CHARACTER ASSOCIATION AND GENETIC DIVERSITY OF POTATO (*Solanum tuberosum* L.)

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DHAKA -1207, BANGLADESH

JUNE, 2015

CHARACTER ASSOCIATION AND GENETIC DIVERSITY OF POTATO (*Solanum tuberosum* L.)

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REGISTRATION NO. 09-03622

A Thesis
submitted to the Faculty of Agriculture,
Sher-e-Bangla Agricultural University, Dhaka,
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

IN

GENETICS AND PLANT BREEDING

SEMESTER: JANUARY-JUNE, 2015

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CERTIFICATE

This is to certify that thesis entitled, "Character Association and Genetic Diversity of Potato (Solanum tuberosum L.)" submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** *in* **GENETICS AND PLANT BREEDING,** *embodies the result of a piece of bona fide research work carried out by Md. Habibur Rahman, Registration No.09-03622 under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed of during the course of this investigation has duly been acknowledged.

Dated : June , 2015
Place: Dhaka, Bangladesh

(Prof. Dr. Mohammad Saiful Islam)
Supervisor

DEDICATED TO

MY

BELOVED PARENTS

ACKNOWLEDGEMENTS

First of all I express my best gratitude to Almightly Allah for His never-ending blessing to complete this work successfully. It is a great pleasure to express profound thankfulness to my respected parents, who entiled much hardship inspiring for prosecuting my studies, thereby receiving proper education.

I would like to to express my earnest respect, sincere appreciation and enormous indebtedness to my reverend supervisor, Prof. Dr. Mohammad Saiful Islam, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka, for his scholastic supervision, helpful commentary and unvarying inspiration throughout the research work and preparation of the thesis.

I wish to express my gratitude and best regards to my respected Co-supervisor and Chairman, Prof. Dr. Md. Sarowar Hossain, Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, Dhaka for his continuous direction, constructive criticism, encouragement and valuable suggestions in carrying out the research work and preparation of this thesis.

I am grateful to Prof. Md. Shadat Ulla, Honourable Vice Chancellor, Sher-e-Bangla Agricultural University, Dhaka for providing me with all possible help during my studies.

I am highly grateful to my honorable teachers Prof. Dr. Md. Shahidur Rashid Bhuiyan , Prof. Dr. Naheed Zeba , Prof. Dr. Firoz Mahmud , Prof. Dr. Jamilur Rahman Associate Prof. Dr. Ashaduzzaman Siddikee and Associate Prof. Dr. Md. Abdur Rahim , Department of Genetics and Plant Breeding, Sher-e-Bangla Agricultural University, for their valuable teaching, direct and indirect advice, and encouragement and co-operation during the whole study period.

It's my great pleasure and priviledge to express deep sense of gratitud e and sincere regard to my honorable teacher Prof. Dr. Tuhin Suvra Ray, Department of Agronomy, Sher-e-Bangla Agricultural University, for his valuable teaching, direct and indirect advice, and encouragement and co-operation during the study period.

I am pleased to thank all staffs and workers of Genetics and Plant Breeding Department and all farm labors and staffs of Sher-e-Bangla Agricultural University, Dhaka for their valuable and sincere help in carring out the research work.

I found no words to thank my parents and my uncle Md. Nazrul Islam for their unquantifiable love and continuous support, their sacrifice never ending affection, immense strength and untiring efforts for bringing my dream to proper shape. They were constant source of inspiration, zeal and enthusiasm in the critical moment of my studies.

June , 2015 ***The Author***

SAU, Dhaka

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ABSTRACT

The experiment was conducted with twenty one genotypes of potato at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka during the period from November 2014 to March 2015 to estimate the genetic variability, correlation, path and diversity among the genotypes. The experiment was conducted using Randomized Complete Block Design with three replications. All the genotypes varied significantly with each other for all the studied characters indicated the presence of considerable variations among the genotypes studied. The PCV values were higher than the respective GCV values for all the characters under study. Number of leaves per plant, stem per hill, leaf area index, number of potato per hill, weight of potato per hill, weight of individual potato weight and potato yield showed high heritability along with high genetic advance as percentage of mean were normally more helpful in predicting the genetic gain under selection. From the correlation and path analysis it was revealed that diameter per stem showed significant positive genotypic correlation with yield as well as employed positive direct effect on yield suggesting that the selection for these traits would helpful for the improvement of yield per plant. As per PCA, D^2 and clusters analysis the genotypes were grouped into five different clusters. Clusters III had the maximum nine and cluster II and V had the minimum one genotype. The highest inter-cluster distance was observed between I and V and the lowest was observed between IV and V. Genotypes in cluster I showed the maximum performance for number of leaves per plant, chlorophyll percentage, weight of individual potato and firmness. Cluster II showed maximum performance for total soluble sugar. Cluster III recorded the highest mean performance for dry matter. Cluster IV showed the maximum performance for number of potato per hill, weight of potato per hill and yield. Cluster V showed the maximum performance for specific gravity. Considering this idea and other characteristic performances, G_8 (Shada pakri) and G_{17} (Shil bilati) from cluster IV; G_4 (BARI-TPS-1) from cluster II; and G_6 (Asterix), G_{21} (Granola) , G_1 (Cardinal) and G_2 (Diamant) from cluster I might be considered better parents for efficient hybridization programme.

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SOME COMMONLY USED ABBREVIATIONS

FULL WORD	ABBREVIATION
Agro-Ecological Zone	AEZ
And others	*et al.*
Accessions	ACC
Bangladesh Agricultural Research Institute	BARI
Bangladesh Agricultural University	BAU
Bangladesh Bureau of Statistics	BBS
Centimeter	cm
Co-efficient of Variation	CV
Etcetera	etc.
. Figure	Fig
Genotype	G
Genetic Advance	GA
Genotypic Co-efficient of Variation	GCV
Genotypic Variance	$\delta^2{}_g$
Gram	g
Heritability in broad sense	h^2b
Journal	j.
High yielding variety	HYV
Meter	m
Mean Sum of Square	MSS
Millimeter	mm
Muriate of Potash	MOP
Number	No.
Percent	%
Phenotypic Co-efficient of Variation	PCV
Phenotypic variance	$\delta^2{}_p$
Randomized Complete Block Design	RCBD
Replication	R
Research	Res.
Sher-e-Bangla Agricultural University	SAU
Standard Error	SE
Square meter	m^2
Triple Super Phosphate	TSP
Variety	Var.

CHAPTER I

INTRODUCTION

Potato (*Solanum tuberosum* L.) popularly known as 'The king of vegetables'. It is a tuber crop belongs to the family solanaceae. It originated in the central Andean area of South America (Keeps, 1979).Potatoes have 48 chromosomes that are arranged into 24 pairs (tetraploid). It is the 4^{th} world crop after wheat, rice and maize. Bangladesh is the 8^{th} potato producing country in the world. In Bangladesh, it ranks 2^{nd} after rice in production (FAO, 2013). It contributes not only energy but also substantial amount of high quality protein and essential vitamins, minerals and trace elements to the diet (Horton, 1987).

In Bangladesh, it ranks second after rice in terms of production. The total area under potato crop, national average yield and total production in Bangladesh are 4,62,032 hectares, 19.371 t ha^{-1} and 89,50,024 metric tons, respectively. The total production is increasing over time as such consumption also rapidly increasing in Bangladesh (BBS, 2014). The yield is very low in comparison to that of the other leading potato growing countries of the world, 40.16 t ha^{-1} in USA, 42.1t ha^{-1} in Denmark and 40.0 t ha^{-1} in UK (FAO, 2013).

Nutritionally, the potato tuber is rich in carbohydrates or starch and is a good 0source of protein, vitamin C and B, potassium, phosphorus and iron. Potato is one of the most important vegetable crops and having a balanced food containing about 75 to 80% water, 16 to 20 % carbohydrates, 2.5 to 3.2% crude protein, 1.2 to 2.2% true protein, 0.8 to 1.2% mineral water, 0.1 to 0.2% crude fats, 0.6% crude fiber and some vitamins (Schoenemann, 1977). It is a staple diet in European countries and its utilization both in processed and fresh food form in increasing considerably in Asian countries (Brown, 2005). Being a carbohydrate rich crop, potato can partially substitute rice, which is our main food item. It is grown in almost all countries of the world. In main countries including those Europe, America and Canada, potato is a staple food.

In Bangladesh, potato is grown during the winter season. In our country potato is mainly used as vegetable and available in the market throughout the year with reasonable price as compared to other vegetables. Potato has also great importance in rural economy in Bangladesh. It is not only a cash crop but also an alternative of food crop against rice and wheat. Bangladesh has a great agro-ecological potential of growing potato. The area and production of potato in Bangladesh has been increasing during the last decades but the yield per unit area remains more or less static. The reasons for such a low yield of potato in Bangladesh are lack of high yielding variety, lack of disease free seed tuber and use of low quality seed. Available reports indicated that potato production in Bangladesh can be increased by using HYV, disease free and optimal sized seed are important which influences the yield of potato (Divis and Barta, 2001).

Parameters of genotypic and phenotypic coefficients of variation (GCV and PCV) are useful in detecting the amount of variability present in the available genotypes. Heritability and genetic advance help in determining the influence of environment expression of the characters and the extent to which improvement is possible after selection (Robinson *et al.,* 1949). Crop improvement depends upon the magnitude of genetic variability and extent to which the desirable characters are heritable. The total variability can be partitioned into heritable and non-heritable components with the help of genetic parameters like genotypic and phenotypic coefficients of variation, heritability and genetic advance. High heritability alone is not enough to make efficient selection in segregating generation, unless the information is accompanied for substantial amount of genetic advance (Johnson *et al.*, 1995).

Study of correlation between different quantitative characters provides an idea of association that could be effectively utilized in selecting a better plant type in potato breeding programme. A few correlation studies pertaining to potato are available in literature (Brithman and Kaul, 1992; Pandita and Sidhu, 1980 and Singh and Chaudhury, 1985). However, knowledge of correlation alone is often misleading because when more variables are included in a study, the indirect association becomes more complex. In such a situation the path-coefficient analysis provides an effective means of finding direct and indirect causes of association of characters is helpful to identify the role of each individual character towards yield.

Path co-efficient is a standard tool which measures the direct influence of one character upon another and permits the separation of correlation co-efficient into components of direct and indirect effects. Path co-efficient between yield and yield contributing characters provides an exact picture of the relative importance of direct and indirect influences of each other component characters on tuber yield. Path analysis, therefore, is a useful tool for understanding yield except chain of relationship between yield and yield contributing characters. It also provides valuable additional information for improving tuber yield via selection for its yield components. The proper evaluation and careful selection provide scope for identifying desirable genes for exploitation, either in itself or through hybridization. The effectiveness of selection depends upon the genetic variability present in the population (Deway and Lu , 1959)

Knowledge on the nature of variability and association of yield with its components is of great impotence for identification of superior parents in any breeding programme. When the variability in a population is largely of genetic nature with least environmental effect, the probability of isolating superior genotypes in high. Since information on potato progeny is not available in our country, the results reported in the study are related to select a suitable plant type having high yield with good natural keeping quality (Kanika, 2010)

It has been found that the progenies derived from crossing between divergent parents give divergent and useful trait. It has been often postulated by the breeders that geographical distribution reflects genetic diversity in selecting parents for hybridization. A limited study has been made on genetic divergence in potato either at tetraploid (Gaur *et al.*, 1978; Sidhu *et al*., 1981 and Singh *et al.*, 1988) or at diploid level (Grag, 1988). An understanding of the nature and magnitude of variability among the genetic stocks is of prime importance to the breeders. Genetic diversity is one of the important tools to qualify genetic variability in both cross and self pollinated crops (Murty and Arunachalam, 1966; Gaur *et al.*, 1978). Considering the above mentioned idea and scope, the study was taken with the following objectives:

Objectives of the research work:

- To study the nature and extent of association of genetic variability in potato genotypes for growth, yield and quality parameters
- To asses genetic diversity among the genotypes
- To find out the best genotype for further use in breeding programme

CHAPTER II

REVIEW OF LITERATURE

In a country like Bangladesh where land is scare, effort should be taken to increase production through cultivation. Potato is the most important vegetable source in Bangladesh. In our country research effort on variability analysis of potato seems to poor. The purpose of this chapter is to describe the researches conducted in genotype of the major focuses of this study. Therefore relevant information available in the literature pertaining to the potato are reviewed in this section. The extent of genetic variability exists among the genotypes of a crop plant is an index of its genetic dynamism. Plant breeding resolves around selection, which can be effectively practiced only in the presence of variability of desired traits. Hence, the success of breeding depends entirely upon the variability.

Sanjoy *et al.* (2015); conducted a field experiment in some potato variety. They reported experimental result was the average tuber weight of potato plant contributed maximum (31.76%), followed by number of tuber per plant (27.56%), internodal length (14.45%) and plant dry matter content (13.61%) for growth characters. For quality characters, ascorbic acid content (24.70%), protein content of tuber (20.84%) and TSS of tuber (20.00%) contributed effectively towards genetic divergence.

Kassim *et al.* (2014); found that reducing physiological functions of above ground part of potato plant (leaf area and total chlorophyll content), the number and the weight of tuber decreased, so the productivity of the plant decreased.

Behjati *et al.* (2013); conducted a field experiment to evaluate the yield and yield components on promising potato clones. Clone No. 397031-1, had the highest yield and Lady Rosetta variety had the lowest yield compared with other varieties. The lowest and highest average number of main stems per plant, related to Lady Rosetta and clone No. 397067-2. Lady Rosetta variety had the highest number of tube per plant and clone No. 397067-2 had the lowest number of tubers per plant. The lowest and highest average tuber weight per plant related to clone No. 397067-2 and Lady Rosetta variety, respectively.

Addisue *et al*. (2013); conducted a field experiment with thirteen (13) potato genotypes for evaluation, genetic variability and association of agronomic characters among themselves and tuber yield. The study aimed to find out the genetic variability and interrelationships among different characters in potato. Genotypic correlation coefficient was found to be higher in magnitude than that of phenotypic correlation coefficients, which clearly indicated the presence of inherent association among various characters. Tuber yield was positively correlated with plant height, biological yield, harvest index and big tuber percentage at both the phenotypic and genotypic levels. In contrast, it was negatively correlated with small and medium tuber percentage at both levels. Path coefficient analysis at the phenotypic level revealed that days to flowering, plant height, tuber diameter, biological yield, harvest index and medium tuber percentage showed positive direct effects on tuber yield. The genotypic path analysis also indicated that biological yield and harvest index showed positive and significant correlation. Therefore, these characters are more important than other traits for the genetic improvement of potato.

Patel *et al*. (2013); conducted an experiment to explicated genetic variability of total 24 potato genotype for table purpose potato with two different sets viz., 75 days and 95 days of harvest. A wide range of phenotypic variability was recorded for reducing sugar, plant height, average weight of tubers, number of tuber per plant and tuber dry matter content. The high genotypic coefficient of variation (GCV) were observed for reducing sugar, number of stem per plant, marketable tuber yield and chip color. While high phenotypic coefficient of variation (PCV) observed for marketable tuber yield and number of stem per plant. High heritability value was noted for reducing sugar (99.98 and 99.96) in 75 days and 95 days of harvest, respectively. The highest value of GA (% mean) observed for reducing sugar 95.34 (C1) and 97.24 (C2). The average weight of tuber, number of tuber per plant, number of stem per plant and marketable yield exhibited significant positive correlation with number of tuber per plant at both genotypic and phenotypic levels. The path coefficient analysis revealed higher positive direct effect on total tuber yield for marketable yield.

Hossain (2011); conducted three experiments with BARI released twelve potato varieties to determine the yield potentiality, natural storage behaviour and degeneration rate for three consecutive years. He found that the highest emergence was observed in Granola at 34 DAP. At 50 DAP plant height (cm) of Diamant was (43.50), BARI TPS 1 (47.70), Felsina (52.00), Asterix (52.97), Granola (38.30), Cardinal (46.33). Foliage coverage (%) of Diamant was (83.33), BARI TPS 1 (85.56), Felsina (82.22), Asterix (89.44), Granola (85.56), Cardinal (81.67). No. of stems hill^{-1} of Diamant was (4.06), BARI TPS 1 (3.21), Felsina (3.14), Asterix (4.03), Granola (3.30), Cardinal (3.89). Tuber yield hill^{-1} (g) of Diamant was (244.2), BARI TPS 1 (227.9), Felsina (300.1), Asterix (276.9), Granola (277.0), Cardinal (316.9). Under the grade 28-40 mm, the highest number (48.63%) of seed tubers was produced by Granola which was statistically identical with Asterix (46.43%). Under the same grade (28-40 mm), the highest weight (43.46%) of seed tubers was produced by Patrones followed by Asterix (37.16%), Granola (36.64%) and Multa (35.39%) among which there was no significant variation.

Sattar *et al*. (2011); conducted a field experiment in twenty eight genotypes of potato representing different sources collected from TCRC, BARI, Gazipur to study genetic divergence utilizing multivariate analysis. The genotypes were grouped into five clusters. No relationship was found between genetic divergence and geographic distribution. Number of tubers per plant and yield contributed maximum, while average weight of a tuber and weight of tubers per plant contributed high towards total divergence which offered due attention to these characters while selecting for increased tuber yield. The inter-cluster distance (D^2)

was maximum (36.29) between III and IV. The highest and the lowest intracluster distances (D^2) were 9.64 and 2.48 in cluster III and II, respectively.

Karim *et al.* (2011); conducted an experiment with ten exotic potato varieties (var. All Blue, All Red, Cardinal, Diamant, Daisy, Granola, Green Mountain, Japanese Red, Pontiac and Summerset) to determine their yield potentiality. The highest total tuber weight per plant (344.60g) recorded in var. Diamant and total tuber weight plant^{-1} was the lowest (65.05 g) recorded in var. All red, all blue varieties showed the most potential yield in this experiment.

Hyder *et al*. (2009); conducted a field experiment in seventeen potato genotypes comprising seven parents and their ten crosses during November 2005 to March 2006 to study their combining ability and genetic variability. High estimates of co-efficient of variability, heritability and genetic gain for plant height, number of branches, tubers number and yield indicated that these traits are largely controlled by additive gene action and that strength selection for them would be effective.

Pradhan *et al*. (2011); conducted an experiment on genetic parameters and association of traits related to yield in potato. Genetic parameters for tuber yield were studied in 5 genotypes of potato (Kufri Surya, Kufri-22, Kufri G-4, Kufri Khyati and Kufri Sadabahar) grown in Hoogly, West Bengal, India, in 2009. The sprouting percentage was highest for Kufri G-4 and Kufri Khyati, whereas plant height at 30 days after planting (DAP) was greatest for Kufri G-4, Kufri Khyati and Kufri-22. Kufri Khyati was superior in terms of plant height at 60 DAP, number of branches, and number of leaflets per leaf. Kufri-22 registered the highest number of marketable tubers. High values of heritability and genetic advance were recorded for plant height at 60 DAP, followed by number of leaves and sprouting percentage. Plant height at 60 DAP had the greatest direct effect yield, resulting in positive correlation coefficients at the phenotypic and genetic levels. The number of interjected leaves had the greatest negative direct effect on yield.

Anonymous (2009a); conducted an experiment with three potato varieties to observe their performance on yield under different soil moisture levels. The highest plant height (50.75 cm) was found in Cardinal which was similar to Diamant (48.88 cm). The lowest plant height was observed in Granola (38.50 cm). The highest foliage coverage (93.25%) was observed in Diamant followed by Cardinal (92.75%) and the lowest in Granola (90.33%). The highest no. of stems hill^{-1} (6.25) was observed in Cardinal which was similar to Diamant (5.42) and the lowest in Granola (4.75). The highest no. of tubers hill^{-1} (13.83) was observed in Granola which was similar to Cardinal (13.33) and the lowest in Diamant (11.92).

Anonymous (2009b); conducted an experiment with twenty five varieties were evaluated at six locations. They found that, plant height (cm) in case of Diamant (47.87), Sagitta (56.20), Quincy (95.40); No. of stem hill^{-1} in Diamant (3.66), Sagitta (2.53), Quincy (2.26); Foliage coverage at 60 DAP (%) in Diamant (73.33), Sagitta (93.67), Quincy (92.00); No of tuber hill^{-1} in Diamant (6.72), Sagitta (3.94), Quincy (9.95); Weight of tuber hill^{-1} (kg) in Diamant (0.30), Sagitta (0.34), Quincy (0.35); Dry matter (%) in case of Diamant (19.54), Sagitta (20.10), Quincy (18.70).

Anonymous (2009c); conducted an experiment with twelve varieties were evaluated at six locations in their third generation. They found that, plant height (cm) in case of Diamant (50.93), Granola (69.10), Sagitta (41.33), Quincy (65.87); No. of stem hill^{-1} in Diamant (5.66), Granola (3.20), Sagitta (3.46), Quincy (4.86); Foliage coverage at 60 DAP (%) in Diamant (92.00), Granola (91.00), Sagitta (89.33), Quincy (96.00); No. of tuber hill^{-1} in Diamant (7.24), Granola (6.82), Sagitta (5.23), Quincy (5.76); Weight of tuber hill^{-1} (kg) in Diamant (0.38), Granola (0.26), Sagitta (0.33), Quincy (0.35); Dry matter (%) in case of Diamant (20.80), Granola (20.45), Sagitta (19.80), Quincy (18.40).

Anonymous (2009d); conducted an experiment with twenty eight varieties were evaluated at five locations. They found that, plant height at 60 DAP (cm) in case of Diamant (54.13), Sagitta (47.27), Quincy (80.93); No. of stem hill^{-1} in Diamant (4.66), Sagitta (5.40), Quincy (5.80); Foliage coverage at 60 DAP (%) in Diamant

(93.67), Sagitta (90.67), Quincy (97.00); No. of tubers hill^{-1} in Diamant (8.11), Sagitta (5.41), Quincy (6.95); Weight of tubers hill^{-1} (kg) in Diamant (0.28), Sagitta (0.37), Quincy (0.45); Dry matter (%) in case of Diamant (19.91), Sagitta (20.60), Quincy (18.34).

Anonymous (2009e); conducted an experiment with four exotic potato varieties along with check Diamant, Cardinal and Granola were evaluated at six locations in Regional Yield Trial. They found that plant height (cm) in case of Diamant (51.20), Cardinal (48.27), Meridian (48.33) and Laura (41.00); No. of stem hill^{-1} in Diamant (5.93), Cardinal (6.20), Meridian (5.67) and Laura (4.73); Foliage coverage (%) in Diamant (88.33), Cardinal (90.33), Meridian (95.67) and Laura (86.67); No. of tuber hill^{-1} in Diamant (9.48), Cardinal (9.81), Meridian (9.63) and Laura (7.50); Weight of tuber hill^{-1} (kg) in case of Diamant (0.313), Cardinal (0.377), Meridian (0.490) and Laura (0.430); Dry matter (%) in case of Diamant (22.69), Cardinal (21.03), Meridian (19.49) and Laura (20.22).

Anonymous (2009f); conducted an experiment with seven potato varieties were evaluated at MLT site. They found that plant height (cm) in case of Diamant (43.00), Lady Rosetta (37.00), and Courage (44.47); No of stem plant^{-1} in Diamant (3.57), Lady Rosetta (2.80), and Courage (3.67); No of tuber plant^{-1} in Diamant (8.07), Lady Rosetta (5.67), and Courage (6.70).

Anonymous (2009g); conducted adaptive trails with new potato varieties at eleven districts. The mean yield of varieties over locations arranged in order of descending as BARI TPS-1 (23.87 t ha^{-1}), Granola (23.68 t ha^{-1}), Diamant (23.63 t ha^{-1}), Asterix (20.83 t ha^{-1}) and Raja (18.28 t ha^{-1}).

Güler (2009); observed that first, second, third class tuber yields and total tuber yield, tuber number per plant, mean tuber weight and leaf chlorophyll. were significantly influenced by potato cultivar. There were significant correlations between chl. and yield and yield related characters. Total yield significantly correlated with leaf chlorophyll. Correlations between first class yield and total yield as well as total yield and tuber number per plant were highly significant.

Mahmud *et al.* (2009); assessed the yield of seed size tubers in five standard potato cultivars (Cardinal, Multa, Ailsa, Heera, and Dheera) in relation to dates of dehaulming (65, 70, and 80 days after planting) in a Seed Potato Production Farm, Debijong, Panchagarh. The maximum seed tuber yield was recorded from Cardinal at 80 DAP followed by Heera and Cardinal at 70 DAP, Dheera and Ailsa at 75 DAP.

Haque (2007); conducted a field experiment with 12 exotic potato germplasm to determine their suitability as a variety in Bangladesh. He found that all the varieties gave more than 90% emergence at 20-35 DAP. He also observed that Plant height (cm) of Quincy was (87.8), Sagitta (65.8), Diamant (62.6); number of stems hill^{-1} was counted in Diamant (7.2), Quincy (4.5), Sagitta (4.4); Plant diameter (cm) of Sagitta was (4.0), Quincy (3.7), Diamant (2.6) at 60 DAP; Foliage coverage (%) of Sagitta was (100.0), Diamant (98.3), Quincy (96.6); number of tubers plant^{-1} of Diamant was (13.06), Sagitta (8.34), Quincy (6.71); weight of tubers plant^{-1} (kg) of Quincy was (0.64), Sagitta (0.63), Diamant (0.49); Dry matter (%) of Sagitta was (20.8), Diamant (20.1), Quincy (18.5).

Hydar *et al*. (2007); conducted a field experiment in some potato variety. Genetic diversity using Mahalanobis's D^2 - technique was studied for tuber yield and its components *viz.*, Plant Height (PH), Number of Leaves/plant (NLPP), Fresh Weight/plant (FWP), Number of Tubers/plant (NLPP), Number of Eyes/tuber (NEPT), Average Tuber Weight of Plant (ATWP) and Tuber weight/plant (TWt./P). Plant height, number of leaves/ plant, fresh weight/plant and tuber weight/plant showed maximum contribution towards total divergence among the genotypes.

Sattar *et al.* (2007); performed the genotypic and phenotypic variability, heritability, genetic advance, correlation co-efficients and path coefficients analysis for yield and its contributing characters in 28 genotypes of potato. High heritability coupled with high genetic advance as percent of mean and high genotypic co-efficients of variation were observed for number of tubers per plant, yield per plant and average weight of a tuber suggesting selection for these traits would give good response. Genotypic and phenotypic correlation of the number of tubers per plant and weight of tubers per plant were highly significant. Plant vigor, number of compound leaves per plant and number of tubers per plant, average weight of a tuber and dry matter content of tuber had high degree of positive association with tuber yield per plant. As per path analysis, average weight of tuber and total number of tubers per plant contributed maximum direct effect to tuber yield indicating their importance as selection index for yield improvement.

Das (2006); carried out an experiment to study the physio-morphological characteristics and yield potentialities of potato varieties. He found that Foliage coverage (%) of Diamant was (93.3), Asterix (71.7), Granola (66.7), Quincy (90.0), Courage (63.3), Felsina (83.3), Lady Rosetta (83.3), Laura (78.3); No. of tubers $hill^{-1}$ of Diamant (11.7), Asterix (8.00), Granola (11.3), Quincy (9.33), Courage (7.33), Felsina (8.00), Lady Rosetta (10.3), Laura (8.33); Tuber weight $hill^{-1}$ (g) of Diamant (380), Asterix (285), Granola (275), Quincy (300), Courage (320), Felsina (333), Lady Rosetta (348), Laura (258); Dry matter (%) of Diamant (25), Asterix (17.5), Granola (23), Quincy (31), Courage (34.5), Felsina (22.5), Lady Rosetta (22.0), Laura (27.0); Regarding size grade distribution of tubers the varieties Courage, Espirit, Granola, Lady rosetta, Laura were found superior.

Anonymous (2005); evaluated twenty one varieties along with two standard checks Diamant and Granola at seven locations. The yields of the varieties varied from location to location as well as within location. Of all the stations, except Pahartoli, none crossed the check variety Diamant but comparatively higher yields were produced by the varieties Espirit, Courage, Innovator, Quincy, Matador, Markies , Laura and Lady Rosetta.

Kumar *et al.* (2005); determined under water weight, specific gravity, dry matter and starch content of potatoes grown at Modipuram, Uttar Pradesh. He found that there was a positive correlation between under water weight and specific gravity (r=0.99), under water weight and dry matter (r=0.92).

Ahmad *et al*. (2005); conducted an experiment to study genetic variability and correlation studies in potato. Variability and character association were studied for eight yield and yield components in fourteen varieties of potato. The highest phenotypic and genetic variability were found in number of leaves/plant and plant height and it was followed by number of tuber/plant and number of branches/plant. High heritability was observed in plant weight with tuber/plant and tuber weight/plant and it was followed by dry mater content/100 gm fresh tuber. Highest genetic advance as % of mean (GA%) was estimated in number of leaves/plant, number of branches/plant and number of tuber/plant.

Mondol (2004); conducted an experiment to evaluate the performance of seven exotic (Dutch) varieties of potato. He found that plant height (cm) of Diamant was (18.07), Granola (13.47); No. of main stem hill^{-1} of Diamant (4.36), Granola (4.90); No. of tubers hill^{-1} of Diamant (12.00), Granola (10.93); Weight of tubers plant^{-1} (kg) of Diamant (0.57), Granola (0.39); Dry matter (%) of Diamant (17), Granola (16.30).

Alam *et al.* (2003); conducted a field experiment with fourteen exotic varieties of potato under Bangladesh condition. The highest emergence (91%) was observed from Cardinal which was statistically identical with most of the varieties except the variety Granola (63%). The highest number of stem per hill was recorded in Ailsa (4.59) followed by Cardinal (4.50). Significantly maximum number of leaves hill^{-1} was produced from the plants of the variety Ailsa (53.80), which was followed by Cardinal (49.75). The yields ranged of exotic varieties were 19.44 to 46.67 t ha^{-1}. Variety Ailsa produced the maximum yield (46.67 t ha^{-1}) which was followed by Cardinal (42.21 t ha^{-1}).

An experiment was conducted in West Bengal, India during 1999-2000 and 2000-01 to study tuber yield, dry matter content and storage life of potato tubers under room temperature using newly released indigenous processing cultivars viz. Kufri Chipsone- 1 and Kjfri Chipsona-2 and six Dutch potato cultivars viz. Cardinal, diamant, Ajax, Fresco, The cultivar Kufri Jyouti was used an control. Amount the nine cultivars, Cardinal recorded the maximum tuber yield (30.53 t/ha) followed by Diamant (29.76 t/ha), K. Chipsona-1 (21.98%), K. Chipsona-2 (20.87%) and Diamant (19.18%) recorded higher dry matter content than that of K. Jyoti (18.87%). Regarding storage life under ambient condition, K. Chipsona-1 showed minimum physiological weight loss (11.22%) while K. Chipsona-2 resulted in minimum rotting of tubers (8.67%) after 90 days of storage. Dutch cultivars viz. Cardinal and Diamant and tubers (8.67%) after 90 days of storage. Dutch cultivars viz. Cardinal and Diamant and indigenous variety K. Jyoti were found to be susceptible to late blight while K. Chipsona-1 and K. Chipsona-2 showed good resistance to late blight and appeared to be promising for cultivation in West Bengal (Pandey and Gupta , 2003).

A study conducted with 12 hybrid populations at Debiganj showed that there were significant variations among the progenies which indicate that there was a scope of selection for improved varieties. Tuber yield varied from 20.67 to 32.44 t/ha. Individual plants were selected from the progenies on the basis of tuber yield and size, shape and colour of the tubers in the hill which will be evaluated in subsequent years for variety development (Anon., 2003).

Ozkaynak *et al*. (2003); conducted an experiment in 2000 and 2001 to determine the correlation coefficients between tuber yield and 12 yield components and the direct and indirect effects on yield in various potato cultivars (Ausonia, Binella, Concorde, Granola, Jaerla, Marabel, Marfona, Satina and Velox) at the research fields of Akdeniz University in Antalya, Turkey. Significant positive correlations were found between tuber yield and plant height, node number, leaf length, leaf width, leaflet length, leaflet width, tuber number and average tuber weight. Path coefficient analysis indicated that tuber number (0.7716 and at 85.25%), followed by the average tuber weight (0.5133 and at 69.27%), were the most important components for tuber yield in potato.

Bhagowati *et al*. (2002); conducted an experiment to study on nature of variability, genetic advance and character association was made in 30 diverse true potato seed (TPS) populations. Additive genetic control for the characters leaf number, tuber number and average tuber weight was recorded as these characters registered higher genetic advance, heritability and genotypic coefficients of variation. This indicates the suitability of these characters for simple directional selection. The character association studies revealed tuber yield of potato as a function of plant height, primary branch number, leaf number, tuber number and average tuber weight. Significant positive correlations both at genotypic and phenotypic levels between plant height and leaf number, tuber number and average tuber weight; primary branch number and leaf number, tuber number and between leaf number and average tuber weight were also recorded. Significant negative association of tuber number and average tuber weight both at genotypic and phenotypic levels indicated the need of breaking the negative genetic linkage between them before using as selection criteria

Ramanjit *et al*. (2001); conducted a field study during autumn season of 1997-98, in Ludhiana, Punjab, India to determine the degree of correlation of different growth and yield bearing characters to potato germplasm 'Kufri Chandramukhi' tuber yield. Leaf area index, and dry matter of leaves, stems, roots + stolon, and tubers were recorded at 30, 60 and 90 days after planting. The number and weight of tubers were recorded at harvest. Tuber yield showed highly significant positive correlations with leaf area index, tuber number, tuber weight, dry matter production of leaves, roots + stolon and tubers at 60 and 90 days after planting.

Luthra (2001); reported that a study with 29 genotypes showed favourable response to selection for plant type, dormancy period, average tuber weight, number of tubers and plant vigor based on high heritability estimates, High genetic advance for tuber yield, average tuber weight, plant height and number of leaves suggested scope of improvement for these traits. An association between different characters revealed that vigor, erect and tall with logh and wider leaves, produced more number of tubers/average tuber weight, having shallow/medium eyes and oval/round shape etc. were to be considered for improvement in potato.

Hossain (2000); conducted an experiment to study the effects of different levels of nitrogen on the yield of seed tubers in four potato varieties. He found that the tallest plants were produced by the seedling tubers of BARI TPS-1 (74.51 cm) and the shortest plants came from the variety Diamant (58.63 cm); Foliage coverage (%) of Diamant at 75 DAP was (79.00), BARI TPS-1 (89.00); No. of stems $hill^{-1}$ of Diamant was (3.50), BARI TPS-1 (2.71); No. of tubers $hill^{-1}$ of Diamant was (7.85), BARI TPS-1 (9.55); Weight of tubers $hill^{-1}$ of Diamant was (416.67), BARI TPS-1 (491.33); Dry matter of tuber (%) of Diamant was (19.71), BARI TPS-1 (18.18).

CHAPTER III

MATERIALS AND METHODS

An experiment was conducted at the experimental field of Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh during the period from November 2014 to March 2015 to study on the genetic diversity, genetic advance, heritibity, correlation and path coefficient analysis in potato *(Solanum tuberosum* L). A brief description about the locations of the experimental site, characteristics of soil, climate, materials, layout and design of the experiment, land preparation, manuring, fertilizing, intercultural operations, harvesting, data recording procedure, and statistical analysis etc., are presented as follows:

3.1 Experimental site

The research work relating to determine the Character Association and Genetic Diversity of Potato was conducted at the Sher-e-Bangla Agricultural University Farm, Dhaka-1207,Bangladesh during the period from 12 November, 2014 to 31 April, 2015. Experimental field is presented in Plate 1.

3.2 Geographical location

The experimental area was situated at 23°77'N latitude and 90°33'E longitude at an altitude of 8.6 meter above the sea level (Anon., 2004).The experimental field belongs to the Agro-ecological zone of "The Modhupur Tract", AEZ-28 (Anon., 1988a). This was a region of complex relief and soils developed over the Modhupur clay, where floodplain sediments buried the dissected edges of the Modhupur Tract leaving small hill rocks of red soils as ‘islands' surrounded by floodplain (Anon., 1988b). The experimental site was shown in the map of AEZ of Bangladesh in (Appendix I).

Plate 1: Potato experiment field

3.3 Climate

Area has subtropical climate, characterized by high temperature, high relative humidity and heavy rainfall in Kharif season (April-September) and scanty rainfall associated with moderately low temperature during the Rabi season (October-March). Weather information regarding temperature, relative humidity, rainfall and sunshine hours prevailed at the experimental site during the study period was presented in Appendix II.

3.4 Characteristics of soil

Soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils under Tejgaon Series. Top soils were clay loam in texture, olive-gray with common fine to medium distinct dark yellowish brown mottles. Soil pH ranged from 6.0- 6.6 and had organic matter 0.84%. Experimental area was flat having available irrigation and drainage system and above flood level. Soil samples from 0-15 cm depths were collected from experimental field. The analyses were done by Soil Resource and Development Institute (SRDI), Dhaka. Physicochemical properties of the soil are presented in (Appendix III).

3.5 Design and layout of the experiment

The study was laid out in Randomized Complete Block Design (RCBD) with three (3) replications. The plot size was 150 m^2. A distance of 1.0 m from block to block, 60 cm from row to row and 25 cm from plant to plant was maintained. The genotypes were randomly distributed to each row within each line.

3.6 Planting materials

Twenty one (21) genotypes of potato were used for the present research work. The genetically pure and physically healthy tuber of these genotypes were collected Bangladesh Agricultural Research Institute (BARI), Gazipur, Dhaka and Dinajpur, Bogra, Joypurhat. The name and source of these genotypes are presented in Table 1.

Table 1. List of Potato genotypes with their source

SL.No.	Genotypes No.	Name	Source
1	G_1	Cardinal	TCRC,BARI
2	G_2	Diamant	TCRC,BARI
3	G_3	Laddy rosetta	TCRC,BARI
4	G_4	BARI-TPS-1	TCRC,BARI
5	G_5	Courage	TCRC,BARI
6	G_6	Asterix	TCRC,BARI
7	G_7	Lal pakri	LM,Bagura
8	G_8	Shada pakri	LM,Dinajpur
9	G_9	Jam alu	TCRC,BARI
10	G_{10}	Tilok Pura	LM,Joypurhat
11	G_{11}	Pahari Pakri	LM,Bogra
12	G_{12}	Pakri	TCRC,BARI
13	G_{13}	Fata pakri	LM,Bogra
14	G_{14}	Tel pakri	LM,Bogra
15	G_{15}	Romana pakri	LM,Joypurhat
16	G_{16}	Bot pakri	LM,Bogra
17	G_{17}	Shil bilati	LM,Joypurhat
18	G_{18}	Local cardinal	LM,Dinajpur
19	G_{19}	Patnai	LM,Dinajpur
20	G_{20}	Lal chokha pakri	LM,Joypurhat
21	G_{21}	Granola	TCRC,BARI

TCRC=Tuber Crop Research Centre, BARI= Bangladesh Agricultural Research Institute and LM=Local Market

3.7 Land preparation

The experimental plot was prepared by several ploughing and cross ploughing followed by laddering and harrowing with tractor and power tiller to bring about to good tilth in the 8 November, 2014. Weeds and other stubbles were removed carefully from the experimental plot and leveled properly.

3.8 Manure and fertilizers application

Total cow dung, vermicompost, gypsum, magnesium sulphate, borax and triple super phosphate (TSP) were applied in the field during final land preparation. Half Urea and half muriate of potash (MOP) were applied in the plot after 30 DAP. Remaining urea and muriate of potash (MOP) were applied after 50 DAP. Doses of manure and fertilizers used in the study are showing in Table 2.

Table 2. Doses of manures and fertilizers used in the study

SL.No.	Fertilizer/Manures	Dose	
		Applied in the plot	Quantity/ha
1	Cowdung	150 kg	10 ton
2	Vermicompost	75 kg	5 ton
3	Urea	4.5 kg	300 kg
4	TSP	3 kg	200 kg
5	MoP	4.5 kg	300 kg
6	Gypsum	1.8 kg	120 kg
7	Magnesium Sulphate	1.8 kg	120 kg
8	Borax	0.15 kg	10 kg

3.9 Sowing of potato tuber

The tuber were planted in the field on 15 November, 2014. The planted tuber were watered regularly to make a firm relation with roots and soil to stand along.

3.10 Intercultural operations

3.10.1 Weeding

Weeding was necessary to keep the plant free from weeds. The newly emerged weeds were uprooted carefully in all the lines after complete emergence of sprouts and afterwards when necessary.

3.10.2 Watering

Frequency of watering was done upon moisture status of soil retained as requirement of plants. Excess water was not given, because it always harmful for potato plant.

3.10.3 Earthing up

Earthing up process was done by pouring the soil in the plot at two times, during crop growing period. First pouring was done at 45 DAP and second was at 60 DAP.

3.10.4 Plant protection measures

Dithane M-45 was applied at 30 DAP as a preventive measure for controlling fungal infection. Ridomil (0.25%) was sprayed at 45 DAP to protect the crop from attack of late blight of Potato.

3.10.5 Haulm cutting

Haulm cutting was done at 24 February, 2015 at 90 DAP, when 40-50 % plants showed senescence and the top started drying. After haulm cutting the tubers were kept under soil for 7 days for skin hardening. The cut haulm was collected, bagged and tagged separately for further data collection.

3.11 Harvesting of Potato

Harvesting of potato was done on 3 March, 2015 at 7 days after haulm cutting. The potatoes of each plot were separately harvested, bagged and tagged and brought to the laboratory. Harvesting was done manually by hand. Photograph showing harvesting of potato in Plate 2.

Plate 2 : Photograph showing harvesting of potato

3.12 Recording of data

Ten plants in each line were selected randomly and were tagged. These tagged plants were used for recording observations for the following characters. A brief outline of the data recording procedure followed during the study is given below. Photograph showing different morphological data collection in Plate 3.

3.12.1 Plant height (cm)

Plant height refers to the length of the plant from ground level to the tip of the tallest stem .The height of each plant of each line was measured in cm with the help of a meter scale and mean was calculated.

3.12.2 Number of leaves plant $^{-1}$

Number of leaves plant $^{-1}$ was counted at harvest time. Leaves number plant $^{-1}$ were recorded by counting all leaves from each plant of each line and mean was calculated.

3.12.3 Number of stems hill $^{-1}$

Number of stems hill^{-1} was counted at harvest time. Stem numbers hill^{-1} was recorded by counting all stem from each line.

3.12.4 Leaf area index

Leaf area index was measured at harvest time by non-destructive method by using CL-202 Leaf area meter (USA). Mature leaf (from 4th node) were measured all time and expressed in cm^2. Three mature plant of each line were measured and then average it after that mean was calculated.

Plate 3 : Photograph showing different morphological data collection of potato plant

3.12.5 Chlorophyll content of leaves (SPAD value)

Chlorophyll content of leaves was measured at 60 DAP. Mature leaf (fourth leaves from top) were measured all time. Three mature plant of each line were measured by using portable Chlorophyll meter (SPAD-502, Minolta, Japan) and then calculated an average SPAD value for each line at each sampling time .The chlorophyll meter (SPAD-502) is a simple and portable diagnostic tool that measures the greenness or the relative chlorophyll concentration of leaves (Kariya *et al*.,1982; Torres-netto *et al*.,2005).It provides instantaneous and non-destructive reading on plants based on the quantification of the intensity of absorbed light by the tissue sample using a red LED (wavelength peak is ~650 nm) as a source. An infrared LED , with a central wavelength emission of approximately 940 nm, acts simultaneously with the red LED to compensate for the leaf thickness (Minolta camera Co.Ltd.,1989). Photograph showing a Digital Chlorophyll meter to determinate leaf Chlorophyll content in Plate 4.

Plate 4 : **Digital Chlorophyll meter to determinate leaf Chlorophyll content**

3.12.6 Stem diameter (cm)

Stem diameter was measured at harvest time. The stem diameter of each plant of each line was measured in cm by using Slide calipers and mean was calculated.

3.12.7 Dry matter content (%)

First the fresh weight of haulm was taken. Then the samples of stem were dried in oven at 72^0 C for 72 hours. From which the dry matter percentage of above ground harvest was calculated with the following formula (Elfinesh *et al*., 2011)-

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

3.12.8 Number of tuber hill $^{-1}$

Number of tubers hill $^{-1}$ was counted at harvest. Tuber numbers hill $^{-1}$ was recorded by counting all tubers from each line.

3.12.9 Average weight of tuber (g)

Average weight of tuber was measured by using the following formula-

$$\text{Average weight of tuber} = \frac{\text{Yield of tuber/plant}}{\text{Number of tubers/hill}}$$

3.12.10 Yield of tuber plant $^{-1}$(g)

Tubers of each line were collected separately from which yield of tuber hill $^{-1}$ was recorded in gram.

3.12.11 Yield hectare $^{-1}$ (ton) Tubers of each line were collected separately from which yield hectare $^{-1}$ was recorded in ton.

3.12.12 Specific gravity (gcm^{-3})

It was measured by using the following formula (Gould,1995)

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in water at } 4℃}$$

3.12.13 Total soluble solids (TSS)

TSS of harvested tubers was determined in a drop of potato juice (Plate 5) by using Hand Sugar Refrectometer –ERMA, Japan, Range : 0-32% according to (AOAC, 1990) And expressed as ^{o} BRIX value. Photograph showing, determination of total soluble solid with Hand Sugar Refrectometer in Plate 6.

3.12.14 Firmness

Fries texture measurements were performed at room temperature by a puncture test performed in a Texture Analyzer (Sun Scientific Co, Ltd, Japan) equipped with a wedge probe imitating front teeth. Maximum force (MF) was defined as the force at which the wedge penetrates the outer layer of the surface of the of the fried potato fries slices (Segnini *et al*.,1999). Higher firmness are suitable for chips/frence fry product . For this result, determination of firmness is essential for processing quality potato. Photograph showing, take firmness data with a Force Gauge in Plate 7.

3.12.15 Number of eye tuber $^{-1}$

Number of eye tuber $^{-1}$ was counted at harvest time. Eye number tuber $^{-1}$ was recorded by counting all tubers from each line.

Plate 5 : Photograph showing extraction of juice from potato tuber

Plate 6 : Photograph showing determination of TSS with Hand Sugar Refrectometer

Plate 7 : Photograph showing data collection with Force Gauge

3.13.1 Statistical analysis

Mean data of the characters were subjected to multivariate analysis. Univariate analysis of the individual character was done for all characters under study using the mean values (Singh and Chaudhury, 1985) and was analyzed by using MSTAT-C computer programme. Duncan's Multiple Range Test (DMRT) was performed for all the characters to test the differences between the means of the genotypes. Mean, range and co-efficient of variation (CV%) were also estimated using MSTAT-C. Multivariate analysis was done by computer using GENSTAT 5.13 and Microsoft Excel 2000 software.

3.13.1.1 Estimation of genotypic and phenotypic variances

Genotypic and phenotypic variances were estimated according to the formula given by Johnson *et al.* (1955).

$$\text{Genotypic variance } (\sigma^2_g) = \frac{GMS - EMS}{r}$$

Where,

σ^2_g = Genotypic variance

GMS = Genotypic mean sum of square

EMS = Error mean sum of square

r = number of replication

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

Where,

σ^2_p= Phenotypic variance

σ^2_g = Genotypic variance

EMS = Error mean sum of square

3.13.1. 2 Estimation of genotypic and phenotypic co-efficient of variation

Genotypic and phenotypic co-efficient of variation were calculated by the formula suggested by Burton (1952) .

Genotypic co-efficient of variation (GCV %) = $\frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100$

Where,

σ^2_g = Genotypic variance

$\bar{x}$ = Population mean

Similarly,

The phenotypic co-efficient of variation was calculated from the following formula.

Phenotypic co-efficient variation (PCV) = $\frac{\sqrt{\sigma^2 ph}}{\bar{x}} \times 100$

Where,

σ^2_p= Phenotypic variance

$\bar{x}$ = Population mean

3.13.1.3 Estimation of heritability

Broad sense heritability was estimated (Lush, 1943) by the following formula, suggested by Johnson *et al.* (1955).

$h^2{}_b\% = \frac{\sigma^2{}_g}{\sigma^2{}_{ph}} \times 100$

Where,

$h^2{}_b$ = Heritability in broad sense

σ^2_g = Genotypic variance

σ^2_p = Phenotypic variance

3.13.1.4 Estimation of genetic advance

The expected genetic advance for different characters under selection was estimated using the formula suggested by Lush (1943) and Johnson *et al.* (1955).

Genetic advance (GA) = K. h^2. σ_{ph}

$$GA = K.\frac{\sigma^2{}_g}{\sigma^2{}_{ph}}.\sigma_{ph}$$

Where,

K = Selection intensity, the value

which is 2.06 at 5% selection intensity

σ_p = Phenotypic standard deviation

$h^2{}_b$= Heritability in broad sense

$\sigma^2{}_g$ = Genotypic variance

$\sigma^2{}_p$ = Phenotypic variance

3.13.1.5 Estimation of genetic advance mean's percentage

Genetic advance as percentage of mean was calculated from the following formula as proposed by Comstock and Robinson (1952).

$$\text{Genetic advance (\% of mean)} = \frac{\text{Genetic Advance (GA)}}{\text{Population mean (}(\bar{x})} \times 100$$

3.13.1.6 Estimation of simple correlation co-efficient

Simple correlation co-efficients (r) was estimated with the following formula (Clarke, 1973; Singh and Chaudhary, 1985).

$$r = \frac{\sum xy - \frac{\sum x.\sum y}{N}}{\sqrt{}[\{\sum x2 - \frac{(\sum x)2}{N}\}\{\sum y2 - \frac{(\sum y)2}{N}\}]}$$

Where, $\sum$ = Summation

x and y are the two variables correlated

N = Number of observations

3.13.1.7 Estimation of genotypic and phenotypic correlation co-efficient

For calculating the genotypic and phenotypic correlation co-efficient for all possible combinations the formula suggested by Miller *et al.* (1958), Johnson *et al.* (1955) and Hanson *et al.* (1956) were adopted.

The genotypic co-variance component between two traits and have the phenotypic co-variance component were derived in the same way as for the corresponding variance components. The co-variance components were used to compute genotypic and phenotypic correlation between the pairs of characters as follows:

Genotypic correlation (r_{gxy}) = $\frac{GCOVxy}{\sqrt{GVx.GVy}} = \frac{\boldsymbol{\sigma_{pxy}}}{\sqrt{\boldsymbol{\sigma^2_{px}} \times \boldsymbol{\sigma^2_{py}}}}$

Where,

σ_{gxy} = Genotypic co-variance between the traits x and y

σ^2_{gx} = Genotypic variance of the trait x

σ^2_{gy} = Genotypic variance of the trait y

Phenotypic correlation (r_{pxy}) = $\frac{PCOVxy}{\sqrt{PVx.PVy}} = \frac{\boldsymbol{\sigma_{pxy}}}{\sqrt{\boldsymbol{\sigma^2_{px}} \times \boldsymbol{\sigma^2_{py}}}}$

Where,

σ_{pxy} = Phenotypic covariance between the traits x and y

σ^2_{px} = Phenotypic variance of the trait x

σ^2_{py} = Phenotypic variance of the trait y

3.13.1.8 Estimation of path co-efficient

Path coefficient analysis was done according to the procedure employed Singh and Chaudhary (1985), using phenotypic correlation coefficient values. In path analysis, correlation coefficients between yield and yield contributing characters were partitioned into direct and indirect effects of yield contributing characters on grain yield per hectare. In order to estimate direct and indirect effects of the correlated characters, i. e. 1, 2, 3……………….and 15 on yield y, a set of simultaneous equations (three equations in this example) is required to be formulated as shown below:

$r_{1.y} = P_{1.y} + r_{1.2} P_{2.y} + r_{1.3} P_{3.y} + r_{1.4} P_{4.y} + r_{1.5} P_{5.y} + r_{1.6} P_{6.y} + r_{1.7} P_{7.y} + r_{1.8} P_{8.y} + r_{1.9} P_{9.y} + r_{1.10}$

$P_{10.y} + r_{1.11} P_{11.y} + r_{1.12} P_{12.y} + P10_{.y} + r_{1.11} P_{11.y} + r_{1.12} P_{12.y} + r_{1.13}P_{13.y} + r_{1.14}P_{14.y} + r_{1.15}P_{15.y}$

$r_{2.y} = r_{1.2} P_{1.y} + P_{2.y} + r_{2.3} P_{3.y} + r_{2.4} P_{4.y} + r_{2.5} P_{5.y} + r_{2.6} P_{6.y} + r_{2.7} P_{7.y} + r_{2.8} P_{8.y} + r_{2.9} P_{9.y} + r_{2.10}$

$P_{10.y} + r_{2.11} P_{11.y} + r_{2.12} P_{12.y} + r_{2.13}P_{13.y} + r_{2.14}P_{14.y} + r_{2.15}P_{15.y}$

$r_{3.y} = r_{1.3} P_{1.y} + r_{2.3} P_{2.y} + P_{3.y} + r_{3.4} P_{4.y} + r_{3.5} P_{5.y} + r_{3.6} P_{6.y} + r_{3.7} P_{7.y} + r_{3.8} P_{8.y} + r_{3.9} P_{9.y} + r_{3.10}$

$P_{10.y} + r_{3.11} P_{11.y} + r_{3.12} P_{12.y} + r_{3.13}P_{13.y} + r_{3.14}P_{14.y} + r_{3.15}P_{15.y}$

Where,

r_{1y} = Genotypic correlation coefficients between y and I th character (y = Tuber yield)

P_{iy} = Path coefficient due to i^{th} character (i= 1, 2, 3,……….,15)

1 = Plant height

2 = Number of leaves per plant

3 = Number of stems per plan

4 = Leaf area index

5 = Chlorophyll content

6 = Dry matter content

7 = Number of tuber per hill

8 = Weight of single tuber

9 = Weight of tuber per hill

10 = Yield of tuber per hill

11 = Yield per hectare

12 = Number of eye per tuber

13=Specific gravity

14=Total soluble solid

15=Firmness

Total correlation, say between 1 and y i. e., r_{1y} is thus partitioned as follows:

$P_{1.y}$ = the direct effect of 1 on y

$r_{1.2}\ P_{2.y}$ = indirect effect of 1 via 2 on y

$r_{1.3}\ P_{3.y}$ = indirect effect of 1 via 3 on y

$r_{1.4}\ P_{4.y}$ = indirect effect of 1 via 4 on y

$r_{1.5}\ P_{5.y}$ = indirect effect of 1 via 5 on y

$r_{1.6}\ P_{6.y}$ = indirect effect of 1 via 6 on y

$r_{1.7}\ P_{7.y}$ = indirect effect of 1 via 7 on y

$r_{1.8}\ P_{8.y}$ = indirect effect of 1 via 8 on y

$r_{1.9}\ P_{9.y}$ = indirect effect of 1 via 9 on y

$r_{1.10}\ P_{10.y}$ = indirect effect of 1 via 10 on y

$r_{1.11}\ P_{11.y}$ = indirect effect of 1 via 11 on y

$r_{1.12}\ P_{12.y}$ = indirect effect of 1 via 12 on y

$r_{1.13}p_{13.y}$= indirect effect of 1 via 13 on y

$r_{1.14}p_{14.y}$= indirect effect of 1 via 14 on y

$r_{1.15}p_{15.y}$= indirect effect of 1 via 15 on y

Where,

$P_{1.y}$, $P_{2.y}$, $P_{3.y..}$……… $P_{15.y}$ = Path coefficient of the independent variables 1,2 3,……….,15 on the dependent variable y, respectively.

$r_{1.y}$, $r_{2.y}$, $r_{3.y}$, …………., $r_{15.y}$ = Correlation coefficient of 1, 2, 3, ………., 15 with y, respectively.

After calculating the direct and indirect effect of the characters, residual effect (R) was calculated by using the formula given below (Singh and Chaudhary, 1985)

$P^2_{RY} = 1- (r_{1.y}P_{1.y} + r_{2.y}P_{2.y} + \ldots\ldots + r_{15.y}P_{15.y})$

Where,

$$P^2_{RY} = R^2$$

And hence residual effect, $R = (P^2_{RY})^{1/2}$

$P_{1.y}$ = Direct effect of the i^{th} character on yield y.$r_{1.y}$ = Correlation of the i^{th} character with yield y.

3.13.2 Multivariate analysis

The genetic diversity among the genotypes was assessed by Mahalanobis's (1936) general distance (D^2) statistic and its auxiliary analyses. The parents selection in hybridization programme based on Mahalanobis's D^2 statistic is more reliable as requisite knowledge of parents in respect of a mass of characteristics is available prior to crossing. Rao (1952) suggested that the quantification of genetic diversity through biometrical procedures had made it possible to choose genetically diverse parents for a hybridization programme. Multivariate analysis viz. Principal Component analysis, Principal Coordinate analysis, Cluster analysis and Canonical Vector analysis (CVA), which quantify the differences among several quantitative traits, are efficient method of evaluating genetic diversity. These are as follows:

3.13.2.1 Principal Component analysis (PCA)

Principal Component analysis, one of the multivariate techniques, is used to examine the inter-relationships among several characters and can be done from the sum of squares and products matrix for the characters. Thus, PCA finds linear combinations of a set variate that maximize the variation contained within them, thereby displaying most of the original variability in a smaller number of dimensions. Therefore, Principles components were computed from the correlation matrix and genotypes scores obtained for first components (which has the property of accounting for maximum variance) and succeeding components with latent roots greater than unity. Contribution of the different morphological characters towards divergence is discussed from the latent vectors of the first two principal components.

3.13.2.2 Principal Coordinate analysis (PCO)

Principal Coordinate analysis is equivalent to PCA but it is used to calculate inter unit distances. Through the use of all dimension of p it gives the minimum distance between each pair of the n points using similarity matrix (Digby *et al.,* 1989).

3.13.2.3 Cluster analysis (CA)

Cluster analysis divides the genotypes of a data set into some number of mutually exclusive groups. Clustering was done using non-hierarchical classification. In Genstat, the algorithm is used to search for optimal values of chosen criterion proceeds as follows. Starting from some initial classification of the genotypes into required number of groups, the algorithm repeatedly transferred genotypes from one group to another so long as such transfer improved the value of the criterion. When no further transfer can be found to improve the criterion, the algorithm switches to a second stage which examines the effect of swooping two genotypes of different classes and so on.

3.13.2.4 Canonical vector analysis (CVA)

Canonical vector analysis (CVA) finds linear combination of original variability's that maximize the ratio of between group to within group variation, thereby giving functions of the original variables that can be used to discriminate between the groups. Thus, in this analysis a series of orthogonal transformations sequentially maximizing of the ratio of among groups to the within group variations. The canonical vector are based upon the roots and vectors of WB, where W is the pooled within groups covariance matrix and B is the among groups covariance matrix.

3.13.2.5 Calculation of D^2 values

The Mahalanobis's distance (D^2) values were calculated from transformed uncorrelated means of characters according to Rao (1952), and Singh and Chaudhury (1985). The D^2 values were estimated for all possible combinations between genotypes. In simpler form D^2 statistic is defined by the formula

$$D^2 = \sum_{i}^{x} d_i^2 = \sum_{i}^{x} (Y_i^j - Y_j^k) \qquad (j \neq k)$$

Where,

Y = Uncorrelated variable (character) which varies from i = 1 ------to x

x = Number of characters.

Superscript j and k to Y = A pair of any two genotypes.

3.13.2.6 Computation of average intra-cluster distances

Average intra-cluster distances were calculated by the following formula as suggested by Singh and Chuadhury (1985).

$$\text{Average intra-cluster distance} = \frac{\sum D_i^2}{n}$$

Where,

D_i^2 = the sum of distances between all possible combinations (n) of genotypes included in a cluster.

n= Number of all possible combinations between the populations in cluster.

3.13.2.7 Computation of average inter-cluster distances

Average inter-cluster distances were calculated by the following formula as suggested by Singh and Chuadhury (1985).

$$\text{Average inter-cluster distance} = \frac{\sum D_{ij}^2}{n_i \times n_j}$$

Where,

$\sum D_{ij}^2$ = The sum of distances between all possible combinations of the populations in cluster i and j.

n_i = Number of populations in cluster i.

n_j = Number of populations in cluster j.

3.13.2.8 Cluster diagram

Using the values of intra and inter-cluster distances ($D = \sqrt{D^2}$), a cluster diagram was drawn as suggested by Singh and Chuadhury (1985). It gives a brief idea of the pattern of diversity among the genotypes included in a cluster.

3.13.2.9 Selection of varieties for future hybridization programme

Divergence analysis is usually performed to identify the diverse genotypes for hybridization purposes. The genotypes grouped together are less divergent among themselves than those, which fall into different clusters. Clusters separated by largest statistical distance (D^2) express the maximum divergence among the genotypes included into these different clusters. Variety (s) or line(s) were selected for efficient hybridization programme according to Singh and Chuadhury (1985). According to them the following points should be considered while selecting genotypes for hybridization programme:

i. Choice of cluster from which genotypes are selected for use as parent (s)
ii. Selection of particular genotype (s) from the selected cluster(s)
iii. Relative contribution of the characters to the total divergence
iv. Other important characters of the genotypes performance

CHAPTER IV

RESULTS AND DISCUSSION

Genetic variability among traits is important for breeding and in selecting desirable types. Heritability of a trait is important in determining its response to selection. Character association derived by correlation coefficient, forms the basis for selecting desirable plant, aiding in evaluation of relative influence of various component characters on yield. Path coefficient analysis discerns correlation into direct and indirect effects. Diversity is the function of parent selection and also heterosis. The availability of transgressive segregants in a breeding programme depends upon the divergence of parents. Thus, the accurate information on the nature and degree of diversity of the parents is the prerequisite of an effective breeding programme. Genetic diversity was analyzed using GENSTAT software programme.

4.1 Analysis of variance

The analysis of variance indicated significantly higher amount of variability among the genotypes for all the charters studied viz., plant height (cm), no. of leaves per plant (no.), stem per hill (no.), diameter per stem (cm), chlorophyll (%) at 60 DAP, leaf area index, no. of potato per hill (no.), weight of potato per hill (gm), weight of individual potato (gm), no. of eyes per tuber (no.), dry matter %, specific gravity, total soluble sugar (%), firmness (N), potato yield (ton / ha) (Appendix, IVa and IVb).

4.2 Genetic parameters

The mean performance and range of potato genotypes for various growth characters, yield components are presented in Table 3. The genotypic and phenotypic coefficients of variation, heritability, genetic advance as percent mean for all the characters were studied and the results were presented in Table 4 and depicted in Figure 1 and Figure 2. Photographs are showing phenotypic variation (tuber length and diameter, number of eyes per tuber and skin colour of potato tuber) among different genotypes of potato in Plate 8a, 8b, 8c and 8d.

4.2.1 Plant height (cm):

The grand mean of plant height recorded was 67.18 cm. It was ranged from 42.33 cm to 79.87 cm (Table 3). The maximum plant height (79.87 cm) was recorded by G_{14} (Tel pakri) and the lowest (42.33 cm) was recorded by G_{21} (Granola), (Table 3). The PCV and GCV were 16.09 and 12.09 percent respectively (Table 4 and Fig.1). There was considerable difference between the phenotypic and genotypic co-efficient of variation indicating significant environmental influence in the expression of this character. The character showed high heritability (56.52) coupled with low genetic advance in percent of mean (18.73) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.2 Leaves per plant (no.):

The grand mean of no. of leaves per plant recorded was 99.44. It was ranged from 23.22 to 230.77 (Table 3). The maximum no. of leaves per plant was recorded by G_8 (Shada pakri) and the lowest was recorded by G_1 (Cardinal), (Table 3). The PCV and GCV were 72.56 and 71.86 percent respectively (Table 4 and Fig 1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (98.07) coupled with high genetic advance in percent of mean (146.59) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

4.2.3 Stem per hill (no.):

The grand mean of stem per hill recorded was 2.53. It was ranged from 1.22 to 4.22 (Table 3). The maximum stem per hill was recorded by G_6 (Asterix) and the lowest was recorded by G_4 (BARI-TPS-1), (Table 3). The PCV and GCV were 33.67 and 31.54 percent respectively (Table 4 and Fig. 1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (87.75) coupled with low genetic advance in percent of mean (60.86) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

Table 3: Mean performance of 21 potato genotyps based on different morphological traits related to yield

Genotype	Plant height (cm)	Leaves per plant (no.)	Stem per hill (no.)	Diameter per stem (cm)	Chlorophyll (%) at 60 DAP	Leaf area index	Potato per hill (no.)
G_1	53.66 de	23.22 h	3.997 ab	1.230 a	55.11 a	1.777ghi	7.107 i
G_2	64.78 bcd	31.44 h	2.220 ef	1.180 ab	49.84 bcde	2.390 ef	4.99 i
G_3	64.11 cd	26.77 h	2.217 ef	1.200 ab	46.24 de	1.520 hi	5.66 i
G_4	66.55 abcd	149.0 b	1.220 g	1.160 ab	45.91 e	8.420 a	6.44 i
G_5	63.88 cd	39.66 h	2.333 ef	1.147 ab	49.32bcde	2.577 ef	5.88 i
G_6	69.55 abc	23.44 h	4.220 a	1.110 abc	45.58 e	4.210 c	8.44 hi
G_7	69.66 abc	96.55cd	1.330 g	1.00 cdef	47.17cde	2.720 ef	11.55 h
G_8	73.89 abc	230.8 a	2.440 ef	1.063bcde	48.77bcde	5.690 b	65.22 a
G_9	66.55 abcd	220.1 a	1.550 g	0.8633 f	45.24 e	2.410 ef	24.11 de
G_{10}	78.88 ab	213.9 a	2.330 ef	0.940 ef	45.88 e	3.890 cd	61.11b
G_{11}	67.77 abc	80.44 de	2.110 f	0.930 ef	52.91 ab	1.58 hi	19.44 fg
G_{12}	67.11 abc	108.0 c	2.440 ef	0.883 f	50.16abcde	2.28 fg	26.89 cd
G_{13}	71.99 abc	82.33de	2.770 de	0.953 def	48.44bcde	2.95 e	16.00 g
G_{14}	79.87 a	80.11 de	2.660 ef	0.913 f	51.42 abcd	1.68 hi	20.67 ef
G_{15}	50.11 e	144.3 b	2.440 ef	0.927 ef	46.73 cde	4.160 c	29.44 c
G_{16}	76.88 abc	65.00 ef	2.220 ef	0.863 f	49.05bcde	1.58 hi	21.22 ef
G_{17}	68.11 abc	229.3 a	3.217 cd	0.893 f	48.29 bcde	3.56 d	59.44 b
G_{18}	69.66 abc	37.22 h	3.550 bc	1.087 abcd	50.38abcde	1.34 i	6.663 i
G_{19}	72.22 abc	108.7 c	2.773 de	0.877 f	50.56abcde	2.89 e	25.89 cd
G_{20}	73.11 abc	57.22 fg	1.550 g	0.863 f	48.17 bcde	2.12 fgh	18.44 fg
G_{21}	42.33 e	40.78 gh	3.550 bc	1.087 abcd	51.62 abc	1.73 ghi	9.22 hi
Minimum	42.33	23.22	1.22	0.86	45.24	1.34	5.00
Maximum	79.87	230.77	4.22	1.20	55.11	8.42	65.22
Mean	67.18	99.44	2.53	1.00	48.89	2.93	21.61

Table 3: (Continued)

Genotype	Weight of potato per hill (g)	Weight of individual potato (g)	Eyes per tuber (no.)	Dry matter %	specific gravity	Total soluble sugar (%)	Firmness (N)	Potato yield (t/ha)
G_1	787.0 fgh	110.7d	11.44 b	27.77 ab	1.09cde	7.00 de	45.32 a	32.48 a
G_2	738.1ghi	147.7 a	10.89 b	23.81d-g	1.09 cde	6.50 efgh	43.65ab	21.32bcd
G_3	570.8 ij	100.8 e	9.663 bc	24.65c-f	1.03 cdef	7.70abcd	26.74gh	22.81bc
G_4	691.1 hi	107.3 d	9.110 bc	25.57 bcd	1.02 cdef	6.00 fgh	45.45a	21.87bcd
G_5	713.6ghi	121.2 c	7.777 c	24.82 cde	1.010def	6.50 efgh	33.43def	24.95b
G_6	1079cd	127.8 b	14.33 a	22.77e-i	1.110cde	5.90 gh	35.20cde	32.38 a
G_7	718.7ghi	62.22 g	11.11 b	23.59d-h	1.240 bc	6.90 def	33.48 def	11.82f
G_8	1334. b	20.46m	9.443 bc	26.78abc	1.02cdef	6.80defg	37.70 cd	19.31 cd
G_9	238.3 k	9.88 o	7.777 c	27.27 ab	0.990def	8.00abc	15.28 j	4.23 g
G_{10}	2543. a	41.61 j	10.77 b	26.33abc	0.830 f	7.60 bcd	30.74 efg	19.75 cd
G_{11}	829.9efgh	42.69 j	10.33 bc	27.99 a	1.507 a	7.60 bcd	32.57 def	13.79 f
G_{12}	868.9efgh	32.32 l	11.11 b	26.60abc	1.150 cd	8.40 ab	22.94 hi	14.62 ef
G_{13}	1122. c	70.15 f	10.00 bc	23.53d-h	1.00 def	8.00abc	33.63 def	14.10 ef
G_{14}	900.1defg	43.56 ij	9.660 bc	23.99d-g	1.09 cde	7.20 cde	23.30 hi	12.98 f
G_{15}	1405. b	47.72 hi	9.773 bc	27.04ab	1.36 ab	7.00de	20.56 i	22.86 bc
G_{16}	1076. cd	50.73 h	9.663 bc	22.31ghi	1.01 def	8.60 a	34.80cde	19.50cd
G_{17}	917.2defg	15.43 n	7.887 c	21.25 i	1.03 cdef	6.40 efgh	28.82 fg	17.89de
G_{18}	472.5 j	70.91 f	10.66 b	21.47 hi	1.13 cde	6.00 fgh	35.02cde	19.47cd
G_{19}	1008 cde	38.95 jk	7.993 c	28.21 a	1.11cde	7.20 cde	30.74 efg	21.52bcd
G_{20}	678.2hi	36.78kl	11.11 b	22.57f-i	0.920 ef	5.80 h	31.14 efg	13.24 f
G_{21}	946.4cdef	102.7 e	9.660 bc	18.45 j	1.14 cde	6.00 fgh	39.71 bc	29.44a
Minimum	238.25	9.88	7.78	18.45	0.83	5.80	15.28	4.23
Maximum	2542.83	147.71	14.33	28.21	1.51	8.60	45.45	32.48
Mean	935.18	66.74	10.01	24.61	1.09	7.00	32.39	19.54

Table 4: Estimation of genetic parameters for morphological characters related to yield

Sl No.	Characters	Phenotypic variance (δ^2p)	Genotypic variance (δ^2g)	Grand mean	PCV (%)	GCV (%)	Heritability (%)	GA	GA (%)
1	**Plant height (cm)**	116.78	66.01	67.18	16.09	12.09	56.52	12.58	18.73
2	**Leaves per plant(no.)**	5206.50	5105.93	99.44	72.56	71.86	98.07	145.77	146.59
3	**Stem per hill (no.)**	0.73	0.64	2.53	33.67	31.54	87.75	1.54	60.86
4	**Diameter per stem (cm)**	0.02	0.01	1.00	14.08	11.78	70.00	0.20	20.30
5	**Chlorophyll (%) at 60 DAP**	11.56	4.30	48.89	6.96	4.24	37.19	2.61	5.33
6	**Leaf area index**	2.90	2.79	2.93	58.17	57.09	96.34	3.38	115.44
7	**Potato per hill (no.)**	349.97	344.31	21.61	86.57	85.86	98.38	37.91	175.44
8	**Weight of potato per hill (g)**	216723.87	204955.26	935.18	49.78	48.41	94.57	906.93	96.98
9	**Weight of individual Potato (g)**	1633.14	1625.55	66.74	60.55	60.41	99.54	82.86	124.15
10	**Eyes per tuber (no.)**	3.48	1.74	10.01	18.63	13.19	50.13	1.93	19.24
11	**Dry matter %**	7.68	6.29	24.61	11.26	10.20	81.99	4.68	19.02
12	**specific gravity**	0.03	0.02	1.09	15.80	11.84	56.18	0.20	18.28
13	**Total soluble sugar (%)**	0.89	0.63	7.00	13.47	11.36	71.11	1.38	19.73
14	**Firmness (N)**	67.18	58.41	32.39	25.30	23.60	86.95	14.68	45.32
15	**Potato yield (ton / ha)**	51.36	46.36	19.54	36.67	34.84	90.27	13.33	68.20

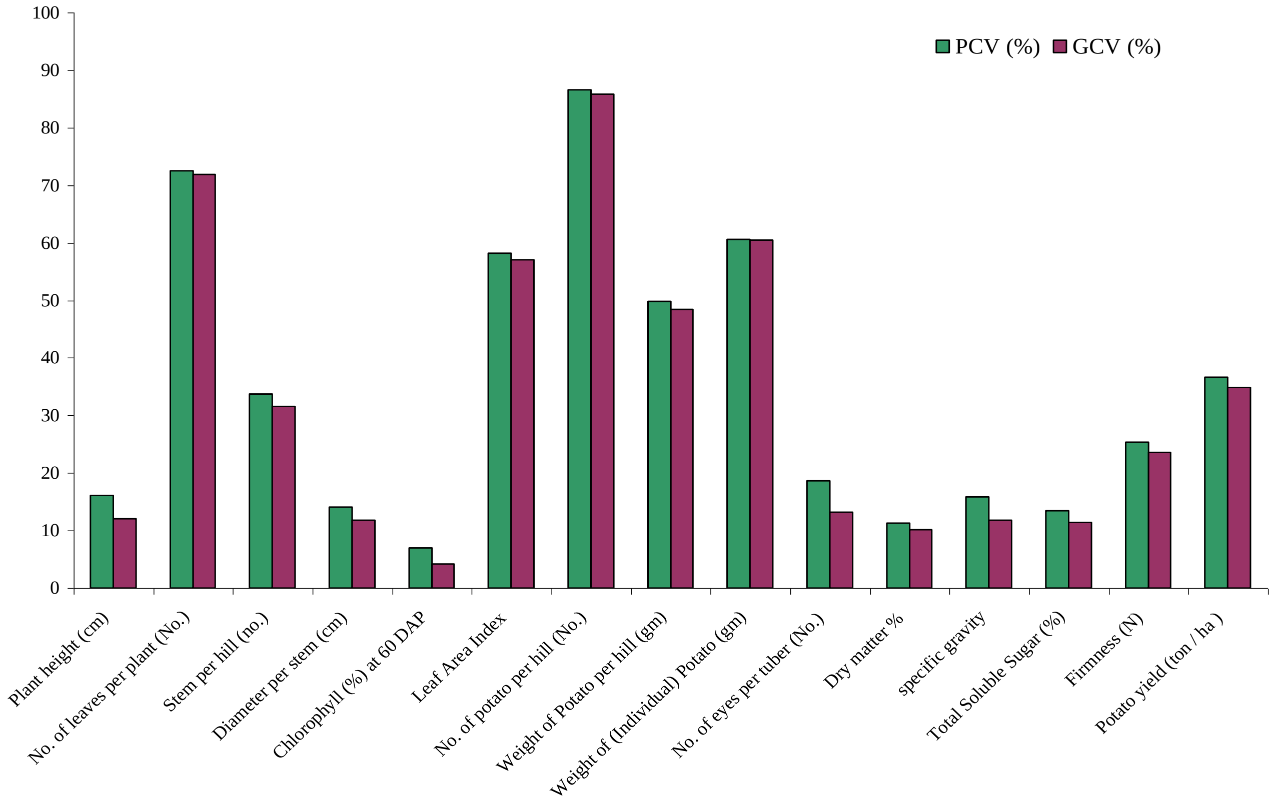

Figure 1 : Genotypic and phenotypic variability in potato genotypes for 15 different Characters.

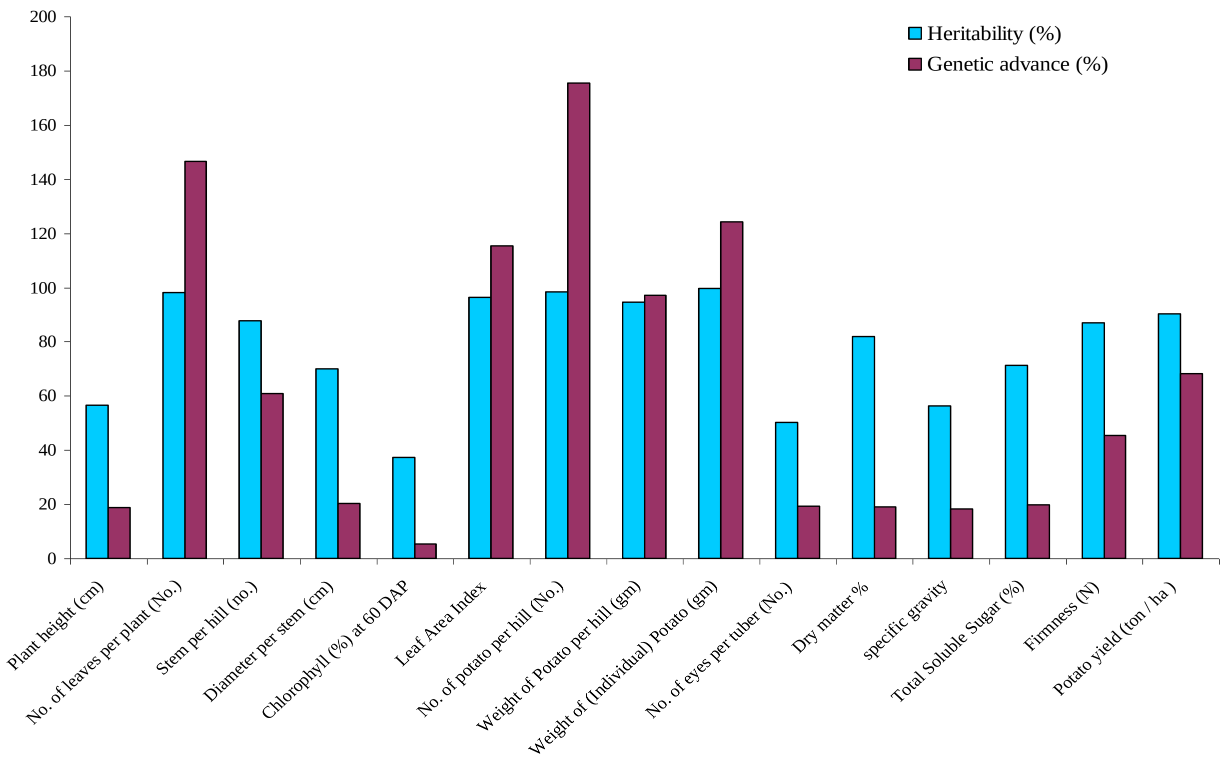

Figure 2 : Heritability and genetic advance over mean in potato genotypes for 15 different characters.

4.2.4 Diameter per stem (cm):

The grand mean of diameter per stem recorded was 1.00. It was ranged from 0.86 to 1.20 cm (Table 3). The maximum diameter per stem was recorded by G_1 (Cardinal) and the lowest was recorded by G_{16} (Bot pakri), (Table 3 and Fig. 1). The PCV and GCV were 14.08 and 11.78 percent respectively (Table 4). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (70.00) coupled with low genetic advance in percent of mean (20.30) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.5 Chlorophyll (%) at 60 DAP:

The grand mean of chlorophyll (%) recorded was 48.89. It was ranged from 45.24 to 55.11 (Table 3). The maximum chlorophyll (%) was recorded by G_1 (Cardinal) and the lowest was recorded by G_9 (Jam alu), (Table 3). The PCV and GCV were 6.96 and 4.24 percent respectively (Table 4 and Fig.1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed low heritability (37.19) coupled with low genetic advance in percent of mean (5.33) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.6 Leaf area Index:

The grand mean of leaf area index recorded was 2.93. It was ranged from 1.34 to 8.42 (Table 3). The maximum leaf area index was recorded by G_4 (BARI-TPS-1)and the lowest was recorded by G_{17} (Shil bilati), (Table 3). The PCV and GCV were 58.17 and 57.09 percent respectively (Table 4 and Fig.1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (96.34) coupled with high genetic advance in percent of mean (115.44) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

4.2.7 Potato per hill (no):

The grand mean of no. of potato per hill recorded was 21.61. It was ranged from 4.99 to 65.22 (Table 3). The maximum no. of potato per hill was recorded by G_8 (Shada pakri) and the lowest was recorded by G_2 (Diamant), (Table 3). The PCV and GCV were 86.57 and 85.86 percent respectively (Table 4 and Fig.1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (98.38) coupled with high genetic advance in percent of mean (175.44) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

4.2.8 Weight of potato per hill (g):

The grand mean of weight of potato per hill recorded was 935.18. It was ranged from 238.3 to 2543 (Table 3). The maximum weight of potato per hill was recorded by G_{10} (Tilok Pura) and the lowest was recorded by G_9 (Jam alu),(Table 3). The PCV and GCV were 49.78 and 48.41 percent respectively (Table 4 and Fig.1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (94.57) coupled with high genetic advance in percent of mean (96.98) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.9 Weight of individual potato (g):

The grand mean of weight of (individual) potato recorded was 66.74. It was ranged from 9.88 to 147.7 (Table 3). The maximum weight of (individual) potato was recorded by G_2 (Diamant) and the lowest was recorded by G_9 (Jam alu), (Table 3 and Fig 1). The PCV and GCV were 60.55 and 60.41 percent respectively (Table 4). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (99.54) coupled with low genetic advance in percent of mean (124.15) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

4.2.10 Eyes per tuber (no):

The grand mean of no. of eyes per tuber recorded was 10.01. It was ranged from 7.78 to 14.33 (Table 3). The maximum no. of eyes per tuber was recorded by G_6 (Asterix) and the lowest was recorded by G_9 (Jam alu), (Table 3). The PCV and GCV were 18.63 and 13.19 percent respectively (Table 4 and Fig. 1). There was considerable difference between the phenotypic and genotypic co-efficient of variation indicating significant environmental influence in the expression of this character. The character showed medium heritability (50.13) coupled with low genetic advance in percent of mean (19.24) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.11 Dry matter (%):

The grand mean of dry matter % recorded was 24.61. It was ranged from 18.45 to 28.21 (Table 3). The maximum dry matter % was recorded by G_{19} (Patnai) and the lowest was recorded by G_{21} (Granola), (Table 3 and Fig.1). The PCV and GCV were 11.26 and 10.20 percent respectively (Table 4). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (81.99) coupled with low genetic advance in percent of mean (19.02) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.12 Specific gravity:

The grand mean of specific gravity recorded was 1.09. It was ranged from 0.83 to 1.51 (Table 3). The maximum specific gravity was recorded by G_{11} (Pahari Pakri) and the lowest was recorded by G_{10} (Tilok Pura), (Table 3). The PCV and GCV were 15.80 and 11.84 percent respectively (Table 4 and Fig.1). There was considerable difference between the phenotypic and genotypic co-efficient of variation indicating significant environmental influence in the expression of this character. The character showed medium heritability (56.18) coupled with low genetic advance in percent of mean (18.28) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.13 Total soluble sugar (%):

The grand mean of total soluble sugar (%) recorded was 7.00. It was ranged from 5.80 to 8.60 (Table 3). The maximum total soluble sugar (%) was recorded by G_{16} (Bot pakri) and the lowest was recorded by G_{20} (Lal chokha pakri), (Table 3). The PCV and GCV were 13.47 and 11.36 percent respectively (Table 4 and Fig.1). There was considerable difference between the phenotypic and genotypic co-efficient of variation indicating significant environmental influence in the expression of this character. The character showed high heritability (71.11) coupled with low genetic advance in percent of mean (19.73) which indicated non additive gene action for expression of this character (Table 4 and Fig 2).

4.2.14 Firmness:

The grand mean of firmness recorded was 32.39. It was ranged from 15.28 to 45.45 (Table 3). The maximum firmness was recorded by G_4 (BARI-TPS-1) and the lowest was recorded by G_9 (Jam alu), (Table 3 and Fig.1). The PCV and GCV were 25.30 and 23.60 percent respectively (Table 4). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (86.95) coupled with medium genetic advance in percent of mean (45.32) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

4.2.15 Potato yield (t/ha):

The grand mean of potato yield recorded was 19.54. It was ranged from 4.23 to 32.48 (Table 3). The maximum potato yield was recorded by G_1 (Cardinal) and the lowest was recorded by G_9 (Jam alu), (Table 3). The PCV and GCV were 36.67 and 34.84 percent respectively (Table 4 and Fig.1). There was little difference between the phenotypic and genotypic co-efficient of variation indicating little environmental influence in the expression of this character. The character showed high heritability (90.27) coupled with high genetic advance in percent of mean (68.20) which indicated additive gene action for expression of this character (Table 4 and Fig 2).

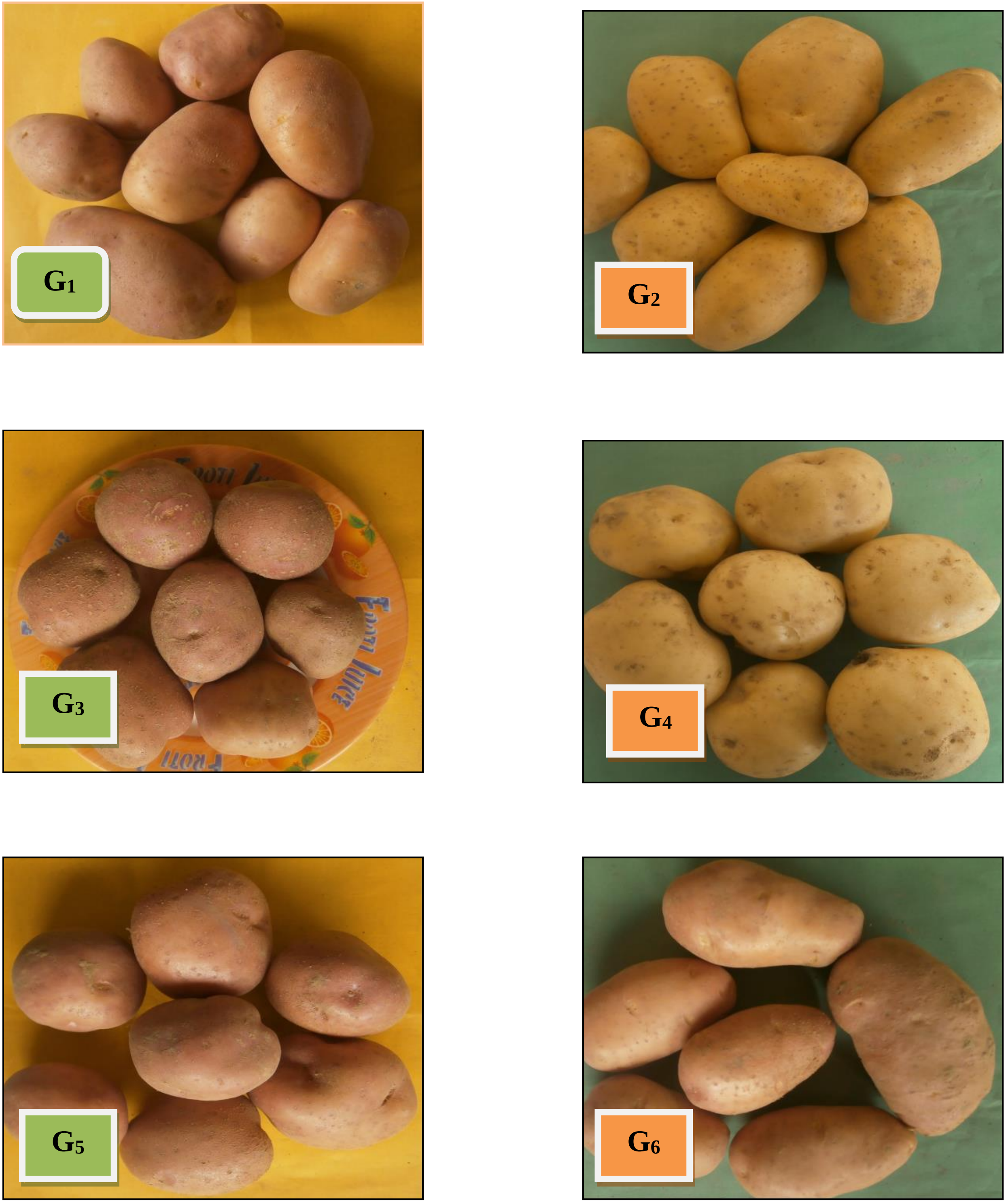

Plate 8a : Showing phenotypic variation in tuber among different genotypes of potato (G_1-G_6)

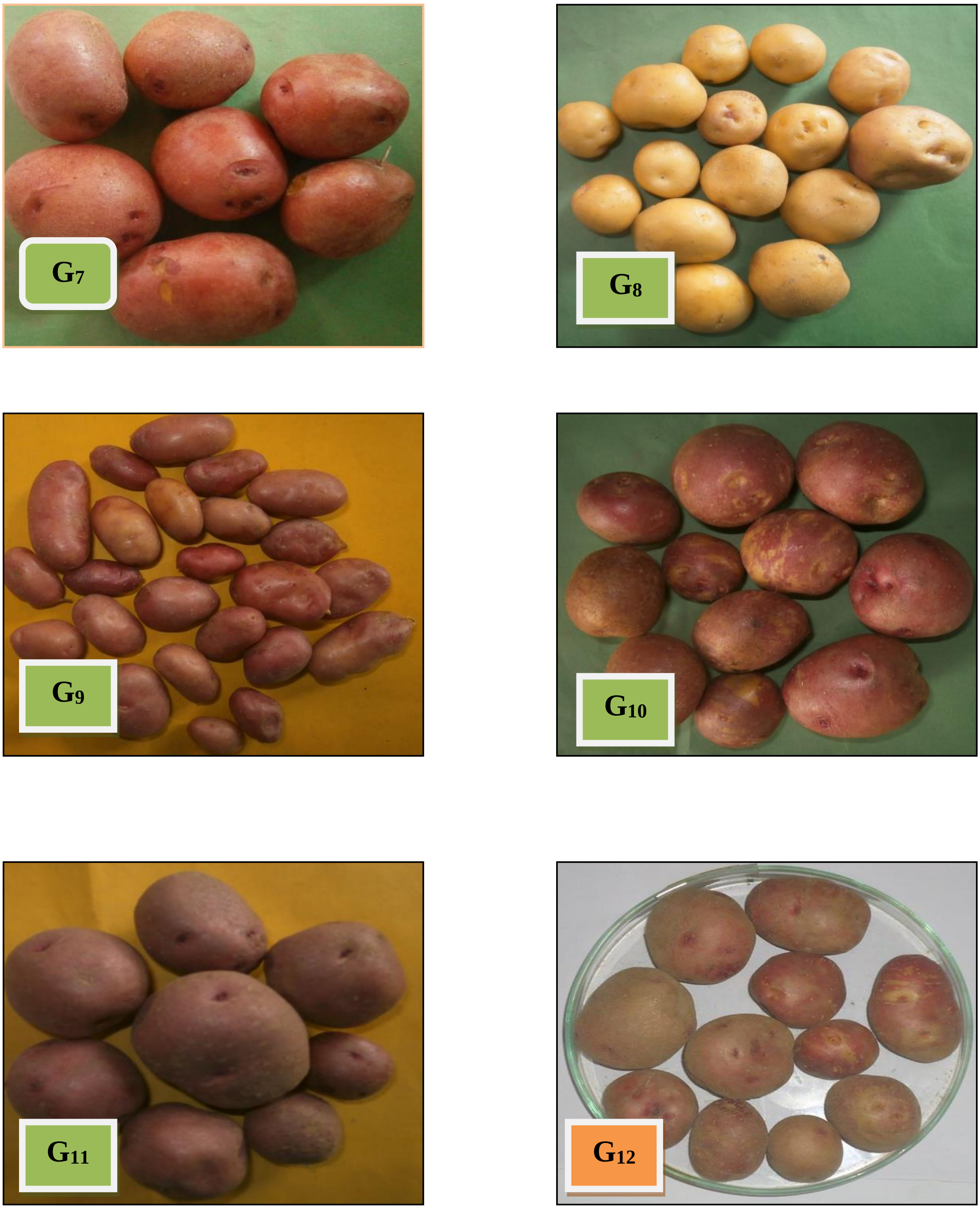

Plate 8b :Showing phenotypic variation in tuber among different genotypes of potato (G_7-G_{12})

Plate 8c : Showing phenotypic variation in tuber among different genotypes of potato (G_{13}-G_{18})

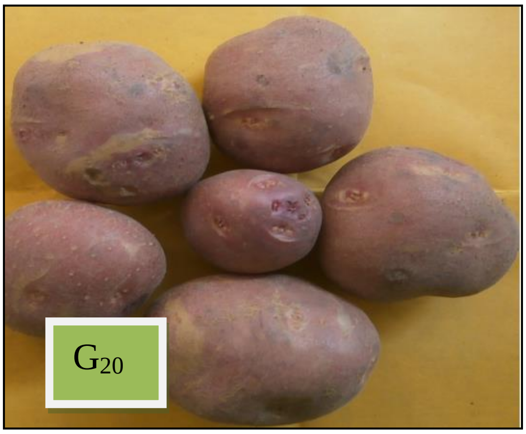

Plate 8d : Showing phenotypic variation in tuber among different genotypes of potato (G_{19}-G_{21})

Where (G_1= Cardinal, G_2= Diamant, G_3= Laddy rosetta, G_4= BARI-TPS-1, G_5= Courage, G_6= Asterix, G_7= Lal pakri, G_8 = Shada pakri, G_9 = Jam alu, G_{10} = Tilok Pura, G_{11} = Pahari Pakri ,G_{12} = Pakri, G_{13} = Fata pakri, G_{14} = Tel pakri G_{15} = Romana pakri, G_{16} = Bot pakri, G_{17} = Shil bilati, G_{18} = Local cardinal, G_{19} = Patnai, G_{20} = Lal chokha pakri, G_{21} = Granola)

4.3 Correlation study

The correlation co-efficient between yield and yield contributing characters in potato are presented in Table 5. Correlation analysis among yield and its contributing character revealed that the genotypic correlation in most cases were higher than their phenotypic correlation coefficients indicating the association is largely due to genetic reason. In some cases phenotypic correlation coefficients were higher than genotypic correlation indicating suppressing effect of the environment which modified the expression of the characters at phenotypic level.

4.3.1 Plant height (cm):

Plant height was significantly negatively correlated with diameter per stem and yield. So we can say that diameter of the stem and potato yield is reduced with the increasing of plant height.

4.3.2 Leaves per plant (no.):

Number of leaves per plant was significantly negatively correlated with diameter of stem, chlorophyll percentage of leaves, weight of individual potato and yield whereas it was positively correlated with leaf area index and number of potato. So yield is reduced but number of potato is increased with the increasing number of leaves.

4.3.3 Stem per hill (no):

Stem per hill was significantly positively correlated with potato yield. So yield is increased with increasing number of stem per hill potato.

4.3.4 Diameter per stem:

Diameter per stem was significantly negatively correlated with number of potato and sugar content whereas it was positively correlated with weight, firmness and yield of potato. So number of potato and sugar content decreased but yield is increased with the increasing of diameter per stem.

Table 5 : Coefficients of phenotypic and genotypic correlation among different yield components

Characters	correla tion	Leaves per plant (no.)	Stem per hill (no.)	Diameter per stem (cm)	Chloroph yll (%) at 60 DAP	Leaf area index	Potato per hill (no.)	Weight of potato per hill (g)	Weight of individua l potato (g)	Eyes per tuber (no.)	Dry matter %	Specific gravity	Total soluble sugar (%)	Firmness (N)	Potato yield (ton / ha)
Plant height (cm)	r_p	0.254	-0.293	-0.415	-0.241	0.073	0.346	0.209	-0.395	0.029	0.121	-0.387	0.274	-0.166	-0.500*
	r_g	0.264	-0.289	-0.466*	-0.271	0.068	0.355	0.221	-0.411	0.020	0.156	-0.425	0.257	-0.206	-0.563**
Leaves per plant (No.)	r_p		-0.326	-0.463*	-0.419	0.524*	0.842**	0.377	-0.705**	-0.454*	0.323	-0.212	0.190	-0.364	-0.446*
	r_g		-0.332	-0.475*	-0.451*	0.523*	0.845**	0.378	-0.706**	-0.482*	0.326	-0.222	0.194	-0.366	-0.448*
Stem per hill (no.)	r_p			0.281	0.418	-0.240	-0.039	0.127	0.280	0.352	-0.278	0.066	-0.239	0.224	0.664**
	r_g			0.290	0.467*	-0.250	-0.044	0.135	0.285	0.386	-0.275	0.067	-0.235	0.237	0.679**
Diameter per stem (cm)	r_p				0.122	0.162	-0.484*	-0.198	0.849**	0.245	-0.091	-0.037	-0.442*	0.665**	0.673**
	r_g				0.093	0.157	-0.499*	-0.203	0.849**	0.293	-0.085	-0.052	-0.452*	0.683**	0.702**
Chlorophyll (%) at 60 DAP	r_p					-0.499*	-0.193	-0.168	0.099	0.019	0.046	0.366	0.015	0.341	0.223
	r_g					-0.528*	-0.209	-0.193	0.099	-0.060	0.082	0.329	0.017	0.387	0.243
Leaf Area Index	r_p						0.301	0.280	0.032	-0.067	0.215	-0.176	-0.304	0.262	0.134
	r_g						0.303	0.285	0.031	-0.056	0.222	-0.183	-0.305	0.263	0.133
Potato per hill (no.)	r_p							0.632**	-0.709**	-0.253	0.207	-0.239	0.197	-0.286	-0.243
	r_g							0.634**	-0.710**	-0.267	0.211	-0.246	0.202	-0.288	-0.245
Weight of Potato per hill (g)	r_p								-0.179	0.176	0.148	-0.204	0.166	0.016	0.203
	r_g								-0.180	0.181	0.151	-0.197	0.171	0.009	0.205
Weight of individual potato (g)	r_p									0.368	-0.251	0.001	-0.413	0.644**	0.691**
	r_g									0.384	-0.254	-0.002	-0.419	0.650**	0.695**
Eyes per tuber (no.)	r_p										-0.139	0.147	-0.188	0.281	0.330
	r_g										-0.143	0.159	-0.255	0.300	0.318
Dry matter %	r_p											0.201	0.435*	-0.225	-0.167
	r_g											0.221	0.443*	-0.232	-0.156
Specific gravity	r_p												0.024	-0.079	0.010
	r_g												0.021	-0.085	0.010
Total Soluble sugar (%)	r_p													-0.467*	-0.427
	r_g													-0.482*	-0.455*
Firmness (N)	r_p														0.585**
	r_g														0.575**

*** and ** indicate significant at 5% and 1% level of probability, respectability.**

4.3.5 Chlorophyll (%) at 60 DAP:

Chlorophyll percentage of leaf significantly negatively correlated with leaf area index. So leaf area is decreased with increasing chlorophyll percentage of leaf.

4.3.6 Leaf area index:

Leaf area index was non significantly positively correlated with no. of potato per hill, weight of potato per hill, weight of individual potato, dry matter percentage, firmness and potato yield.

4.3.7 Potato per hill (no.):

Number of potato per hill was significantly negatively correlated with weight of individual potato whereas it was significantly positively correlated with weight of potato per hill. So with the increasing number of potato per hill weight of individual potato is decreased but weight of potato per hill is increased.

4.3.8 Weight of potato per hill (g):

Weight of potato per hill was non significantly positively correlated with no. of eyes per tuber, dry matter percentage, total soluble sugar percentage firmness and potato yield.

4.3.9 Weight of individual potato (g):

Weight of individual potato was significantly positively correlated with firmness and yield. So firmness and yield is increased with the increase of weight of individual potato.

4.3.10 Eyes per tuber (no.):

No. of eyes per tuber was non significantly positively correlated with specific gravity, firmness and potato yield.

4.3.11 Dry matter:

Dry matter content was significantly positively correlated with sugar content. So with the increase of dry matter content sugar content is increased.

4.3.12 Specific gravity:

Specific gravity was non significantly positively correlated with total soluble sugar percentage and potato yield.

4.3.13 Total soluble sugar (%):

Soluble sugar was significantly negatively correlated with yield and firmness. So with the increase of soluble sugar yield and firmness is decreased.

4.3.14 Firmness:

Firmness was significantly positively correlated with yield. So yield is increased with the increase of firmness.

Pleiotropy or linkage relations among genes controlling the traits are some of the reasons of genetic trait correlations. Directions and rates of short term evolution are effected by genetic trait correlations (Falconer, 1989; Roff, 1997; Lynch & Walsh, 1998). Much of dissimilarity phenotypic and genetic correlation estimates seems to be due to imprecise estimates of genetic correlations. In many situations, phenotypic correlations are likely to be fair estimates of their genetic counterparts (Cheverud, 1988). Genetic correlations between morphological traits are more often positive than correlation between other traits (Roff, 1996 & 1997). Competition between processes for a resource may result in negative correlations (Atchley, 1987).

4.4 Path coefficient analysis

Path co-efficient is a standard tool which measures the direct influence of one character upon another and permits the separation of correlation co-efficient into components of direct and indirect effects. Path co-efficient between yield and yield contributing characters provides an exact picture of the relative importance of direct and indirect influences of each other component characters on tuber yield. Path analysis, therefore, is a useful tool for understanding yield except chain of relationship between yield and yield contributing characters. It also provides valuable additional information for improving tuber yield via selection for its yield components. Recent publications involving path co-efficient analysis between yield and components of yield relevant to the present study are reviewed in this section (Table 6).

4.4.1 Plant height (cm):

Plant height employed negative direct effect (-0.227) on yield as well as negative indirect effect via no. of leaves per plant, stem per hill, diameter per stem, chlorophyll percentage, weight of individual potato weight, dry matter and total soluble sugar percentage. It also employed positive indirect effect of leaf area index, no. of potato per hill, weight of potato per hill, no. of eyes per tuber, specific gravity and firmness (Table 6).

4.4.2 Leaves per plant (no.):

No. of leaves per plant employed negative direct effect (-0.579) on yield as well as negative indirect effect via plant height, stem per hill, diameter per stem, chlorophyll percentage, weight of individual potato weight, no. of eyes per tuber, dry matter and total soluble sugar percentage. It also employed positive indirect effect of leaf area index, no. of potato per hill, weight of potato per hill, specific gravity and firmness (Table 6).

Table 6: Partitioning of genotypic into direct and indirect effects of morphological characters of 21 potato varieties by path coefficient analysis

Characters	Plant height (cm)	Leaves per plant (no.)	Stem per hill (no.)	Diameter per stem (cm)	Chlorophyll (%) at 60 DAP	Leaf area index	Potato per hill (no.)	Weight of Potato per hill (g)	Weight of individual Potato (g)	Eyes per tuber (No.)	Dry matter %	Specific gravity	Total soluble sugar (%)	Firmness (N)	Potato yield (ton / ha)
Plant height (cm)	**-0.227**	-0.153	-0.033	-0.282	-0.194	0.055	0.083	0.086	-0.073	0.0009	-0.043	0.066	-0.005	0.158	-0.563**
Leaves per plant (No.)	-0.060	**-0.579**	-0.038	-0.288	-0.323	0.422	0.197	0.147	-0.125	-0.021	-0.091	0.035	-0.004	0.281	-0.448*
Stem per hill (no.)	0.066	0.192	**0.114**	0.176	0.335	-0.202	-0.010	0.052	0.051	0.017	0.076	-0.010	0.005	-0.182	0.679**
Diameter per stem (cm)	0.104	0.275	0.033	**0.606**	0.067	0.127	-0.116	-0.079	0.153	0.013	0.024	0.008	0.009	-0.524	0.702**
Chlorophyll (%) at 60 DAP	0.062	0.261	0.053	0.056	**0.717**	-0.426	-0.049	-0.075	0.018	-0.003	-0.023	-0.051	-0.0004	-0.297	0.243
Leaf area Index	-0.013	-0.303	-0.028	0.095	-0.378	**0.808**	0.071	0.111	0.006	-0.0024	-0.062	0.0285	0.006	-0.202	0.133
Potato per hill (no.)	-0.081	-0.489	-0.005	-0.302	-0.149	0.245	**0.233**	0.246	-0.126	-0.012	-0.059	0.038	-0.0042	0.221	-0.245
Weight of potato per hill (g)	-0.050	-0.219	0.0153	-0.123	-0.138	0.230	0.148	**0.388**	-0.032	0.0079	-0.042	0.031	-0.004	-0.007	0.205
Weight of individual Potato (g)	0.093	0.409	0.032	0.524	0.071	0.025	-0.166	-0.070	**0.177**	0.017	0.071	0.0003	0.0087	-0.499	0.695**
Eyes per tuber (no.)	-0.0045	0.279	0.044	0.178	-0.043	-0.045	-0.032	0.070	0.068	**0.044**	0.039	-0.025	0.005	-0.230	0.318
Dry matter %	-0.035	-0.189	-0.031	-0.051	0.059	0.179	0.049	0.059	-0.046	-0.006	**-0.278**	-0.034	-0.009	0.178	-0.156
Specific gravity	0.097	0.128	0.008	-0.032	0.236	-0.148	-0.06	-0.076	-0.0004	0.007	-0.061	**-0.156**	-0.0004	0.065	0.010
Total soluble sugar (%)	-0.058	-0.112	-0.027	-0.274	0.012	-0.246	0.047	0.066	-0.074	-0.011	-0.123	-0.0033	**-0.021**	0.370	-0.455*
Firmness (N)	0.047	0.212	0.027	0.414	0.277	0.212	-0.067	0.0035	0.115	0.013	0.064	0.013	0.010	**-0.767**	0.575**
															Residual effect = 0.0583

4.4.3 Stem per hill:

Stem per hill employed positive direct effect (0.114) on yield as well as positive indirect effect via plant height, no. of leaves per plant, diameter per stem, chlorophyll percentage, weight of potato per hill, weight of individual potato weight, no. of eyes per tuber, dry matter and total soluble sugar percentage. It also employed negative indirect effect of leaf area index, no. of potato per hill, specific gravity and firmness (Table 6).

4.4.4 Diameter per stem:

Diameter per stem employed positive direct effect (0.606) on yield as well as positive indirect effect via plant height, no. of leaves per plant, stem per hill, chlorophyll percentage, leaf area index, weight of individual potato weight, no. of eyes per tuber, dry matter, total soluble sugar percentage and specific gravity. It also employed negative indirect effect of no. of potato per hill, weight of potato per hill and firmness (Table 6).

4.4.5 Chlorophyll (%) at 60 DAP:

Chlorophyll percentage employed positive direct effect (0.717) on yield as well as positive indirect effect via plant height, no. of leaves per plant, stem per hill, diameter per stem and weight of individual potato weight. It also employed negative indirect effect of leaf area index, no. of potato per hill, weight of potato per hill, specific gravity, firmness, no. of eyes per tuber, dry matter and total soluble sugar percentage (Table 6).

4.4.6 Leaf area index:

Leaf area index employed positive direct effect (0.808) on yield as well as positive indirect effect via diameter per stem, no. of potato per hill, weight of potato per hill, weight of individual potato weight and specific gravity. It also employed negative indirect effect of plant height, no. of leaves per plant, stem per hill, chlorophyll percentage, no. of eyes per tuber (Table 6).

4.4.7 Potato per hill (no.):

No. of potato per hill employed positive direct effect (0.233) on yield as well as positive indirect effect via leaf area index, weight of potato per hill, specific gravity and firmness. It also employed negative indirect effect of plant height, no. of leaves per plant, stem per hill, chlorophyll percentage, no. of eyes per tuber, dry matter, total soluble sugar percentage, diameter per stem, chlorophyll percentage and weight of individual potato weight (Table 6).

4.4.8 Weight of potato per hill (g):

Weight of potato per hill employed positive direct effect (0.388) on yield as well as positive indirect effect via leaf area index, no. of potato per hill, no. of eyes per tuber and specific gravity. It also employed negative indirect effect of plant height, no. of leaves per plant, stem per hill, chlorophyll percentage, dry matter, total soluble sugar percentage, diameter per stem, chlorophyll percentage, weight of individual potato weight, dry matter, total soluble sugar percentage and firmness (Table 6).

4.4.9 Weight of individual potato (g):

Weight of individual potato employed positive direct effect (0.177) on yield as well as positive indirect effect via plant height, no. of leaves per plant, stem per hill, dry matter, total soluble sugar percentage, diameter per stem, chlorophyll percentage, weight of individual potato weight, dry matter, leaf area index and total soluble sugar percentage. It also employed negative indirect effect of firmness, weight of potato per hill and no. of potato per hill (Table 6).

4.4.10 Eyes per tuber (no.):

No. of eyes per tuber employed positive direct effect (0.044) on yield as well as positive indirect effect via no. of leaves per plant, stem per hill, diameter per stem, weight of potato per hill, weight of individual potato weight, dry matter and total soluble sugar percentage. It also employed negative indirect effect of plant height, chlorophyll percentage, leaf area index, no. of potato per hill, specific gravity and firmness (Table 6).

4.4.11 Dry matter:

Dry matter percentage employed negative direct effect (-0.278) on yield as well as negative indirect effect via no. of leaves per plant, stem per hill, diameter per stem, plant height, weight of individual potato weight, no. of eyes per tuber, specific gravity and total soluble sugar percentage. It also employed positive indirect effect of chlorophyll percentage, leaf area index, no. of potato per hill, weight of potato per hill and firmness (Table 6).

4.4.12 Specific gravity:

Specific gravity employed negative direct effect (-0.156) on yield as well as negative indirect effect via diameter per stem, leaf area index, no. of potato per hill, weight of potato per hill, weight of individual potato weight, dry matter and total soluble sugar percentage. It also employed positive indirect effect of no. of leaves per plant, stem per hill, plant height, chlorophyll percentage, no. of eyes per tuber and firmness (Table 6).

4.4.13 Total soluble sugar (%):

Total soluble sugar percentage employed negative direct effect (-0.021) on yield as well as negative indirect effect via no. of leaves per plant, stem per hill, diameter per stem, weight of individual potato weight, dry matter, plant height, no. of eyes per tuber and specific gravity. It also employed positive indirect effect of chlorophyll percentage, no. of potato per hill, weight of potato per hill and firmness (Table 6).

4.4.14 Firmness:

Firmness employed negative direct effect (-0.767) on yield as well as negative indirect effect via no. of potato per hill. It also employed positive indirect effect of total soluble sugar percentage, no. of leaves per plant, stem per hill, diameter per stem, weight of individual potato weight, dry matter, plant height, no. of eyes per tuber, specific gravity, chlorophyll percentage, no. of potato per hill, weight of potato per hill and firmness (Table 6).

4.5 Genetic Diversity

4.5.1 Principal component analysis

The principal components analysis yielded eigen values of each principal component axes of coordination of genotypes in which the first axes totally accounting for the variation among the genotypes, whereas four of these eigen values above unity accounted for 70.761%**.** The first three principal axes accounted for 61.457 % of the total variation among the 15 characters describing in 21 potato genotypes (Table **7**). Based on principal component axis 1 and 2 (Table 8) a two dimensional scatter diagram of the genotypes were presented in Figure 3. The scatter diagram (Figure 3) represented that apparently there were mainly five clusters and the genotypes were distantly located from each other.

4.5.2 Construction of scatter diagram

Based on the values of principal component scores 1 and 2 obtained from the principal component analysis (Table 8) a two dimensional scatter diagram was constructed, using component score 1 as X-axis and component score 2 as Y-axis, which was presented in Figure 3. The positions of the genotypes in the scatter diagram were random, which indicated the considerable diversity among the genotypes included in the cluster. Some distantly located genotypes of different clusters were the genotypes number G_{10}, G_8, G_4, G_6, G_{21}, G_{21} and G_1

Table 7: Eigen value, % variation and cumulative (%) total variation of the principal components

Principal component axis	Eigen value	% Variation	Cumulative (%) total variation
I	5.070	33.803	33.803
II	2.436	16.238	50.041
III	1.712	11.416	61.457
IV	1.396	9.303	70.761
V	1.167	7.782	78.543
VI	0.934	6.224	84.768
VII	0.802	5.349	90.117
VIII	0.475	3.166	93.283
IX	0.276	1.841	95.124
X	0.267	1.780	96.904
XI	0.249	1.658	98.562
XII	0.097	0.648	99.211
XIII	0.064	0.430	99.640
XIV	0.040	0.264	99.904
XV	0.014	0.096	100.000

Table 8. Mean principal components (PC) scores from analysis of variance (ANOVA) of first two PCs of 21 potato genotypes

Genotypes	PC1	PC2
G_1	-3.8696	0.5123
G_2	-2.8592	-0.1629
G_3	-1.1747	0.6987
G_4	-0.8483	-3.0632
G_5	-1.7228	-0.0097
G_6	-3.3565	-1.8683
G_7	0.3350	0.7041
G_8	2.1202	-2.6749
G_9	4.1008	1.5005
G_{10}	3.0805	-3.1986
G_{11}	0.5080	2.6008
G_{12}	1.6755	1.6145
G_{13}	0.5567	0.2266
G_{14}	1.1601	1.4914
G_{15}	0.9913	-0.0947
G_{16}	1.0026	0.9060
G_{17}	2.1514	-1.1071
G_{18}	-2.0474	0.9170
G_{19}	1.2277	0.4921
G_{20}	0.6502	0.3329
G_{21}	-3.6815	0.1825

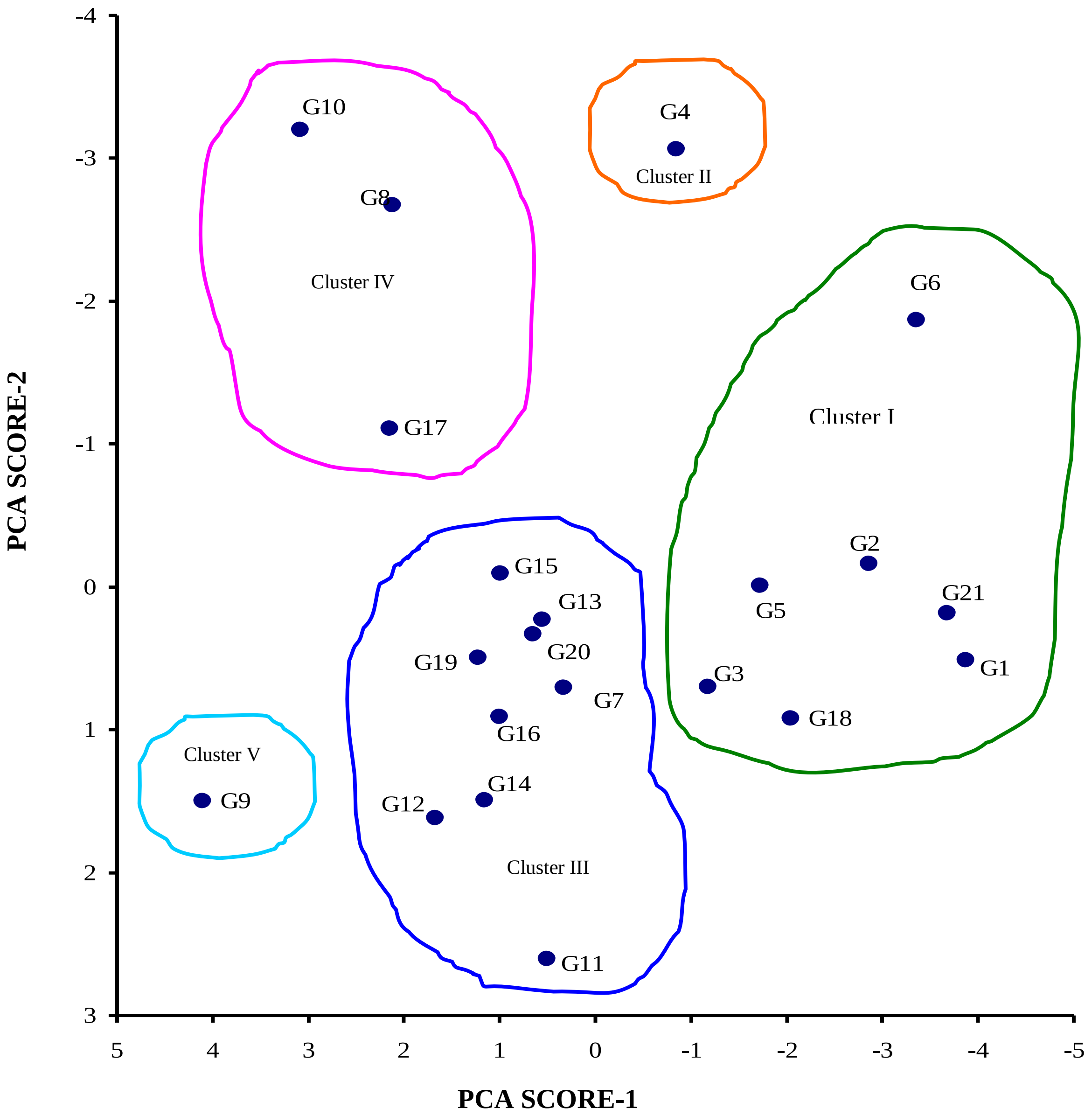

Figure 3 . Scatter diagram of 21 potato varieties of based on their principal component scores

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4.5.3 Non-hierarchical clustering

By using these inter-genotypic distances intra-cluster genotypic distances were calculated (Table 9) as suggested by Singh and Chowdhary (1985). On the basis of D^2 values, the 21 genotypes were grouped into five highly divergent clusters (Table 10).The clusters divergence was proved by the high inter- cluster and low intra clusters D^2 values. Cluster III was the largest and consisted of nine genotypes followed by cluster I with seven genotypes, clusters IV, II and V had 3, 1 and 1 genotypes respectively. The grouping pattern did not show any relationship between genetic divergence and geographical diversity which has been a point of debate in the past. A perusal of the Table 9 clearly showed the genotypes usually did not cluster according to geographical distributions. One of the possible reasons may be the fact that it is very difficult to establish the actual location of origin of a genotype. The free and frequent exchange of genetic material among the crop improvement programmes in the country makes it difficult to maintain the real identify of the genotypes. Moreover, breeding progenies incorporate genes from varied sources, thus losing the basic geographical identity of the genotype. The absence of relationship between genetic diversity and geographical distance indicates that forces others than geographical origin, such as exchange of genetic stocks, genetic drift, spontaneous variation, natural and artificial selection are responsible for genetic diversity, It may also be possible that causes for clustering pattern were much influenced by environment and (genotype x environment) interaction resulting in differential gene expression. Another possibility may be that estimates might not have been sufficient to account for the variability caused some other traits of physiological or biochemical nature which might have important in depicting the total genetic diversity in the population.

The cluster mean of 21 genotypes (Table 11) showed that the mean value of clusters varied in magnitude for all the fifteen characters. Genotypes in cluster I showed maximum performance for number of leaves per plant (10.63), stem per hill (3.16), chlorophyll percentage (49.73), weight of individual potato (111.69 g) and firmness (26.12). Cluster II showed maximum performance for diameter per stem (1.16), leaf area index (8.42) and total soluble sugar (45.45). Cluster III recorded highest mean performance for dry matter (1.15). Cluster IV showed maximum performance for number of potato per hill (61.92), weight of potato per hill (1598.06 gm) and yield (224.66 t/ha). Cluster V showed maximum performance for number of eyes per tuber (27.27) and specific gravity (8.00).

4.5.4 Canonical variate analysis (CVA)

Canonical variate analysis was performed to compute the inter-cluster Mahalanobis's values. Statistical distances represent the index of genetic diversity among the clusters. The divergence within the cluster (intra- cluster distance) indicates the divergence among falling in the same cluster. On the other hand, inter cluster divergence suggest the distance (divergence) between the genotypes of different clusters. The intra and inter clusters D^2 values among 21 genotypes presented in Table 9 revealed that cluster II and V showed minimum intra cluster D^2 value (0.00) distance followed by cluster III (14.03), whereas, maximum intra cluster D^2 value (19.04) was shown by cluster IV followed by cluster I (18.70) indicated that genotypes included in this cluster are very diverse and was due to both natural and artificial selection forces among the genotypes. Minimum inter cluster D^2 value was observed between the clusters IV and V (21.44) indicated close relationship among the genotypes included in these clusters. Maximum inter – clusters D^2 value was observed between the clusters I and V (57.13) indicated that the genotypes belongings to these groups were genetically most divergent and the genotypes included in these clusters can be used as a parent in hybridization programme to get higher heterotic hybrids from the segregant population (Mehta and Asati, 2008). Several authors also reported profound diversity in the germplasm of rice by assessing genetic divergence on the basis of quantitative traits following Mahalanobis D^2 statistics (Ovung *et al*. 2012, Thomas and Lal, 2012 and Chakrovorty *et al*. 2013). Average inter and intra-cluster distance revealed that, in general inter- cluster distance were much higher than those of intra- cluster distances, suggesting homogenous and heterogeneous nature of the germplasm lines within and between the clusters, respectively. These results are in accordance with the findings of Ovung *et al*. (2012).

Results obtained from different multivariate techniques from which it may be concluded that all the techniques gave more or less similar results and one technique supplemented and confirmed the results of another one.

The clustering pattern of the genotypes revealed that varieties/lines originating from the same places did not form a single cluster because of direct selection pressure. This indicated that geographic diversity was not related to genetic diversity that might be due to continuous exchange of genetic materials among the countries of the world. Same results have been reported by Murty and Arunachalam (1966); Anand and Rawat (1984) in brown mustard; Patel *et al*. (1989) in sunflower; Verma (1970) in groundnut and soybean. It had been observed that geographic diversity was not always related to genetic diversity and therefore, it was not adequate as an index of genetic diversity. Murty and Arunchalam (1966) studied that genetic drift and selection in different environment could cause greater diversity than geographic distance. Furthermore, there was a free exchange of seed material among different region, as a consequence, the characters constellation that might be associated with particular region in nature, lose their individually under human interference, and however, in some cases effect of geographic origin influenced clustering that was why geographic distribution was not the sole criterion of genetic diversity.

The free clustering of the genotypes suggested dependence upon the directional selection pressure applied for realizing maximum yield in different regions; the nicely evolved homeostatic devices would favour constancy of the associated characters would thus indiscriminate clustering. This would be suggested that it was not necessary to choose diverse parents for diverse geographic regions for hybridization.

Table 9 : Intra and inter cluster distance (D^2) for 21 genotypes

Characters	I	II	III	IV	V
I	**18.70**	32.89	35.65	56.82	57.13
II		**0.00**	31.17	42.69	46.43
III			**14.03**	32.83	27.99
IV				**19.04**	21.44
V					**0.00**

Table 10 : Number, percent and name of genotypes in different cluster

Cluster number	Number of genotypes	Percent (%)	Genotypes
I	7	33.33	G_1, G_2, G_3, G_5, G_6, G_{18} and G_{21}
II	1	4.76	G_4
III	9	42.86	G_7, G_{11}, G_{12}, G_{13}, G_{14}, G_{15}, G_{16}, G_{19} and G_{20}
IV	3	14.29	G_8, G_{10} and G_{17}
V	1	4.76	G_9

Table 11 : Cluster mean for twelve yield and yield characters of 21 potato genotypes

Characters	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Plant height (cm)	61.14	66.55	69.86	73.63	66.55
Leaves per plant (no.)	10.63	9.11	10.08	9.37	7.78
Stem per hill (no.)	3.16	1.22	2.25	2.66	1.55
Diameter per stem (cm)	1.14	1.16	0.91	0.96	0.86
Chlorophyll (%) at 60 DAP	49.73	45.91	49.40	47.65	45.24
Leaf area index	2.22	8.42	2.44	4.38	2.41
Potato per hill (no.)	6.85	6.44	21.06	61.92	24.11
Weight of potato per hill (gm)	758.25	691.11	956.38	1598.06	238.25
Weight of individual Potato (gm)	111.69	107.26	47.24	25.83	9.88
Eyes per tuber (no.)	23.39	25.57	25.09	24.79	27.27
Dry matter %	1.09	1.02	1.15	0.96	0.99
Specific gravity	6.51	6.00	7.41	6.93	8.00
Total soluble sugar (%)	37.01	45.45	29.24	32.42	15.28
Firmness (N)	26.12	21.87	16.05	18.98	4.23
Potato yield (ton / ha)	31.79	149.00	91.40	224.66	220.11

4.5.5 Comparison of different multivariate techniques

The clustering pattern of D^2 analysis through non-hierarchical clustering had taken care of simultaneous variation in all the characters under study. The D^2 and principal component analysis was found to be alternative methods in giving the information regarding the clustering pattern of genotypes. However, the principal component analysis provided the information regarding the contribution of characters towards divergence of potato.

4.5.6 Selection of parents for future hybridization

Genotypically distant parents were able to produce higher heterosis (Falconer, 1960; Moll *et al.*, 1962; Ramanujam *et al*., 1974; Chauhan and Singh, 1982; Arunachalam *et al.*, 1981; Ghaderi *et al*., 1984; Mian and Bhal, 1989). Beside this, Arunachalam *et al.* (1981) reported in groundnut that the higher heterosis for yield and its components could be obtained from the crosses between the intermediate divergent parents than extreme ones. Mian and Bahl (1989) also reported the same in chick pea that medium divergent genotypes showed higher heterosis in crosses for different yield contributing characters. Srivastava and Arunachalam (1977) reported in triticale that very high or very low parental divergent failed result in heterosis.

Considering this idea and other characteristic performances, G_8 (Shada pakri) and G_{17} (Shil bilati) from cluster IV; G_4 (BARI-TPS-1) from cluster II; and G_6 (Asterix), G_{21} (Granola) , G_1 (Cardinal) and G_2 (Diamant) from cluster I might be considered better parents for efficient hybridization programme.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the research farm of Sher-e-Bangla Agricultural University. Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh during the period from November 2014 to March 2015.The experiment is carried out in randomized complete block design with three replications.

All the genotypes varied significantly with each other for all the studied characters indicated the presence of considerably variations among the genotypes studied. The PCV values were higher than the respective GCV values for all the characters under study. Number of leaves per plant, stem per hill, leaf area index, number of potato per hill, weight of potato per hill, weight of individual potato and potato yield showed high heritability along with high genetic advance as percentage of mean were normally more helpful in predicting the genetic gain under selection. Plant height was significantly negatively correlated with diameter per stem and yield. So we can say that diameter of the stem and potato yield is reduced with the increasing of plant height. Number of leaves per plant was significantly negatively correlated with yield. So yield is reduced with the increasing number of leaves. Stem per hill was significantly positively correlated with potato yield. So yield is increased with increasing number of stem per hill potato. Diameter per stem was significantly negatively correlated with number of potato and sugar content whereas it was positively correlated with weight, firmness and yield of potato. So number of potato and sugar content decreased but yield is increased with the increasing of diameter per stem. Number of potato per hill was significantly negatively correlated with weight of individual potato whereas it was significantly positively correlated with weight of potato per hill. So with the increasing number of potato per hill weight of individual potato is decreased but weight of potato per hill is increased. Firmness was significantly positively correlated with yield. So yield is increased with the increase of firmness. Weight of individual potato was significantly positively correlated with yield. So yield is increased with the increase of weight of individual potato. Dry matter content was significantly positively correlated with sugar content. So with the increase of dry matter content sugar content is increased. Soluble sugar was significantly negatively correlated with yield. So with the increase of soluble sugar yield is decreased. From the correlation and path analysis it was revealed that diameter per stem showed significantly positive genotypic correlation with yield as well as employed positive direct effect on yield suggesting that the selection for these traits would helpful for the improvement of yield per plant.

On the basis of D^2 values, the 21 genotypes were grouped into five highly divergent clusters. The clusters divergence was proved by the high inter- cluster and low intra clusters D^2 values. Cluster III was the largest and consisted of nine genotypes followed by cluster I with seven genotypes. The grouping pattern did not show any relationship between genetic divergence and geographical diversity. The cluster mean of 21 genotypes showed that the mean value of clusters varied in magnitude for all the fifteen characters. Genotypes in cluster I showed maximum performance for number of leaves per plant chlorophyll percentage (49.73), weight of individual potato (111.69) and firmness (26.12). Cluster II showed maximum performance for total soluble sugar (45.45). Cluster III recorded highest mean performance for dry matter (1.15). Cluster IV showed maximum performance for number of potato per hill (61.92 no.), weight of potato per hill (1598.06) and yield (224.66). Cluster V showed maximum performance for specific gravity (8.00).

Maximum intra cluster D^2 value (19.04) was shown by cluster I followed by cluster IV (18.70) indicated that genotypes included in this cluster are very diverse and was due to both natural and artificial selection forces among the genotypes. Maximum inter – clusters D^2 value was observed between the clusters I and V (57.13) indicated that the genotypes belongings to these groups were genetically most divergent and the genotypes included in these clusters can be used as a parent in hybridization programme to get higher heterotic hybrids from the segregant population. Considering this idea and other characteristic performances, G_8 (Shada pakri) and G_{17} (Shil bilati) from cluster IV; G_4 (BARI-TPS-1) from cluster II; and G_6 (Asterix), G_{21} (Granola) , G_1 (Cardinal) and G_2 (Diamant) from cluster I might be considered better parents for efficient hybridization programme.

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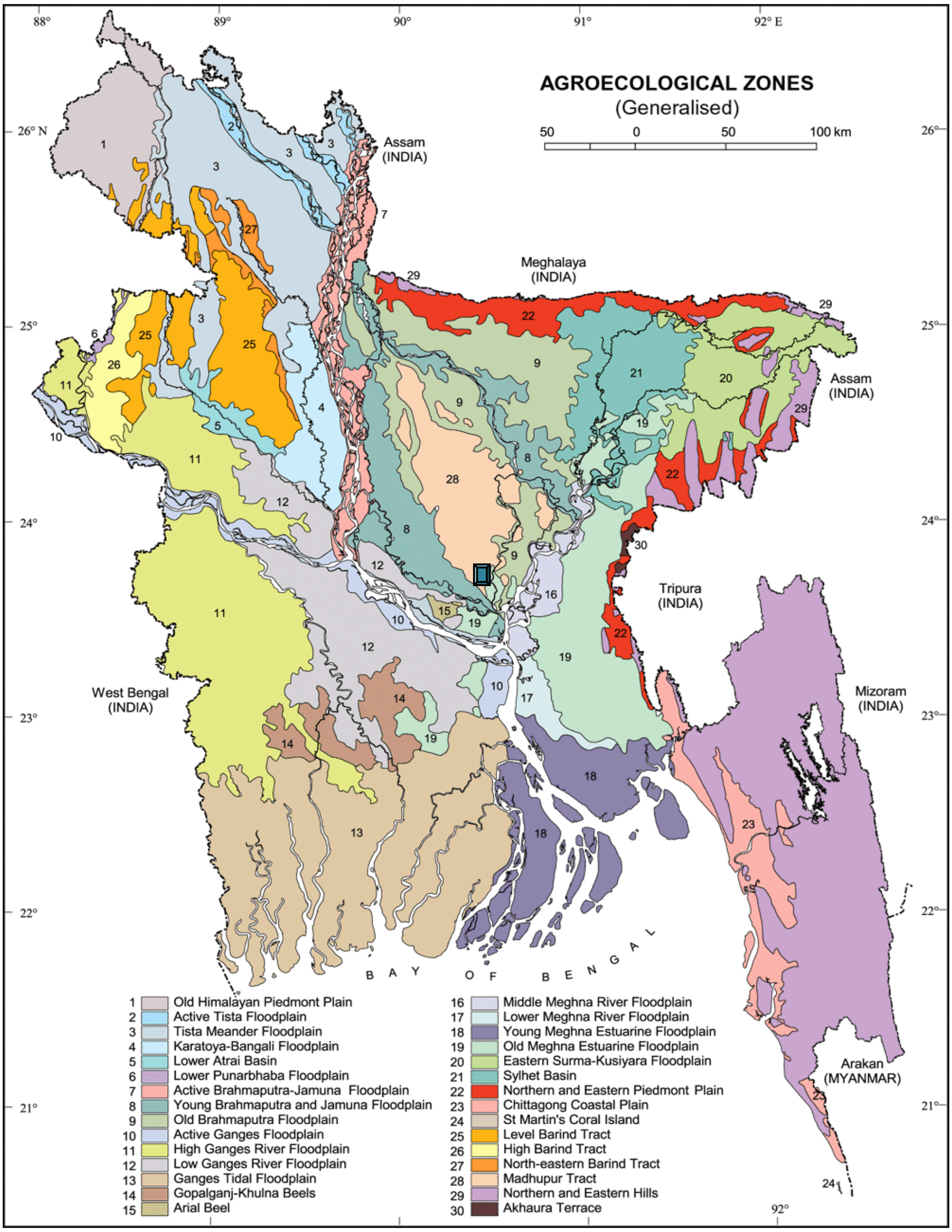
APPENDICES

Appendix I. Map showing the experimental site under the study



The experimental site under study

Appendix II. Monthly records of air temperature, relative humidity, rainfall and sunshine hours during the period from October 2014 to March 2015.

Month	Year	Monthly average air temperature (^{o} C)			Average RH (%)	Total rainfall (mm)	Total sunshine (hours)
		Max.	Min.	Mean			
Oct.	2014	29.36	18.54	23.95	74.80	0.0	218.50
Nov.	2014	28.52	16.30	22.41	68.92	0.0	216.50
Dec.	2014	27.19	14.91	21.05	70.05	0.0	212.50
Jan.	2015	25.23	18.20	21.80	74.90	4.0	195.00
Feb.	2015	31.35	19.40	25.33	68.78	3.0	225.50
Mar.	2015	32.22	21.25	26.73	72.92	4.0	235.50

Source: Bangladesh Meteorological Department (Climate division), Agargaon Dhaka-1212.

Appendix III. The mechanical and chemical characteristics of soil of the experimental site as observed prior to experimentation (0 - 15 cm depth).

Mechanical composition:

Particle size	constitution
Sand	40%
Silt	40%
Clay	20%
Texture	Loamy

Chemical composition:

Soil characters	Value
Organic matter	1.44 %
Potassium	0.15 meq/100 g soil
Calcium	3.60 meq/100 g soil
Magnesium	1.00 meq/100 g soil
Total nitrogen	0.072
Phosphorus	22.08 µg/g soil
Sulphur	25.98 µg/g soil
Boron	0.48 µg/g soil
Copper	3.54 µg/g soil
Iron	262.6 µg/g soil
Manganese	164 µg/g soil
Zinc	3.32 µg/g soil

Source: Soil Resources Development Institute (SRDI), Khamarbari, Dhaka

Appendix IV a. Analysis of variances of eight yield and yield related characters of potato

Source of variation	d.f	Mean sum of square							
		Plant height (cm)	Leaves per plant (No.)	Stem per hill (no.)	Diameter per stem (cm)	Chlorophyll (%) at 60 DAP	Leaf Area Index	Potato per hill (no.)	Weight of potato per hill (g)
Replication	2	51.23	352.05	0.037	0.070	58.848	0.108	7.69	20282.68
Genotypes	20	248.80**	15418.36**	2.001**	0.048**	20.165**	8.478**	1038.58**	626634.39**
Error	40	50.77	100.57	0.089	0.006	7.264	0.106	5.66	11768.61

** Significant at 1%

d.f = Degrees of freedom

Appendix IV b. Analysis of variances of seven yield and yield related characters of potato.

Source of variation	d.f	Mean sum of square						
		Weight of Individual Potato (gm)	Eyes per tuber (No.)	Dry matter %	Specific gravity	Total soluble sugar (%)	Firmness (N)	Potato yield (ton / ha)
Replication	2	1.19	4.860	2.333	0.010	0.369	2.338	22.17
Genotypes	20	4884.24**	6.964**	20.266**	0.063**	2.155**	184.000**	144.08**
Error	40	7.59	1.734	1.383	0.013	0.257	8.766	4.99

** Significant at 1%

d.f = Degrees of freedom