5.633	5.66	5.70	41.75	43.00	43.00	5.46	5.53	5.53	6.16	4.68
HT-21-10	42.10	43.41	43.41	5.40	5.43	5.46	42.43	42.96	42.96	6.33	6.86	6.86	6.64	4.90
HT-21-11	42.58	44.01	44.01	5.43	5.46	5.56	43.30	43.64	43.64	5.20	6.33	6.33	6.10	4.75
HT-21-12	43.79	44.57	44.57	5.06	5.13	5.13	43.00	43.72	43.72	5.46	5.66	5.56	6.27	5.05
HT-21-13	43.58	44.20	44.20	5.43	5.53	5.56	42.73	43.63	43.63	5.70	6.00	6.20	6.87	5.18
HT-21-15	43.70	44.62	44.62	5.03	5.10	5.23	42.17	43.10	43.10	5.00	6.46	6.53	5.61	4.81
HT-21-16	43.64	44.57	44.57	5.30	5.50	5.56	43.36	43.87	43.87	6.13	6.63	6.63	6.10	4.82
HT-21-17	41.91	42.77	42.77	5.46	5.56	5.60	42.79	43.30	43.30	5.66	6.13	6.13	5.81	4.52

Table 4.4. Mean performance of potato genotypes for morphological traits (contd.)

HT-20-3	44.29	44.25	44.25	5.86	6.23	6.23	43.09	43.68	43.68	6.13	6.20	6.20	6.51	5.36
HT-20-11	43.10	43.53	43.53	5.40	5.43	5.50	42.50	43.46	43.46	6.13	6.13	6.13	5.90	4.66
HT-20-12	43.87	44.18	44.18	4.96	5.20	5.26	43.04	43.56	43.56	5.66	6.66	6.66	7.36	6.44
HT-18-4	43.06	43.83	43.83	5.433	5.50	5.60	42.83	43.53	43.53	5.66	5.80	5.80	6.93	4.76
HT-18-7	42.62	43.38	43.38	5.13	5.46	5.53	42.03	42.83	42.83	6.06	6.40	6.40	6.25	5.44
K.Surya	43.06	44.00	44.00	5.40	5.43	5.66	43.40	43.87	43.87	5.46	6.73	6.73	5.40	4.73
K.Khyati	42.36	43.09	43.09	5.30	5.46	5.53	43.05	43.23	43.23	5.00	6.46	6.46	5.43	4.82
K.Lima	43.16	44.05	44.05	5.46	5.56	5.66	43.25	43.75	43.75	5.13	5.73	5.73	5.59	4.44
K.Pukhraj	43.07	43.65	43.65	5.56	5.86	5.90	43.20	43.47	43.47	5.13	5.40	5.86	6.06	5.70
Grand Mean	43.07	43.93	43.93	5.38	5.56	5.63	42.86	43.47	43.47	5.50	6.05	6.08	6.24	5.01

Table 4.4. Mean performance of potato genotypes for morphological traits (contd.)

Genotype	Shoot wt. (g/plant) after harvest	Root wt. (g/plant) after harvest	Rottage (t/ha)	Marketable tuber yield (t/ha)	Non-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
HT-21-1	18.200	9.827	1.187	17.970	1.987	19.400
HT-21-2	16.863	7.997	1.620	10.660	1.600	11.980
HT-21-3	18.753	8.953	0.787	15.150	0.877	15.780
HT-21-4	18.067	7.577	1.737	18.193	0.943	18.870
HT-21-5	18.567	8.297	0.927	13.447	0.640	13.907
HT-21-6	19.343	10.106	1.133	12.107	1.077	12.883
HT-21-7	18.947	8.257	2.143	15.133	2.997	17.293
HT-21-8	18.513	8.937	2.603	15.883	1.430	16.917
HT-21-9	18.907	8.523	1.360	14.310	1.150	15.137
HT-21-10	18.117	8.480	1.127	13.497	1.503	14.577
HT-21-11	18.513	7.957	1.243	17.333	1.153	18.160
HT-21-12	18.743	8.430	1.537	16.260	1.150	17.087
HT-21-13	19.047	8.723	2.083	10.040	1.390	11.040
HT-21-15	18.347	8.713	0.927	13.947	0.853	14.563
HT-21-16	18.153	8.353	1.390	17.470	0.857	18.090
HT-21-17	18.623	8.140	1.157	15.087	0.837	15.683
HT-20-3	18.297	8.363	1.677	20.580	1.257	21.483
HT-20-11	18.690	8.487	1.223	16.787	0.723	17.310
HT-20-12	18.887	9.163	2.590	14.817	1.257	15.720
HT-18-4	18.283	7.767	0.837	10.240	0.627	10.693
HT-18-7	18.893	8.360	1.390	16.570	0.817	17.217
K.Surya	18.453	8.130	1.503	12.650	0.950	13.330
K.Khyati	18.260	8.273	1.157	13.413	1.120	14.217
K.Lima	18.493	8.580	1.297	13.017	1.343	13.980
K.Pukhraj	18.340	7.287	1.366	12.283	1.247	13.183
Grand Mean	18.492	8.467	1.440	14.67	1.191	15.540

4.3. Biochemical Characters

4.3.1. Tuber density (g/cc)

Tuber density in different genotypes ranged from 1.028-1.065 g/cc (Table 4.5). Highest tuber density of 1.065 g/cc was observed in HT-21-15 (0.098) and HT-21-16 (0.198) while minimum value was observed for HT-21-3 (1.028) (Table 4.6).

4.3.2. Peel % on dry weight basis

A significant range of 1.876 -3.456 was observed for peel % on dry weight basis. Maximum peel % on the dry basis was recorded for genotype HT-21-8 (3.457) followed by HT-18-4 (2.957) and HT-21-6 (2.927) and lowest peel % was noted in K. Khyati (1.877)

4.3.3. Tuber dry matter %

Highest tuber dry matter (%) was observed for HT-20-12 (20.510) followed by HT 21-3 (20.288) and the lowest tuber dry matter was recorded in genotype HT-21-15 (18.289).

4.3.4. Starch content (%)

A significant range of 71.033 -77.966 was observed for starch content (%). Maximum starch content was recorded for genotype K.pukhraj (77.967) followed by HT- 21-9 (76.967), HT-21-1 (76.733) and lowest starch content was recorded in HT-21-6 (71.033).

4.3.5. Ascorbic acid (mg/100g)

A significant range of 14.771 -20.913 was observed for Ascorbic acid. Genotype HT-21-12 (20.913) contain highest amount of Ascorbic acid followed by HT-21-13 (20.829) and HT-21-3 (19.971) while lowest was recorded for HT-21-8(4.772).

4.3.6. Reducing sugar (mg/100g)

A significant range of 0.095- 0.136 was observed for reducing sugar content. Maximum amount of reducing sugar was present in the genotype HT-18-7 (0.386) followed by HT-21-1(0.136), HT-21-2 (0.133) and lowest value for reducing sugar was recorded for genotype HT-21-6 (0.095)

4.3.7. Chlorophyll a (mg/g)

A significant range of 0.314 -0.593 was recorded for .chlorophyll a content. Maximum amount of chlorophyll was present in genotype HT-21-15(0.593) followed by HT-21-8(0.591),HT-21-17(0.571) while genotype HT-18-7(0.119)contain minimum amount of it.

4.3.8. Chlorophyll b (mg/g)

A significant range of 0.156 -0.416 was observed for chlorophyll b and highest chlorophyll b was noted in HT-21-9(0.416) followed by HT-21-8(0.376), HT-21-1 (0.335) and HT-21-2(0.156) have minimum chlorophyll content.

4.3.9. Total chlorophyll content (mg/g)

A significant range of 0.506 -0.987 was observed for total chlorophyll content. The total chlorophyll content was found to be highest in genotype HT-21- 9 (0.987) followed by HT-21-8(0.967), HT-21-15(0.894) and genotype HT-21-2(0.506) contain minimum amount of it.

4.3.10. Zinc content (ppm)

A significant range of 46.653 -68.870 was observed for zinc content. It was recorded that genotype HT-210 (68.871) contains maximum amount of zinc followed by HT-18-4 (65.945) and HT-21-13 (65.334) while genotype HT-21-3 (46.653) contains minimum amount of zinc.

Table 4.5. Biochemical characters of 25 heat tolerant potato genotypes

Sl. No.	Characters	Mean	Range	SE (\pm m)	CD(0.05)	CV (%)
1	Tuber density (g/cc)	1.047	1.028-1.065	0.001	0.003	1.174
2	Peel % on dry weight basis	2.588	1.876 -3.456	0.261	0.743	17.493
3	Tuber Dry matter (%)	19.407	18.289-20.510	0.611	1.738	4.930
4	Starch content (%)	75.353	71.033 -77.966	1.891	5.378	4.348
5	Ascorbic acid (mg/100g)	17.953	14.771 -20.913	0.699	1.987	6.745
6	Reducing sugar (mg/100g)	0.113	0.095- 0.136	0.005	0.016	8.802
7	Chlorophyll a (mg/g)	0.447	0.314 -0.593	0.046	0.130	17.838
8	Chlorophyll b (mg/g)	0.263	0.156 -0.416	0.029	0.083	19.249
9	Total chlorophyll (mg/g)	0.705	0.506 -0.987	0.069	0.197	17.062
10	Zinc content (ppm)	57.315	46.653 -68.870	1.430	4.067	4.323
11	Total Tuber Yield (t/ha)	15.540	10.693-21.483	0.605	1.720	6.743

Table 4.6. Mean performance of potato genotypes for biochemical traits

Genotype	Tuber density (g/cc)	Peel % on dry wt. basis	Tuber Dry matter %	Starch content (%)	Ascorbic acid (mg/100g)	Reducing sugar (mg/100g)	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total chlorophyll (mg/g)	Zinc content (ppm)	Total Tuber Yield (t/ha)
HT-21-1	1.049	2.217	19.085	76.733	15.800	0.136	0.540	0.335	0.841	46.966	19.400
HT-21-2	1.038	2.680	19.235	75.067	18.827	0.133	0.350	0.156	0.506	47.334	11.980
HT-21-3	1.028	2.547	20.288	76.133	19.971	0.105	0.423	0.187	0.610	46.653	15.780
HT-21-4	1.033	2.590	18.349	75.167	16.555	0.096	0.399	0.237	0.636	56.266	18.870
HT-21-5	1.054	2.583	19.077	74.233	17.879	0.098	0.556	0.282	0.837	59.409	13.907
HT-21-6	1.044	2.927	18.493	71.033	15.258	0.095	0.431	0.266	0.697	55.590	12.883
HT-21-7	1.060	2.707	19.631	73.900	19.496	0.102	0.390	0.266	0.593	59.777	17.293
HT-21-8	1.033	3.457	19.66	75.933	14.772	0.115	0.591	0.376	0.967	52.203	16.917
HT-21-9	1.049	2.003	20.053	76.967	19.034	0.125	0.571	0.416	0.987	63.733	15.137
HT-21-10	1.038	2.817	19.089	76.667	18.262	0.124	0.381	0.253	0.634	68.871	14.577
HT-21-11	1.054	2.857	20.194	75.233	15.140	0.130	0.537	0.269	0.805	54.399	18.160
HT-21-12	1.049	2.627	19.779	76.100	20.913	0.105	0.397	0.244	0.641	63.233	17.087
HT-21-13	1.044	2.813	18.712	73.567	20.829	0.098	0.432	0.249	0.680	65.334	11.040
HT-21-15	1.065	2.577	18.289	74.933	19.711	0.107	0.593	0.301	0.894	62.401	14.563
HT-21-16	1.065	2.507	19.781	74.400	15.285	0.108	0.439	0.252	0.691	63.280	18.090
HT-21-17	1.038	2.010	19.643	73.133	18.986	0.104	0.557	0.296	0.852	55.984	15.683
HT-20-3	1.044	2.047	19.85	74.233	19.533	0.130	0.322	0.237	0.559	52.808	21.483
HT-20-11	1.060	2.807	19.058	76.767	19.406	0.107	0.490	0.302	0.792	54.628	17.310
HT-20-12	1.054	2.623	20.51	75.267	15.810	0.116	0.314	0.220	0.534	55.076	15.720
HT-18-4	1.060	2.957	19.044	75.367	16.718	0.106	0.401	0.238	0.639	65.945	10.693
HT-18-7	1.060	2.640	19.325	76.900	18.260	0.386	0.119	0.258	0.644	64.569	17.217
K.Surya	1.054	2.850	20.244	76.367	15.632	0.112	0.341	0.176	0.517	49.440	13.330
K.Khyati	1.038	1.877	19.605	75.767	19.878	0.115	0.443	0.207	0.650	53.815	14.217
K.Lima	1.033	2.597	19.302	76.000	17.238	0.128	0.371	0.293	0.664	54.426	13.980
K.Pukhraj	1.038	2.390	18.888	77.967	19.625	0.114	0.513	0.252	0.765	60.752	13.183
Grand Mean	1.047	2.588	19.407	75.353	17.953	0.113	0.447	0.263	0.705	57.316	15.540

4.4. Estimation of genetic parameters

In the present study, the phenotypic variance was in general higher than the genotypic variance for all the characters. Thus, it suggests that there is significant influence of environment besides the effect of genotype on expression of these traits. Highest phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) was observed for non marketable tuber yield (t/ha). Heritability was the highest for marketable tuber yield (t/ha) and lowest for top most leaf length (cm), GA over mean was highest for Non-Marketable tuber yield (t/ha) and lowest for leaflets/leaf at 30 DAP.

The traits which exhibited high estimates of GCV and PCV have high probability of improvement through selection while the improvement of traits is difficult or virtually impractical through selection which exhibited low estimates for both variability components due to the masking effect of environment on the genotypic effect (Singh, 1990).

4.4.1. Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV)

The genotypic coefficient of variance ranged from 0.678 for leaves per plant at 50 DAP to 38.433 for non-marketable tuber yield (t/ha). At the same time, phenotypic coefficient of variance ranged from 1.721 for leaves per plant at 50 DAP to 47.010 for non-marketable tuber yield (t/ha). Other traits like leaflets/leaf, top leaf length and top leaf breadth exhibited moderate PCV ranging from 13.820 to 15.308. Similarly, characters like shoots per plant and root weight after harvest exhibited moderate GCV. Lowest value of PCV (1.721) and GCV (0.678) was shown by leaves per plant at 50 DAP

Among the biochemical traits, highest PCV (26.937) and GCV (18.844) was exhibited by chlorophyll b content and lowest PCV (1.426) and GCV (0.810) by tuber density.

4.4.2. Heritability

Heritability (broad sense) estimates ranged from 64.82 to 76.78. High heritability above 70% were observed in traits like rottage (t/ha) (72.22) and total tuber yield (t/ha) (76.67).

Moderate heritability of over 70 % was observed for shoots/plant at 30, 40 and 50 DAP, and rottage. Other traits like top leaf length and breadth, shoot and root weight after harvest and plant height showed heritability of comparatively lower magnitude (<70%).

Among biochemical traits, highest heritability was shown by zinc content (%), and heritability ranged from 62.44% for starch (%) to 76.68% for zinc content (%).

4.4.3. Genetic advance

High genetic advance of 4.965 was observed in total tuber yield followed by 4.944 in marketable tuber yield (t/ha). The lowest value was recorded in top leaf length (0.017). Highest expected genetic gain by selection (GA expressed as percentage of mean) was observed in Non-Marketable tuber yield (64.725) followed by rottage (43.912) while rest of the characters showed moderate to low value.

Among biochemical traits, genetic advance varied from 0.001 for tuber density to 11.780 for zinc content.

Table. 4.7. Genetic parameters for morphological traits

Sl No	Character	Time of observation	Heritability (%)	PCV (%)	GCV (%)	Genetic advance	Genetic advance (%) over mean
1	Plant height(cm)	30 days	69.44	2.083	1.185	0.598	1.388
		40 days	68.26	1.763	0.866	0.385	0.876
		50 days	68.30	1.756	0.867	0.388	0.883
2	Shoots/plant	30 days	73.24	9.867	7.636	0.656	12.175
		40 days	72.18	8.965	6.470	0.536	9.620
		50 days	71.56	9.140	6.301	0.504	8.949
3	Leaves/plant	30 days	67.59	2.117	0.934	0.364	0.849
		40 days	67.01	1.721	0.678	0.239	0.550
		50 days	67.01	1.721	0.678	0.239	0.550
4	Leaflets/leaf	30 days	64.86	13.820	1.471	0.018	0.323
		40 days	65.76	13.197	3.517	0.117	1.931
		50 days	65.06	13.301	2.084	0.041	0.673
5	Top leaf Length(cm)	40 days	64.82	15.308	1.440	0.017	0.279
6	Top leaf breadth(cm)	40 days	65.96	14.892	4.323	0.130	2.585

Table 4.7. Genetic parameters for morphological traits (contd.)

Sl.No.	Characters	Heritability (%)	PCV (%)	GCV (%)	Genetic advance	Genetic advance (%) over mean
7	Shoot weight (g.) after harvest	65.28	4.230	0.836	0.063	0.340
8	Root weight (g.) after harvest	69.72	9.724	5.698	0.582	6.879
9	Rottage (t/ha)	72.22	40.727	29.465	0.632	43.912
10	Marketable tuber yield (t/ha)	76.78	18.833	17.551	4.944	33.696
11	Non-Marketable tuber yield (t/ha)	74.17	47.010	38.433	0.771	64.725
12	Total tuber yield (t/ha)	76.67	18.033	16.725	4.965	31.953

Table 4.8. Genetic parameters for biochemical traits

Sl No	Character	Heritability (%)	PCV (%)	GCV (%)	Genetic advance	Genetic advance (%) over mean
1	Tuber density (g/cc)	69.42	1.426	0.810	0.001	0.947
2	Peel (%) on dry weight basis	67.88	19.741	9.149	0.226	8.735
3	Tuber Dry matter (%)	65.62	5.089	1.264	0.139	0.646
4	Starch content (%)	62.44	4.063	1.548	0.915	-1.215
5	Ascorbic acid (mg/100g)	74.52	12.213	10.181	3.138	17.484
6	Reducing sugar (mg/100g)	72.47	13.003	9.572	0.016	14.513
7	Chlorophyll a (mg/g)	71.43	24.407	16.659	0.104	23.422
8	Chlorophyll b (mg/g)	71.75	26.937	18.844	0.071	27.154
9	Total chlorophyll (mg/g)	71.63	23.673	16.411	0.165	23.436
10	Zinc content (ppm)	76.68	11.590	10.754	11.780	20.554

4.5. Character association

The yield components may not necessarily be independent, they could be linked together. As a result, the choice made for one character may also influence another. Therefore, a thorough grasp of the relationships between yield and the characters that contribute to yield is necessary. This might be useful in choosing qualities that manifest themselves strongly and are associated with yield without impacting other features.

If characters are positively correlated, selection is effective where as if the characters are correlated negatively, selection is not rewarding for such traits except for phenological features or disease and pest infestation.

4.5.1. Correlation of yield with morphological traits

Plant height at 30 DAP ($r_p=0.064$, $r_g=0.089$), leaflet per leaf at 30 DAP ($r_p=0.131$, $r_g=1.429$), Top leaf length ($r_p=0.013$, $r_g=0.700$), Top leaf breadth ($r_p=0.071$, $r_g=0.534$), root weight after harvest ($r_p=0.035$, $r_g=0.140$), rottage ($r_p=0.194$, $r_g=0.184$), marketable tuber yield ($r_p=0.989$, $r_g=0.991$), non-marketable tuber yield ($r_p=0.191$, $r_g=0.159$) exhibited positive correlation with total tuber yield both at genotypic and phenotypic level.

Plant height at both 40DAP ($r_p=-0.029$, $r_g=-0.039$) and 50 DAP ($r_p=-0.027$, $r_g=-0.307$), shoots per plant at 30 DAP ($r_p=-0.161$, $r_g=-0.262$), shoots per plant at 40 DAP ($r_p=-0.054$, $r_g=-0.136$), shoots per plant at 50 DAP ($r_p=-0.092$, $r_g=-0.206$), leaves per plant at 30 DAP ($r_p=-0.075$, $r_g=-0.161$), leaves per plant at 40 DAP ($r_p=-0.059$, $r_g=0.184$), leaves per plant at 50 DAP ($r_p=-0.059$, $r_g=-0.184$) and leaflets per leaf ($r_p=-0.073$, $r_g=-0.120$) were found to be negatively correlated with total yield both at genotypic and phenotypic level.

4.5.2 Correlation of yield with biochemical traits

Peel % on dry weight basis ($r_p=-0.167$, $r_g=-0.361$), starch % ($r_p=-0.053$, $r_g=-0.292$), Ascorbic acid ($r_p=-0.092$, $r_g=-0.163$) and zinc content ($r_p=-0.208$, $r_g=-0.243$) exhibited negative correlation with total tuber yield both at genotypic and phenotypic level while tuber density ($r_p=0.009$, $r_g=0.092$), dry matter of tuber ($r_p=0.999$, $r_g=0.318$), reducing sugar ($r_p=0.221$, $r_g=0.291$), chlorophyll a ($r_p=0.074$, $r_g=0.013$), chlorophyll b ($r_p=0.182$, $r_g=0.286$) and total chlorophyll ($r_p=0.101$, $r_g=0.101$) exhibited positive correlation with tuber yield both at genotypic and phenotypic level.

Table 4.9. Estimation of phenotypic and genotypic correlation coefficient among 20 morphological characters for 25 potato genotypes

Character	Time of observation	r	Plant height (cm)			Shoots /plant			Leaves/plant			Leaflets/leaf		
			30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP
Plant height(cm)	30 DAP	r _p r _g	1.0											
	40 DAP	r _p r _g	0.719 ** 0.906	1.0										
	50 DAP	r _p r _g	0.720** 0.908	0.999** 1.000	1.0									
Shoots/plant	30 DAP	r _p r _g	0.114 0.385	-0.015 0.243	-0.014 0.243	1.0								
	40 DAP	r _p r _g	0.064 0.345	-0.071 0.176	-0.070 0.174	0.896** 0.937	1.0							
	50 DAP	r _p r _g	0.107 0.421	-0.020 0.246	-0.020 0.243	0.853** 0.967	0.957** 1.007	1.0						
Leaves/plant	30 DAP	r _p r _g	-0.011 -0.059	0.053 0.059	0.054 0.061	0.051 0.354	0.076 0.438	0.019 0.457	1.0					
	40 DAP	r _p r _g	0.140 0.088	0.149 0.255	0.150 0.257	0.046 0.305	0.040 0.384	-0.009 0.396	0.814** 1.262	1.0				
	50 DAP	r _p r _g	0.140 0.088	0.149 0.255	0.150 0.257	0.046 0.305	0.040 0.384	-0.009 0.396	0.814** 1.262	1.000** 1.000	1.0			
Leaflets/leaf	30 DAP	r _p r _g	0.072 1.011	0.027 -1.580	0.025 -1.555	0.010 1.012	0.099 0.757	-0.116 0.711	0.002 -2.226	0.098 -2.741	0.098 -2.741	1.0		
	40 DAP	r _p r _g	-0.024 -0.122	-0.085 -0.307	-0.084 -0.307	0.069 0.475	-0.048 0.219	-0.054 0.279	0.121 -0.347	0.075 -0.782	0.075 -0.782	0.602 ** -1.254	1.0	
	50 DAP	r _p r _g	-0.007 -0.159	-0.059 -0.715	-0.059 -0.715	0.104 0.732	0.004 0.279	-0.008 0.378	0.131 -0.566	0.086 -1.394	0.086 -1.394	0.577 ** -1.394	0.975** -2.643	1.0

Table 4.9. Estimation of phenotypic and genotypic correlation coefficient among 20 morphological characters for 25 potato genotypes (Contd.)

Character	r	Plant height (cm)			Shoots /plant			Leaves/ plant			Leaflets/ leaf		
		30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP
Top leaf length	r _p	0.196	0.116	0.118	-0.113	-0.062	-0.026	-0.086	0.018	0.018	0.062	-0.120	-0.127
	r _g	2.631	1.484	1.469	-0.219	0.522	0.514	-3.181	-4.012	-4.012	12.364	-1.295	-1.892
Top leaf breadth	r _p	0.193	0.054	0.057	-0.135	-0.075	-0.049	-0.053	-0.0562	-0.056	0.020	-0.040	-0.027
	r _g	1.009	0.392	0.386	-0.286	0.086	0.099	-0.805	-1.166	-1.166	1.418	-0.301	0.126
Shoot weight (g.) after harvest	r _p	0.087	-0.123	-0.121	0.177	0.113	0.148	-0.260*	-0.324**	-0.324**	0.048	0.110	0.115
	r _g	1.578	0.521	0.525	0.787	0.538	0.445	-0.513	0.487	0.487	7.695	1.522	2.546
Root weight (g.) after harvest	r _p	0.086	0.182	0.185	0.096	-0.013	-0.034	-0.103	-0.182	-0.182	0.008	0.114	0.055
	r _g	0.524	0.722	0.716	0.250	0.235	0.192	-0.672	-0.475	-0.475	0.493	0.879	1.296
Rottage (t/ha)	r _p	0.071	-0.025	-0.025	-0.164	-0.047	-0.077	-0.081	-0.059	-0.059	0.139	-0.024	-0.060
	r _g	0.114	-0.040	-0.034	0.206	0.269	0.173	0.395	0.416	0.416	0.681	0.338	0.599
Marketable tuber yield (t/ha)	r _p	-0.031	-0.067	-0.061	-0.004	-0.058	-0.107	0.045	-0.011	-0.011	-0.040	-0.092	-0.099
	r _g	0.120	-0.026	-0.026	-0.265	-0.131	-0.187	-0.186	-0.187	-0.187	1.354	0.095	-0.118
Non-marketable tuber yield (t/ha)	r _p	0.064	-0.029	-0.027	-0.161	-0.054	-0.092	-0.075	-0.059	-0.059	0.131	-0.037	-0.073
	r _g	-0.196	-0.064	-0.050	0.020	-0.053	-0.165	0.104	-0.057	-0.057	0.893	0.009	0.095
Total tuber yield(t/ha)	r _p	0.064	-0.029	-0.027	-0.161	-0.054	-0.092	-0.075	-0.059	-0.059	0.131	-0.037	-0.073
	r _g	0.089	-0.039	-0.037	-0.262	-0.136	-0.206	-0.161	-0.184	-0.184	0.429	0.087	-0.120

Table 4.9. Estimation of phenotypic and genotypic correlation coefficient among 20 morphological characters for 25 potato genotypes (Contd.)

Character	r	Top leaf length (cm)	Top leaf breadth (cm)	Shoot weight (g.) after harvest	Root weight (g.) after harvest	Rottage (t/ha)	Marketable tuber yield (t/ha)	Non-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
Top leaf length	rp rg	1.0							
Top leaf breadth	rp rg	0.693** 0.780	1.0						
Shoot wt.(gm.) after harvest	rp rg	-0.096 11.166	-0.020 1.813	1.0					
Root wt.(gm.) after harvest	rp rg	0.135 0.428	0.208 -0.577	0.308** 1.107	1.0				
Rottage (t/ha)	rp rg	0.222 0.869	0.356 ** 1.123	0.105 0.192	0.076 0.062	1.0			
Marketable tuber yield (t/ha)	rp rg	0.011 0.749	0.058 0.515	0.065 0.024	0.016 0.118	0.137 0.116	1.0		
Non-marketable tuber yield (t/ha)	rp rg	-0.006 0.104	0.032 0.375	-0.026 -0.096	0.135 0.213	0.430 ** 0.513	0.053 0.027	1.0	
Total tuber yield (t/ha)	rp rg	0.013 0.700	0.071 0.5348	0.053 -0.005	0.035 0.140	0.194 0.184	0.989 0.991	0.191 0.159	1.0

Table.4.10. Estimation of phenotypic and genotypic correlation coefficient among 10 biochemical characters for 25 genotypes

Character	r	Tuber density (g/cc)	Peel % on dry weight basis	Dry matter %	Starch %	Ascorbic acid (mg/100g)	Reducing sugar (mg/100g)	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total Chlorophyll (mg/g)	Zinc (ppm)	Total Tuber Yield (t/ha)
Tuber density (g/cc)	rp rg	1.0										
Peel % dry	rp rg	0.213 -0.083	1.0									
Dry matter (%)	rp rg	-0.008 -0.117	-0.268 * 0.035	1.0								
Starch (%)	rp rg	- 0.1417 -0.134	-0.1006 -0.075	0.133 -1.225	1.0							
Ascorbic acid (mg/100g)	rp rg	-0.034 -0.246	-0.278 * -0.653	-0.007 -0.002	-0.016 -0.278	1.0						
Reducing sugar (mg/100g)	rp rg	-0.125 -0.130	-0.182 -0.313	0.198 0.797	0.082 -0.890	-0.089 -0.208	1.0					
Chlorophyll.a (mg/g)	rp rg	0.125 0.014	-0.023 -0.137	0.045 -0.558	0.037 -0.061	-0.020 -0.040	-0.079 -0.075	1.0				
Chlorophyll.b (mg/g)	rp rg	0.137 0.060	0.006 -0.094	0.069 -0.755	0.099 -0.059	-0.092 -0.167	0.056 0.166	0.716** 0.732	1.0			
Total chlorophyll (mg/g)	rp rg	0.128 -0.007	0.008 -0.123	-0.047 -0.638	-0.079 -0.061	0.057 -0.100	-0.021 0.013	0.954 ** 0.960	0.877** 0.883	1.0		
Zinc content (ppm)	rp rg	0.284 * 0.474	0.066 0.095	-0.155 -0.454	-0.038 -0.059	0.200 0.279	-0.254 * -0.347	0.042 0.076	0.152 0.279	0.100 0.179	1.0	
Total tuber yield (t/ha)	rp rg	0.009 0.092	-0.167 -0.361	0.999 0.318	-0.053 -0.292	-0.092 -0.163	0.221 0.291	0.074 0.013	0.182 0.286	0.101 0.101	-0.208 -0.243	1.0

4.6. Path Analysis:

4.6.1. Morphological character:

Marketable tuber yield exhibited highest direct positive effect on total tuber yield (0.999) (Table 4.11). Lowest direct positive effect was exhibited by top leaf breadth and shoot weight after harvest (0.006).

Similarly, plant height at 50 DAP showed highest direct negative effect on total tuber yield and lowest direct negative effect was exhibited by both shoots per plant at 30 DAP and top leaf length (-0.002)

Top leaf length showed highest indirect positive effect on total tuber yield (0.749) and lowest indirect positive effect was exhibited by marketable tuber yield (0.0002).

Highest indirect negative effect was exhibited by leaflets/leaf (-0.7206) and plant height at 30 DAP (0.0003) had lowest indirect negative effect on tuber yield.

Table 4.11. Path analysis for morphological traits

Character	DAP	Plant height (cm)			Shoots /plant			Leaves/plant			Leaflets/leaf		
		30 Days	40 days	50 days	30 days	40 Days	50 days	30 days	40 days	50 days	30 days	40 days	50 days
Plant height (cm)	30 Days	-0.006	-0.005	-0.005	-0.002	-0.002	-0.002	0.0004	-0.0005	-0.0005	-0.006	0.0008	0.001
	40 days	0.413	0.456	0.456	0.111	0.080	0.112	0.027	0.1164	0.116	-0.720	-0.140	-0.326
	50 days	-0.424	-0.466	-0.466	-0.113	-0.081	-0.113	-0.028	-0.120	-0.120	0.726	0.143	0.334
Shoots/ plant	30 days	$-9*10^{-4}$	$-6*10^{-4}$	$-6*10^{-4}$	-0.002	-0.002	-0.002	$-9*10^{-4}$	$-7*10^{-7}$	$-7*10^{-4}$	-0.002	-0.001	-0.001
	40 days	0.018	0.0093	0.0092	0.0493	0.052	0.053	0.023	0.020	0.020	0.039	0.0116	0.014
	50 days	-0.021	-0.012	-0.012	-0.049	-0.051	-0.050	-0.023	-0.020	-0.020	-0.036	-0.0142	-0.019
Leaves/ plant	30 days	-0.0003	0.0003	0.0003	0.0019	0.0024	0.002	0.005	0.006	0.006	-0.012	-0.0019	-0.003
	40 days	0.001	0.0044	0.0044	0.005	0.006	0.006	0.021	0.017	0.017	-0.046	-0.013	-0.023
	50 days	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.000	0.000	0.000
Leaflets/ leaf	30 days	-0.002	0.003	0.003	-0.002	-0.001	-0.001	0.0052	0.0064	0.0064	-0.002	0.002	0.006
	40 days	0.005	0.014	0.014	-0.022	-0.010	-0.013	0.0165	0.0370	0.0370	0.059	-0.047	-0.054
	50 days	-0.004	-0.020	-0.020	0.0211	0.0081	0.0109	-0.016	-0.040	-0.040	-0.076	0.0331	0.028

Table 4.11. Path analysis for morphological traits (Contd.)

Character	DAP	Top leaf length	Top leaf breadth	Shoot weight (g.) after harvest	Root weight(g.) after harvest	Rottage (t/ha)	Marketable tuber yield (t/ha)	Non-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
Plant height	30 Days	-0.016	-0.006	-0.009	-0.003	$-7*10^{-4}$	$-7*10^{-4}$	0.001	0.089
	40Days	0.677	0.178	0.237	0.329	-0.018	-0.012	-0.029	-0.039
	50 days	-0.686	-0.180	-0.245	-0.334	0.016	0.012	0.023	-0.037
Shoots/plant	30 days	$5*10^{-4}$	$7*10^{-4}$	-0.001	$-6*10^{-4}$	$-5*10^{-4}$	$6*10^{-4}$	$1*10^{-4}$	-0.262
	40 days	0.027	0.004	0.028	0.006	0.014	-0.006	-0.002	-0.136
	50 days	-0.026	-0.005	-0.022	-0.009	-0.008	0.009	0.008	-0.206
Leaflet/leaf	30 days	-0.017	-0.004	-0.002	-0.003	0.002	-0.001	$6*10^{-4}$	-0.161
	40 days	-0.068	-0.019	0.008	-0.008	0.007	-0.003	-0.001	-0.184
	50 days	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.184
leaflet/leaf	30 days	-0.0290	-0.0033	-0.018	-0.0012	-0.0016	-0.003	-0.002	1.429
	40 days	0.061	0.014	-0.072	-0.041	-0.016	-0.004	$5*10^{-4}$	0.087
	50 days	-0.054	0.003	0.073	0.037	0.017	-0.003	0.002	-0.120

Table 4.11. Path analysis for morphological traits (Contd.)

Character	Top leaf length (cm)	Top leaf breadth (cm)	Shoot weight (g.) after harvest	Root weight (g.) after harvest	Rottage (t/ha)	Marketable tuber yield (t/ha)	Non-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
Top leaf length (cm)	-0.002	-0.001	-0.022	-9×10^{-4}	-0.001	-0.001	-2×10^{-4}	0.700
Top leaf breadth (cm)	0.004	0.006	0.011	-0.003	0.006	0.003	0.002	0.534
Shoot weight (g.) after harvest	0.077	0.012	0.006	0.007	0.001	2×10^{-4}	-78×10^{-4}	-0.005
Root weight (g.) after harvest	0.006	-0.008	0.015	0.014	9×10^{-4}	0.001	0.003	0.140
Rottage (t/ha)	-0.018	-0.023	-0.004	-0.001	-0.021	-0.002	-0.010	0.184
Marketable tuber yield (t/ha)	0.749	0.515	0.024	0.118	0.116	0.999	0.027	0.991
Non-marketable tuber yield (t/ha)	0.014	0.0519	-0.0133	0.0295	0.071	0.003	0.138	0.159

4.7. D² Analysis

The D² value was estimated following Mahalanobis D² method (1928) for all the combinations among 25 genotypes on the basis of 20 morphological and 10 biochemical characters studied.

4.7.1 Morphological characters

Among morphological characters, marketable tuber yield contributes maximum (54.0) towards divergence followed by non-marketable tuber yield (11.57) and rottage (11.00) (Table 4.12)

By applying Tocher's method, 25 potato genotypes were classified into 11 clusters. The cluster I included 15 genotypes while cluster II, cluster III, Cluster IV, cluster V, cluster VI, cluster VII, cluster VIII, Cluster IX, cluster X and cluster XI included one genotype each.

From the average intra and inter cluster distance (Table 4.14), it is clear that cluster VII and cluster III had the maximum inter cluster distance having the value of 57.26 and the lowest inter cluster distance was between the cluster II and cluster V having the value of 7.93. So it has been recorded that cluster III and cluster VII are most divergent from each other having intercluster distance of 57.26. At the same time, cluster II and cluster V are less divergent from each other having intercluster distance of 7.93.

Table 4.12. Morphological Character contribution towards divergence

Morphological characters	Contribution (%)
Plant height at 30 DAP	2.67
Plant height at 40 DAP	0.33
Plant height at 50 DAP	0.00
Shoots/plant at 30 DAP	5.0
Shoots/plant at 40 DAP	1.33
Shoots/plant at 50 DAP	0.00
Leaves /plant at 30 DAP	2.33
Leaves /plant at 40 DAP	0.00
Leaves /plant at 50 DAP	0.00
Leaflets /leaf at 30 DAP	0.00
Leaflets /leaf at 40 DAP	2.33
Leaflets /leaf at 50 DAP	3.33
Top leaf length at 40 DAP	0.33
Top leaf breadth at 40 DAP	0.33
Shoot weight (g.) after harvest	1.00
Root weight (g.) after harvest	4.33
Rottage (t/ha)	11.0
Marketable tuber yield (t/ha)	54.0
Non marketable tuber yield(t/ha)	11.67
Total tuber yield(t/ha)	0.00

Table.4.13 Clustering of 25 genotypes for morphological traits on the basis of D² analysis

Cluster	No. of genotypes	Name of the potato genotypes
I	15	HT-21-17, K.Khyati, K.Surya, HT-21-9, HT-21-10, K.Lima, HT-21-12, HT-21-15, HT-20-11, HT-18-4, HT-21-11, HT-21-16, HT-21-3, HT-20-12, HT-21-5
II	1	HT-18-7
III	1	HT-20-3
IV	1	HT-21-4
V	1	HT-21-13
VI	1	K. Pukhraj
VII	1	HT-21-2
VIII	1	HT-21-6
IX	1	HT-21-8
X	1	HT-21-1
XI	1	HT-21-7

Table.4.14.Cluster Distance involving morphological traits of 25 genotypes of potato

Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10	Cluster 11
Cluster 1	7.97	15.98	20.60	18.23	20.49	14.94	22.58	17.88	16.52	21.88	25.07
Cluster 2	15.98	0.00	50.58	41.84	7.93	10.77	16.75	16.89	28.66	50.46	31.67
Cluster 3	20.60	50.58	0.00	19.47	56.07	39.48	57.26	35.90	20.85	20.18	39.43
Cluster 4	18.23	41.84	19.47	0.00	45.89	30.95	39.64	42.91	32.14	16.79	41.17
Cluster 5	20.49	7.93	56.07	45.89	0.00	11.86	11.23	14.51	23.19	50.96	22.15
Cluster 6	14.94	10.77	39.48	30.95	11.86	0.00	16.08	25.89	25.89	39.01	20.16
Cluster 7	22.58	16.75	57.26	39.64	11.23	16.08	0.00	22.51	21.84	49.81	23.03
Cluster 8	17.88	16.89	35.90	42.91	14.51	25.89	22.51	0.00	14.14	40.85	32.35
Cluster 9	16.52	28.66	20.85	32.14	23.19	24.55	21.84	14.14	0.00	39.05	25.11
Cluster10	21.88	50.46	20.18	16.79	50.96	39.01	49.81	40.85	39.05	0.00	34.21
Cluster11	25.07	31.67	39.43	41.17	22.15	20.16	23.03	32.35	25.11	34.21	0.00

Table 4.15. Cluster Mean of 25 genotypes for morphological traits on the basis of D² analysis

Cluster	Plant height			Shoots/ plant			Leaves /plant			Leaflets/leaf
	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30 DAP	40 DAP	50 DAP	30DAP
Cluster 1	43.12	43.96	43.96	5.32	5.45	5.54	42.82	43.46	43.46	5.56
Cluster 2	43.06	43.83	43.83	5.43	5.50	5.60	42.83	43.53	43.53	5.67
Cluster 3	44.29	44.25	44.25	5.87	6.23	6.23	43.10	43.68	43.68	6.13
Cluster 4	41.79	42.90	42.90	4.37	5.23	5.23	43.00	43.60	43.60	5.00
Cluster 5	43.58	44.21	44.21	5.43	5.53	5.57	42.73	43.63	43.63	5.70
Cluster 6	43.07	43.65	43.65	5.57	5.87	5.90	43.21	43.47	43.47	5.13
Cluster 7	42.27	44.22	44.22	5.33	5.60	5.60	43.94	44.30	44.30	4.80
Cluster 8	42.95	43.98	43.98	6.33	6.50	6.50	42.76	43.16	43.16	5.53
Cluster 9	43.37	44.17	44.17	6.57	6.67	6.70	43.05	43.61	43.61	5.00
Cluster10	44.37	44.37	4.50	4.77	4.77	41.57	41.57	42.32	42.32	5.20
Cluster11	42.98	43.43	43.47	5.47	5.50	5.50	43.20	43.63	43.63	6.13

Table 4.15. Cluster Mean of 25 genotypes for morphological traits on the basis of D² analysis (contd.)

Cluster	Leaflets/ leaf		Top leaf length (cm)	Top leaf breadth(cm)	Shoot weight(g..) after harvest	Root weight (g.) after harvest	Rottage (t/ha)	Marketable tuber yield (t/ha)	Non-marketable tuber yield (t/ha)	Total tuber yield (t/ha)
	40 DAP	50 DAP								
Cluster 1	6.18	6.19	6.16	4.96	18.56	8.46	1.31	14.92	1.02	15.65
Cluster 2	5.80	5.80	6.94	4.76	18.28	7.77	0.84	10.24	0.63	10.69
Cluster 3	6.20	6.20	6.51	5.36	18.30	8.36	1.68	20.58	1.26	21.48
Cluster 4	5.40	5.40	6.59	5.18	18.07	7.58	1.74	18.19	0.94	18.87
Cluster 5	6.00	6.20	6.87	5.19	19.05	8.72	2.08	10.04	1.39	11.04
Cluster 6	5.40	5.87	6.06	5.70	18.34	7.29	1.37	12.28	1.25	13.18
Cluster 7	5.53	5.53	5.38	4.54	16.86	8.00	1.62	10.66	1.60	11.98
Cluster 8	6.87	6.87	6.10	4.56	19.34	10.11	1.13	12.11	1.08	12.88
Cluster 9	5.73	5.73	6.36	5.31	18.51	8.94	2.60	15.88	1.43	16.92
Cluster10	5.53	5.53	6.52	5.24	18.20	9.83	1.19	17.97	1.99	19.40
Cluster11	6.13	6.13	6.38	5.15	18.95	8.26	2.14	15.13	3.00	17.29

4.7.2 Biochemical characters

By applying Tocher's method, 25 potato genotypes were classified into 10 clusters based on biochemical traits. The cluster I and II included 8 genotypes each; cluster III, cluster IV and cluster V were having 1 genotype each; cluster VI was having 2 genotypes; cluster VII, cluster VIII, cluster IX and cluster X were having one genotype each.

Among biochemical characters, zinc content contributed maximum towards divergence (29.33%) followed by total chlorophyll content (Table 4.16).

Cluster III was having only one genotype and possessed maximum value (46.65) for the character zinc content (ppm) towards total tuber yield and minimum value is for the reducing sugar.

From the table 4.18, it has been seen that cluster IV and cluster IX are more divergent from each other having intercluster distance of 81.54. At the same time cluster V and cluster VIII are less divergent from each other having intercluster distance of 8.12.

Table 4.16. Contribution of biochemical characters towards divergence

Sl. no.	Character (Biochemical)	Contribution (%)
1	Tuber density (g/cc)	0.33
2	Peel (%) on dry weight basis	0.67
3	Tuber dry matter (%)	0.33
4	Starch content (%)	0.00
5	Ascorbic acid (mg/100g)	9.33
6	Reducing sugar (mg/100g)	2.33
7	Chlorophyll a (mg/g)	3.00
8	Chlorophyll b (mg/g)	4.00
9	Total chlorophyll (mg/g)	4.33
10	Zinc content (ppm)	29.33

Table 4.17. Clustering of 25 genotypes on the basis of D² analysis involving biochemical traits

Cluster	No of genotypes	Name of the potato genotypes
I	8	HT-21-5, HT-21-17, K. Khyati, HT-21-15, K. Pukhraj, K. Surya, HT-21-6, HT-18-7
II	8	HT-21-16, HT-18-4, HT-21-12, HT-20-11, HT-21-4, HT-20-12, HT-21-7, HT-21-11
III	1	HT-21-3
IV	1	HT-21-13
V	1	K. Lima
VI	2	HT-21-9, HT-21-10
VII	1	HT-21-8
VIII	1	HT-21-2
IX	1	HT-21-1
X	1	HT-20-3

Table 4.18. Cluster Distance of 25 genotypes involving morphological traits on the basis of D² analysis

Group	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8	Cluster 9	Cluster 10
Cluster 1	8.64	18.29	16.11	13.73	14.40	14.39	17.90	16.59	40.47	41.42
Cluster 2	18.29	9.58	23.13	37.49	19.63	15.88	14.46	34.16	22.22	15.75
Cluster 3	16.11	23.13	0.00	30.34	9.88	34.12	17.58	9.51	35.39	33.67
Cluster 4	13.73	37.49	30.34	0.00	34.01	19.04	41.42	27.15	81.54	73.85
Cluster 5	14.40	19.63	9.88	34.01	0.00	31.48	14.55	8.12	27.98	36.92
Cluster 6	14.39	15.88	34.12	19.04	31.48	6.78	22.33	36.84	42.46	34.14
Cluster 7	17.90	14.46	17.58	41.42	14.55	22.33	0.00	25.80	17.26	25.04
Cluster 8	16.59	34.16	9.51	27.15	8.12	36.84	25.80	0.00	43.13	54.37
Cluster 9	40.47	22.22	35.39	81.54	27.98	42.46	17.26	43.13	0.00	15.28
Cluster 10	41.42	15.75	33.67	73.85	36.92	34.14	25.04	54.37	15.28	0.00

Table 4.19. Cluster mean of 25 genotypes for biochemical traits

Cluster	Char. 1	Char. 2	Char. 3	Char. 4	Char. 5	Char. 6	Char. 7	Char. 8	Char. 9	Char. 10	Char. 11
Cluster 1	0.19	2.49	21.29	74.80	18.16	0.11	0.48	0.27	0.75	58.54	13.64
Cluster 2	0.20	2.67	21.58	75.47	17.61	0.11	0.42	0.26	0.67	58.90	17.47
Cluster 3	0.19	2.55	22.29	76.13	19.97	0.11	0.42	0.19	0.61	46.65	46.65
Cluster 4	0.19	2.81	20.71	73.57	20.83	0.10	0.43	0.25	0.68	65.33	11.04
Cluster 5	0.20	2.85	22.24	76.37	15.63	0.11	0.34	0.18	0.52	49.44	13.33
Cluster 6	0.19	2.41	21.57	76.82	18.65	0.12	0.48	0.33	0.81	66.30	14.86
Cluster 7	0.19	3.46	21.66	75.93	14.77	0.12	0.59	0.38	0.97	52.20	16.92
Cluster 8	0.19	2.68	21.24	75.07	18.83	0.13	0.35	0.16	0.51	47.33	11.98
Cluster 9	0.19	2.22	21.08	76.73	15.80	0.14	0.54	0.34	0.84	46.97	19.40
Cluster 10	0.19	2.05	21.85	74.23	19.53	0.13	0.32	0.24	0.56	52.81	21.48

Char.1- Tuber density (g/cc); Char.2- Peel (%) on dry weight basis; Char.3- Tuber dry matter (%); Char.4- Starch content (%); Char.5- Ascorbic acid (mg/100g); Char.6-Reducing sugar (mg/100g); Char.7- Chlorophyll a (mg/g); Char.8- Chlorophyll b (mg/g); Char.9-Total chlorophyll (mg/g); Char.10- Zinc content (ppm)

DISCUSSION

The most significant economic characteristic, yield, is complicated and is the reflection of various direct and indirect components. It has been noted that choosing a yield includes choosing one or more of its constituent parts. Therefore, understanding the nature of how various qualities relate to yield is crucial.

Path coefficient analysis is a very important and useful method as it permits separation of correlation into measures of direct and indirect effects and thereby reveals the importance of the casual factor proceeding the end effect. Further the utility of multivariate analysis in grouping the varieties with regards to several characters has been emphasized. It has been observed that selection of parents for hybridization on the basis of D^2 analysis was more effective for improvement of yield.

Considering the importance of potato in the state of Odisha, the present study "Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes" was undertaken to select the superior genotypes. The experimental findings of the above studies are presented in fore going pages which have shown some interesting results are being discussed hereafter.

Analysis of Variance

Twenty five genotypes of potato were used in genetic variability study for 25 distinct yield and component character traits. The quantitative characters were subjected to analysis of variance (ANOVA) in accordance with the method described by Gomez and Gomez (1984).

For all of the characters under study, the mean sum of squares due to genotype were highly significant, indicating that there is enough genetic variation. Similar outcomes in potatoes were previously attained (Petros *et al.* 2013, Gopal *et al.* 1999, and Solomon *et al.* 2015).

The mean squares was maximum in case of total tuber yield (21.363) followed by marketable tuber yield (20.903). Among biochemical characters, mean square was maximum for Zinc content (120.112).

Variability, heritability and genetic advance

An examination of ANOVA shows that the nature and magnitude of variability for 20 different quantitative characters can be clearly visualised in potato which showed great variations for all the characters studied and on statistical analysis the difference was found to be highly significant. The large amount of variation existing in the collected germplasm revealed that considerable improvement can be made in this crop through the characters studied which showed significant differences among the varieties.

Highest PCV and GCV were recorded for non marketable tuber yield and lowest for leaves per plant; heritability was highest for total tuber yield and lowest for top most leaf length; GA over mean was the highest for total tuber yield and lowest for leaves per plant.

Two things are most important to have ideas about breeding principles i.e. selection cannot create variability but act only on that which is already in existence. Selection can act effectively on heritable differences (Allard 1960). Basing on this fact, it is most important to ascertain the extent of genetic variability for the characters to be studied at significant level or not. Further phenotypic mean may not give a clear picture for selection as influenced by environmental effect and may even be misleading and may not truly represent the genotypic values.

It was observed that in general, phenotypic coefficient of variation was greater than genotypic co-efficient of variation for all the characters studied . It has been observed that the leaves per plant at 40 or 50 DAP exhibited low PCV and GCV while marketable tuber yield exhibited highest PCV as well as GCV.

The genotypic coefficient of variation ranged from 0.678 for leaves per plant at both 40 and 50 DAP to 38.433 for non-marketable tuber yield (t/ha) At the same time, phenotypic co- efficient of variation ranged from 1.721 for leaves per plant at 40 or 50 DAP to 47.010 for non-marketable tuber yield.

Among biochemical traits, highest PCV (26.937) and GCV (18.844) was exhibited by chlorophyll b content and lowest PCV (1.426) and GCV (0.810) was exhibited by tuber density.

Character Association

The most economically significant characteristic of potatoes, which is the result of the interaction of quantitative features that are very susceptible to environmental change, is tuber yield. Therefore, selection based solely on yield may not be a wise and effective choice. Consequently, for designing a profitable and efficient breeding programme, a sound knowledge of such association among yield and its components is prime requisites for success of programme.

Robinson (1966) asserts that correlation studies can be used to identify superior genotypes based on how they manifest in phenotype. Therefore, it is desirable to investigate the interactions between these qualitative features at both the genotypic and phenotypic levels after obtaining interaction related to phenotypic coefficient variation, genotypic coefficient of variation, and genetic progress.

The genotypic correlation coefficient exhibited greater values for most of the variable pairings than the phenotypic correlation coefficient, indicating that there was a strong underlying relationship between the different characters under study.

Plant height at both 40 DAP and 50 DAP, shoots per plant at 30, 40 & 50 DAP, leaves per plant at 30, 40 & 50 DAP and leaflets per leaf show negative correlation with total tuber yield both at genotypic and phenotypic level.

Plant height at 30 DAP, leaflets per leaf at 30 DAP, top leaf length and breadth, root weight after harvest, rottage, marketable tuber yield and non-marketable tuber yield were positively correlated with total tuber yield both at genotypic and phenotypic level.

Path coefficient analysis,

It is a crucial and practical tool that allows for the separation of correlation into measurements of direct and indirect effects. The importance of multivariate analysis in classifying the types according to a number of characters has also been underlined. It has been found that D^2 analysis-based parent selection for hybridization improved yield more than parent selection based on other techniques.

Direct and indirect effect of characters on plant yield

The marketable tuber yield has highest direct positive effect on tuber yield (0.999) followed by plant height at 40 DAP (0.456). Lowest direct positive effect is exhibited by top leaf breadth and shoot weight after harvest (0.006)

Similarly, plant height at 50 DAP had highest direct negative effect on tuber yield and lowest direct negative effect was exhibited by both shoots per plant at 30 DAP and top leaf length.

Top leaf length had highest indirect positive effect on tuber yield (0.749) and lowest indirect positive effect was exhibited by Marketable tuber yield.

Highest indirect negative effect was exhibited by leaflets/leaf and plant height at 30 DAP has lowest indirect negative effect on tuber yield.

Genetic divergence

A potent approach for assessing genetic divergence among the test genotypes is the multivariate analysis using Mahalanobis D^2 statistics. The multivariate analysis, which is a numerical estimate, has the added benefit over other criteria of allowing accurate comparisons between all potential pairs of population in any given group.

In the present study, 25 potato genotypes are grouped into 11 clusters based on the morphological characters and formed 10 clusters based on the biochemical characters.

From the average intra and inter cluster distance, it is evident that among the multivariate clusters, cluster VII and cluster III had the maximum inter cluster distance having the value of 57.26 and the lowest inter cluster distance was between the cluster II and cluster V having the value of 7.93. So it has been recorded that cluster III and cluster VII are more divergent from each other having intercluster distance of 57.26 while cluster II and cluster V are less divergent from each other having intercluster distance of 7.93.

Among morphological characters, marketable tuber yield contributed maximum towards divergence followed by non-marketable tuber yield and rottage, and among biochemical characters, zinc content contributed maximum percentage towards divergence.

Based on biochemical characters, cluster IV and cluster IX are most divergent from each other having intercluster distance of 81.54 while cluster V and cluster VIII are least divergent from each other having intercluster distance of 8.12.

SUMMARY AND CONCLUSION

- The present study entitled “Genetic variability in crop growth, quality attributes and tuber yield of heat tolerant potato genotypes” was carried out in All India Co-ordinated Research Project on Potato during Rabi-2021-22 with twenty-five genotypes of potato to assess the comparative performance of varieties, genetic variability, heritability, genetic advance, correlation among characters, path analysis to study the direct and indirect effect, and genetic divergence. Genetic divergence was assessed through Mahalanobis D^2 statistics.
- Observations were recorded on plant height, number of shoots per plant, number of leaves per plant and number of leaflets per leaf at 30, 40 and 50 DAP; shoot weight (g) after harvest, root weight (g) after harvest, dry matter percentage of tubers and tuber yield per hectare. The biochemical parameters like tuber dry matter content (%), total starch content (%), Ascorbic acid content of fresh tubers (mg/100g), reducing sugar content of fresh tubers (mg/100g), leaf chlorophyll content at 60 days after planting (mg/g) and Zinc content of tuber after harvest (ppm) were also recorded during the course of investigation. The salient findings of this investigation are summarized below.
- There exists significant variation among heat tolerant potato genotypes for several important characters studied.
- Highest tuber yield was exhibited by HT 20-3 (21.483 t/ha) among 25 test genotypes.
- Among morphological characters, the mean squares was maximum in case of total tuber yield. Among biochemical characters, mean square was maximum for Zinc content (120.112) followed by Ascorbic acid (11.489).
- The quality parameters like reducing sugars, specific gravity, ascorbic acid content and dry matter content in tubers did not vary much during the course of investigation. The reducing sugars were low in some genotypes like HT 21-4, HT 21-5, HT 21-6 and HT 21-13, as compared to others which is desired for processing type of potato.
- Closeness of phenotypic co-efficient of variation and genotypic co-efficient of variation for all characters represent true to genotypes. Moderate heritability estimates were observed for most of characters under study. Heritability was high for marketable tuber yield (76.78) followed by non marketable tuber yield. Rest of the characters showed low to moderate heritability.

- Highest genetic advances in percentage of mean was observed for non-marketable tuber yield followed by rottage. Rest of the characters showed moderate to very low values for this parameter.
- Analysis of phenotypic and genotypic correlation coefficient among the various quantitative characters studied revealed that the genotypic correlation coefficient exhibited greater values for most of the variable pairings than the phenotypic correlation coefficient, indicating that there was a strong underlying relationship between different characters under study.
- Many characters such as plant height at both 40 and 50 DAP, shoots per plant at 30, 40 and 50 DAP, leaves per plant at 30, 40 and 50 DAP, and leaflets per leaf showed negative correlation with total yield both at genotypic and phenotypic level.
- At both genotypic and phenotypic level, marketable tuber yield showed highly significant positive correlation with total tuber yield. Also, marketable tuber yield exhibited highest direct positive effect (0.999) on total tuber yield.
- In the present study, 25 potato genotypes are grouped into 11 clusters based on the morphological characters and formed 10 clusters based on the biochemical characters.
- Among morphological characters, marketable tuber yield contributed maximum towards divergence followed by non-marketable tuber yield and rottage, and among biochemical characters, zinc content contributed maximum percentage towards divergence.
- Based on biochemical characters, cluster IV and cluster IX were most divergent from each other having intercluster distance of 81.54 while cluster V and cluster VIII were least divergent from each other having intercluster distance of 8.12.

REFERENCES

- Bhagowati RR, Saikia M and Sutluj D. 2002. Variability, heritability, genetic advance and Character association in True Potato Seed (TPS) populations. *Journal of Agricultural Science Society of North-East India*, **15** (1) : 119-122.
- Biswas MK, Mondal MA, Ahmad MG, Hoque A, Hossain MM. Islam R. 2005. Study on genetic variability and heterosis in potato. *Pakistan Journal of Biological Science*, **8** (1) : 6-9.
- Burton GW.(1952). Quantitative inheritance in grasses.proceedings of 6th *International Congress 1* :277-283.
- Chandra R, Choudhary DR and Bishman RK. 1992. Genotypic variability for microtubule production in potatoes. *Journal of Indian Potato Association*. **19**(2) : 50-54.
- Desai N C and Jaimini S N. 1997. Studies on genetic divergence in potato (*Solanum tuberosum* L.). *Journal of Indian Potato Association*. **24** (3/4) : 154-160.
- Desai NC and Jaimini S N. 1998. Correlation and path analysis of some economic characters in potato. *Journal of Indian Potato Association*. **25** (1/2) : 25-29.
- Dewey, D.R. and Luke N, 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal*, 51:515-518
- Garg L P and Bhutani RD. 1991. Studies on correlation and path analysis in potato (*Solanum tubersum* L.). *Haryana Journal of Horticultural. Science*. **20** (3/4) : 255-260.
- George, T. S., Taylor, M. A., Dodd, I. C., and White, P. J. 2017. Climate Change and Consequences for Potato Production: a Review of Tolerance to Emerging Abiotic Stress. *Potato Res.* **60**: 239–268.
- Gomez, K.A. and Gomez, A.A. (1984) *Statistical Procedures for Agricultural Research*. 2nd Edition, John Wiley and Sons, New York, 680 p..
- Halwai R. 2000. Evaluation of potato cultures/hybrids under Chhattisgarh Plains. *M.Sc. (Ag.) Thesis*, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).
- Hancock, R. D., Morris, W. L., Ducreux, L. J. M., Morris, J. A., Usman, M. and Verrall, S. R. 2014. Physiological, biochemical and molecular responses of the potato (*Solanum tuberosum* L.) plant to moderately elevated temperature. *Plant Cell Environ.* **37**: 439–450.
- Hastilestari, B. R., Lorenz, J., Reid, S., Hofmann, J., Pscheidt, D. and Sonnewald, S. 2018. Deciphering source and sink responses of potato plants (*Solanum tuberosum* L.) to elevated temperatures. *Plant Cell Environ.* **41**: 2600–2616.

- Haydar A, Ahmed MB, Hannan MM, Razvy MA, Mandal MA, Salahin M, Karim R and Hossain M. 2007. Analysis of genetic diversity in some potato varieties grown in Bangladesh. *Middle East Journal of Scientific Research*, **2** (3-4) : 143-145.
- Iqbal MZ, and Khan SA. 2003. Genetic variability, partial regression, co-heritability studies and their implication in selection of high yielding potato genotypes. *Pakistan Journal of Scientific and Industrial Research* **46** (2) : 126-128.
- Joseph TA, Gopal J and Sood, SK. 2005. Genetic parameters and character associations in potato under sub-tropical plains and temperate hill conditions. *Potato Journal*, **32** (1-2) : 49-53.
- Johnson HW, Robinson HF, Comstock RE. 1955. Estimates of genetic and environmental variability in soybeans. *Agron. J.*, 47:314-318
- Kamal SR, Raghav M Singh YV and Singh NP. 2007. Correlation and path analysis of yield determinants in potato (*Solanum tuberosum* L.) hybrids. *Pantnagar Journal of Research*, **5** (2) : 120-124.
- Kumar R and Kang GS. 2000. Characterizing genetic diversity in andigena potato using non-hierarchical Euclidean cluster analysis. *Potato Global Research and Development Proceedings of the Global Conference on Potato, New Delhi*, . **1** : 146-149.
- Lehretz GG, Sonnewald S, Lugassi N, Granot D and Sonnewald U. 2021. *Frontiers in Plant Science*. 11:614534. doi: 10.3389/fpls.2020.614534.
- Lehretz, G. G., Sonnewald, S., Hornyik, C., Corral, J. M., and Sonnewald, U. 2019. Post-transcriptional regulation of flowering locus- T modulates heat-dependent source-sink development in potato. *Curr. Biol.* **29**: 1614–1624.
- Luthra SK and Gopal J PC. 2005. Genetic divergence and its relationship with heterosis in potato. *Potato Journal*, **32** (1-2) : 37-42.
- Luthra SK. 2001. Heritability, Genetic advance and character association in potato. *Journal of Indian Potato Association*. **28** (1) : 1-3.
- Luthra SK. 2010 , Genetic Divergence of Germplasm Accessions in Potato (*Solanum tuberosum* subsp. *tuberosum*), *Indian Journal of Plant Genetic Resources*, **22**(2):98-101.
- Mahalanobis PC. 1936. Studies on the generalized distance in statistics. *Proceedings of National Institute of Science- India*. **21** : 49-55.
- Mahalanobis, P.C., 1936. On the generalized distance in statistics. *Proceedings of National academic Science (India)*, **2**: 79-85.
- Maris B. 1990. Comparison of diploid and tetraploid potato families derived from *Solanum phureja* x diploid *Solanum tuberosum* L hybrids and their vegetatively doubled counter parts. *Euphytica*. **46** : 15-33.

- Murthy, B.R. and V. Arunachalam. 1966. Nature of genetic divergence in relation to breeding system in crop plants. *IndianJ. Genetics*. **26**: 188-98
- Ozkaynak E, Samanc B and Cetin MD. 2003. Correlation and path coefficient analysis of yield components in potato (*Solanum tuberosum* L.) *Turkish Journal of Field Crops*, **8** (2) : 1-6.
- Panigrahi K.K, Sarkar K.K., Baisakh B and Mohanty A. 2014. Assessment of Genetic Divergence in Potato (*Solanum Tuberosum* L.) Genotypes for Yield and Yield Attributing Traits, *International Journal of Agriculture, Environment and Biotechnology*, **7**(2):247-254.
- Patel CJ, Patel NH, Gami RA, Patel AK and Chauhan RM. 2013. Assessment of Potato (*Solanum tuberosum* L) Hybrids-Varieties for Processing Purpose among Yield and Quality Traits, *Trends in Biosciences*, **6** (5): 676-681.
- Patel PB, Patel, NH and Patel, RN. 2003. Correlation and path analysis of some economic characters in potato. *J. Indian Potato Association*. **29** (3/4) : 163-164.
- Ramanjit K, Singh N and Kler DS. 2001. Correlation studies among leaf area index, tuber number, tuber weight, dry matter production and tuber yield in autumn sown potato. *Environment and Ecology*, **19** (1) : 19-22.
- Rasul MG, Islam MA, Nahar MS and Rashid MM. 1995. Heritability, variability and correlation in the first clonal generation of tuberlets progenies derived from true potato seed. *Bangladesh Journal of Scientific and Industrial Research*. **30** (2/3) : 161-170.
- Regassa D and Basavaraja N. 2005. Correlation and path analysis in potato (*Solanum tuberosum* L.). *Potato Journal*, **32** (3-4) : 233-256.
- Roy A K and Singh P K. 2006. Genetic variability, Heritability and genetic advance for yield in potato (*Solanum tuberosum* L.). *International Journal of Plant Science*. **1** (2) : 282-285.
- Santhosh N, Indiresk K. M., Puneeth M., Thyagaraj G. N and Padmaraja S. R, 2014, Genetic Variability of Early Maturing Advanced Potato (*Solanum tuberosum* L.) Hybrids, *Trends in Biosciences*, **7**(18): 2775 - 2777.
- Schafleitner, R., Gutierrez-Rosales, R. O., Gaudin, A., Alvarado Aliaga, A. A., Nomberto Martinez, G. and Tincopa Marca, L. R. 2007. Capturing candidate drought tolerance traits in two native Andean potato clones by transcription profiling of field grown plants under water stress. *Plant Physiol. Biochem*. **45**: 673–690.
- Sharma D, Sarnaik DA, Shukla N, Sharma P, Tirkey T and Girolkar AK. 2007. Genetic variability and association studies in early maturing potato hybrids. *Journal of Agricultural Issues*, **12** (2) : 42-47.

- Singh SV, Pandey SK, Kumar D, Marwaha RS, Kumar P and Manivel P. 2008. Potential of advanced potato (*Solanum tuberosum*) hybrids for processing in Agra and indoor region of west-central plains. *Indian Journal Agricultural Science*. **78** (3) : 198-202.
- Trapero-Mozos, A., Ducreux, L. J. M., Bitá, C. E., Morris, W., Wise, C. and Morris, J. A. . 2018. A reversible light - and genotype - dependent acquired thermo-tolerance response protects the potato plant from damage due to excessive temperature. *Planta*. **247**: 1377–1392.
- Yenagi, B.S., Meli, S.S. and Angadi, S.S. 2008. Correlation study in potato variety Kufri Chandramukhi under rainfed condition. *Agricultural Science Digest*. **28** : 1.
- Yildirim, M.B.; Budak, N.; Yldrm, Z. and Calskan, C.F. 1995. Path analysis of potato yield and yield components. *Ege Universitesi Zirrat Fakultesi Dergisi*. 32 (**1**) : 9-13.