Estimation of Genetic Variability among Potato (Solanum tuberosum) genotypes For Drought prone areas Of North Wollo Gazo District, Eastern Amhara Region

Tadesse Wudu, Amhara Agricultural Research Institute, Sirinka Agricultural Research Center, Woldia, Ethiopia

Yohannes Gedamu, Ethiopian Institute of Biotechnology,
Adis Ababa, Ethiopia

A B S T R A C T

This study evaluates the genetic diversity of 49 drought-resistant potato genotypes at the Sirinka Agricultural Research Center during the 2023–2024 rainy seasons, with five varieties serving as standard checks. The research aimed to identify genotypes associated to phenotypic traits that enhance yield potential. The findings reveal high heritability for total starch content (80%) and significant genetic advancement, indicating strong improvement potential. Additionally, traits such as maturity and flowering timing also exhibited high heritability, suggesting opportunities for optimizing growth period. Conversely, while specific gravity displayed low genetic variability, it maintained 100% heritability, reflecting resilience to environmental variations. These results underscore the importance of integrating genetic and environmental considerations in breeding strategies, particularly for traits sensitive to environmental changes, thereby enhancing the development of superior potato genotypes.

KEYWORDS: Potato genotypes, Genetic variability, Heritability

Introduction

As a staple food and a major source of carbohydrates, the potato (Solanum tuberosum) is an important crop in many countries. Breeding initiatives aiming at enhancing production, disease resistance, and environmental adaptability must take into account the genetic heterogeneity within potato genotypes. To evaluate the potential for selection and improvement in potato breeding, key genetic indices such heritability, genetic advance, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and genetic advance as a percentage of the mean are essential. The term "genetic variability" describes the variation in genetic characteristics among members of a community. The percentage of phenotypic variance attributable to genetic variance is measured by heritability, especially broad-sense heritability.
A trait with a high heritability value is one that is well suited for selection in breeding programs since it is primarily determined by genetic factors. According to recent research, a number of potato features have high heritability estimates, indicating that selective breeding may be an efficient way to enhance these qualities (Gebrehanna et al., 2022). Both the genotypic and phenotypic coefficients of variation (PCV and GCV) are crucial indicators for determining how variable a trait is. In contrast to GCV, which takes into consideration the genetic component of variability, PCV represents the overall variability seen in a variable. A high GCV in relation to PCV suggests that genetic factors dominate a trait, which is advantageous for selection. Recent studies have demonstrated that characteristics with substantial GCV include tuber production and size (Tiwari et al., 2022). A relative measure of this improvement is provided by genetic advance as a percentage of the mean, whereas genetic advance itself is the expected improvement in a trait as a result of selection. Significant gains can be made through selection, according to high genetic advance values. Research has shown that qualities with substantial genetic progress and heritability also typically have high GCV, indicating that these traits are viable breeding program targets (Ali et al., 2022).

Material and methods

Description of the Study Area

During the main growing season of 2023–2024, the experiment was carried out at the Sirinka Agricultural Research Center's Estaysh research site in Northeastern Amhara. Gazo is almost 669 kilometers away from Addis Ababa. Geographically, it is situated at an elevation of 2867 meters above sea level at latitude 11040'N and longitude 38050'0E. Rainfall averages between 934 and 1342 mm per year (National Meteorological Agency Bahir Dar Branch, 2018).

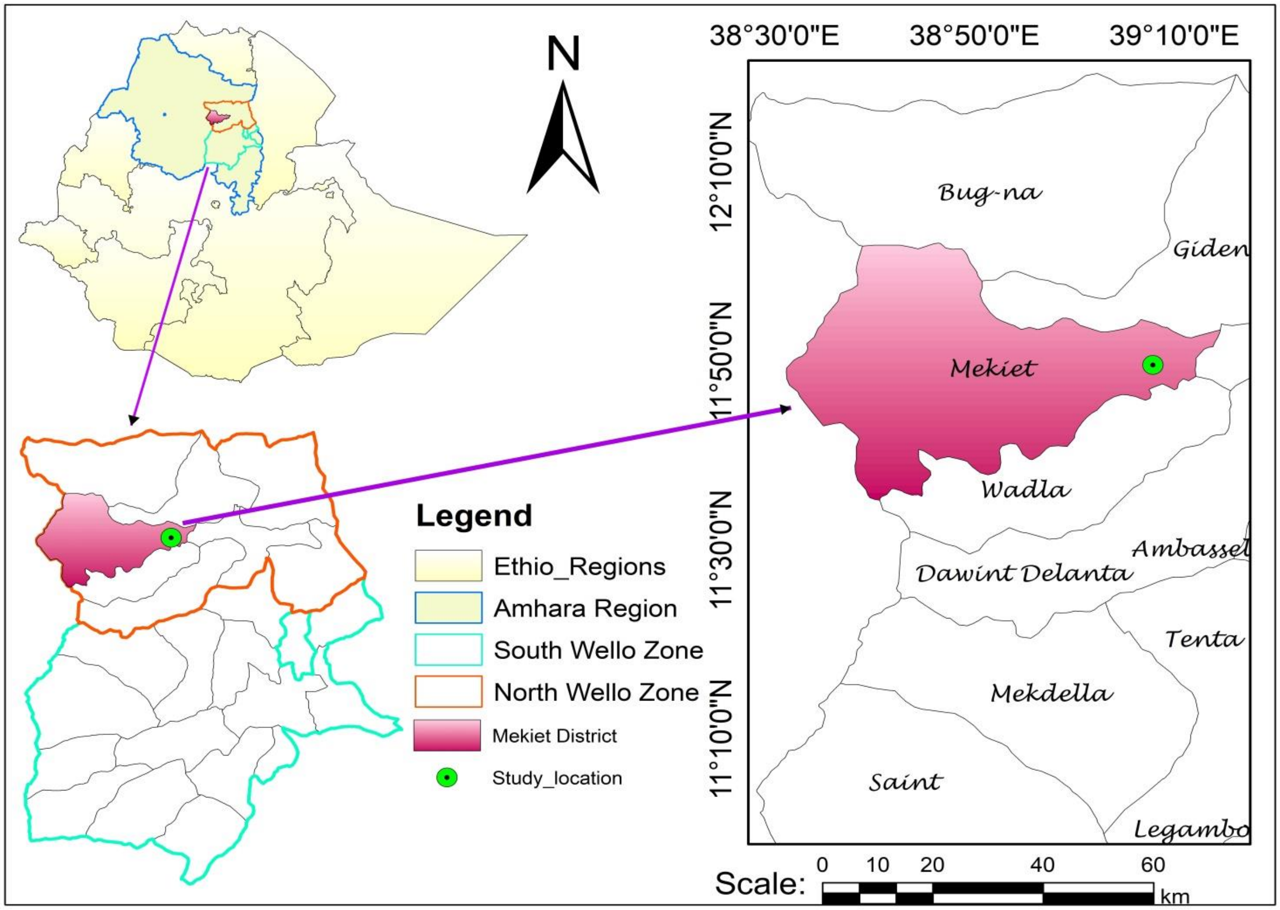

Fig 1 Description of the Study Area

Table 1 Description of testing site

Location	Altitude	Soil description**				
		Texture	PH	OM%	Total N	Available P (ppm)
Gazo	3270	Clay loam	5.3	4.6	0.24	16.5

Source SARC Soil Laboratory Analysis

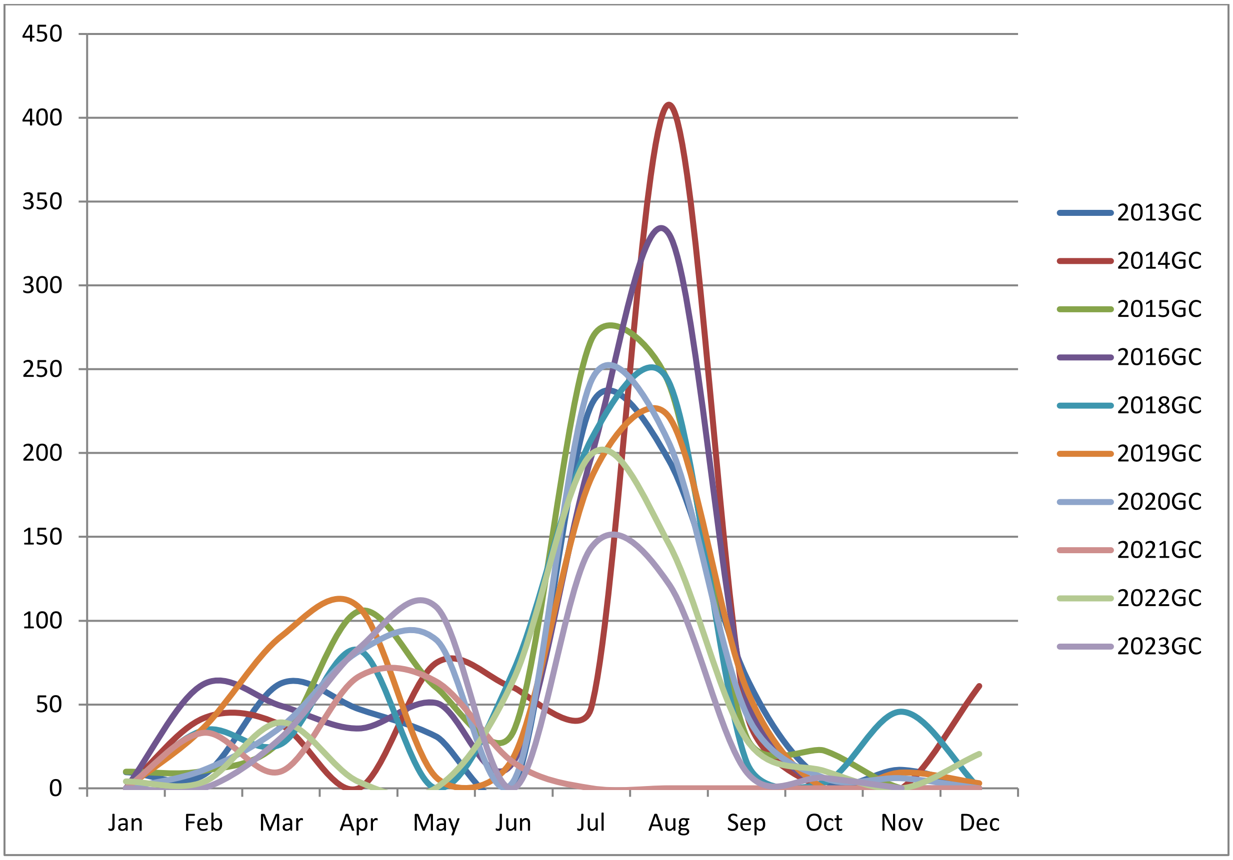

Fig 2 Monthly rainfall from January- December 10 years (2013-2023)
Source: kombolcha metrological station

Treatment and Experimental Design

The International Potato Center (CIP) created 49 distinct potato accessions especially for moisture-stressed (drought-prone) regions, which were used in the experiment. Through the Adet Agricultural Research Center, genotypes were introduced. 43 new genotypes used in the Gazo district, one farmer's cultivar, and five potato kinds that had been released nationwide were all included in the trial. Seed tubers for all genotypes were obtained from the Adet Agricultural Research Center. A list of the genotypes and checks is provided in Table 1. A field trial was conducted using a simple lattice design with seven blocks. Each block contained seven potato genotypes. genotypes were assigned randomly within each block. Each genotypes was planted in a plot size of 4.5 m2 (1.5m x 3m), accommodating 20 plants.

Table 2 : List of potato accessions used in the experiment

No	genotypes Code	No	genotypes Code
1.	bub/AD5020111.58	26.	Aba/AD5020140.57
2.	gud/AD502050.32	27.	aa/AD5020114.27
3.	174/bel/AD5020115.74	28.	122/gud/AD5020114.27
4.	110/gud/AD502050.11	29.	Gera
5.	178/bel/AD5020115.78	30.	Jers/AD5020200.77
6.	109/bub/AD5020111.109	31.	140/aba/AD5020140.93
7.	95/aba/AD5020140.95	32.	Aba/AD5020140.94
8.	Bub/AD5020111.14	33.	Bel/AD5020115.59
9.	101/bub/AD5020111.101	34.	181/gud/AD502050.18
10.	105/bub/AD5020111.105	35.	150/gud/AD502050.15
11.	she/AD502060.51	36.	Gudeni
12.	Bub/AD5020111.31	37.	106/bub/AD5020111.106
13.	163/jers/AD5020200.163	38.	She/AD502060.26
14.	Jers/AD5020200.55	39.	135/shen/AD502060.30
15.	104/aa/AD5020114.113	40.	jers/AD5020200.73
16.	107/aa/AD5020114.107	41.	Burka
17.	Local	42.	jers/AD5020200.24
18.	gud/AD502050.31	43.	bel/AD5020115.59
19.	Bel/Ad5020115.42	44.	117/bub/AD5020111.57
20.	147/gud/AD502050.17	45.	158/aba/AD5020140.108
21.	103/bub/AD5020111.103	46.	119/shen/AD502060.13
22.	148/bub/AD5020111.69	47.	Belete
23.	aba/AD5020140.34	48.	aba/AD5020140.89
24.	jers/AD5020200.79	49.	Shenkola
25.	bub/AD5020211.25		

Standard Checks: Burka, Belete, Shenkola, Gera and Gudeni

Experimental Procedures and Field Management

According to national guidelines, medium-sized, well-sprouted potato tubers measuring 35 to 45 mm in diameter were planted on July 15, 2023, with a 75 cm gap between rows and a 30 cm gap between plants. 108 kg ha-1 of nitrogen and 138 kg NPS of fertilizer were applied. In contrast, the nitrogen fertilizer was applied in two parts: 50% urea (46% N), which included nitrogen from planting, and the remaining 50% was applied 30 days after planting. The complete phosphorus was applied during planting. The proper timing of weeding, cultivation, and earthling-up was used to promote the growth of roots, stolons, and tubers. The plants were de-haulled to harden the tuber skin two weeks prior to harvest, when the crop attained maturity (shown by yellowed stems and senescent leaves).

Data Collection

All of the plants in a row were examined for phonological criteria, such as days to emergence, flowering, and maturity. Other yield and yield components were assessed from the net plot, and the average number of stems per plant/hill was calculated from five randomly selected plants in the middle. The following describes the measurement methods and parameters.

Yield and yield related parameters

Days to flowering (DF): The time it takes for 50% of the plants in each plot to flower after planting will be noted.

Days to maturity (DM): The amount of time that passes between planting and the point at which 90% of the plants in a plot reach physiological maturity.

Stem number per plant/hill: This is done by counting the total number of stems that arise from the ground from at least eight plants in the central two rows and averaged in each plot to get the mean number of stems per hill for each genotype. The actual number of stems per hill will be recorded when 50% of the plants attained flowering stage.

Stand count at harvest (STCH): the number of potato plants counted within a net plot at the harvesting time.

Total tuber number per plot (TTNPP): is a metric used to assess how well different potato varieties perform. It is the total number of tubers produced from the net plot area.

Number of tuber per plant (NTPP): total count of tubers produced by a single plant from net plot.

Average tuber weight(atw): The total weight of harvested tubers from the net plot was divided by the total number of harvested plants, and the resulting average tuber weight was recorded as the tuber yield per plant.

Unmarketable tuber yield (t ha-1): This refers to tubers that had blemishes due to attack by pests, infection by diseases, deformed due to physiological disorder and that weighted less than 20g. It was first determined per plot and then converted to ton ha-1 for each treatment at harvest.

Total tuber yield (t ha-1): The total weight of tubers that was harvested from entire harvestable plot was used to calculate total tuber yield tons ha-1.

Bulking rate (g day-1): Was calculated as total weight of tubers harvested from net plot divided by number of days taken from days to flowering to physiological maturity (CIP, 2014).

Quality parameters

Specific gravity of tubers (Sg): it will be determined using the weight in air/weight in water method. Four kilogram tubers of all shapes and sizes will be randomly taken from each plot. The selected tubers will be washed with water. First it will be weighed in air and then re-weighed suspended in water and the specific gravity determined according to the following formula (Gould, 1995).

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

Dry matter content

The total dry matter content (DMC) will be calculated according to Porras et al, (2014) Five tubers of each treatment will be chopped (about 500 g total) into small 1-2 cm cubes. They will be mixed thoroughly and two sub-samples of 200 g each will be taken. The exact weight of each sub-sample will be recorded as fresh weight. Subsequently, each sub-sample will be stored in an oven at 80°C for 48 hours and dried them until constant weight recorded. Each subsample will be weighed immediately and recorded as dry weight. The dry matter content for each sub-sample will be estimated with the following formula.

$$\text{Dry matter} = \frac{\text{dry weight}}{\text{fresh weight}} * 100$$

Total starch content (g/100 g): Starch content in percent was estimated from specific gravity as established by Talburt and Smith (1959), as cited by Yildrim and Tokuşoğlu (2005) as follows: **Starch content (%)** = 17.546 + 199.07 × (specific gravity-1.0988), Where specific gravity was determined as indicated above by the weight in air and weight in the water method.

Statistical data analysis

The collected data were subjected to analysis of variance (ANOVA) using R Software version 4.0. To compare the mean performance of different genotypes, the Least Significant Difference (LSD) test was employed at both the 5% and 1% significance levels, focusing on the mean squares relevant to genetic studies. In addition, estimated various components of variability, including genotypic and phenotypic variance, coefficients of variation, heritability in broad sense, and genetic progress expressed as a percentage of the mean. The methodologies outlined by Burton and de Vane (1953) were utilized to calculate the phenotypic and genotypic variation. Furthermore, the significance of the phenotypic correlation coefficient was assessed using the formula proposed by Sharma (1998), while the genotypic correlation coefficient was evaluated according to the approach suggested by Robertson (1959). This rigorous statistical framework allows for a nuanced understanding of the genetic attributes under investigation, facilitating informed conclusions about genotype performance and variability within the studied population.

Heritability and genetic advance

Low Heritability characteristics, which have a heritability estimate of less than 20%, are frequently impacted by environmental variables rather than genetic causes. Potato features like tuber form or size may have poor heritability due to considerable environmental interactions. Khan et al. (2020) found that certain morphological features in potatoes might fluctuate greatly depending on environmental conditions, resulting in reduced heritability estimates.

Moderate heritability traits, with estimates ranging from 20 to 50%, are impacted by both genetic and environmental variables while still responding to selection. For example, disease resistance in potatoes may have a modest heritability because both genetic predisposition and environmental circumstances (such as pathogen pressure) play important roles. A study by Bai et al. (2021) discovered that certain disease resistance qualities in potatoes have moderate heritability, implying that while selection can increase these traits, environmental factors must also be considered.Traits with high heritability typically have estimates more than 50%, and they are predominantly governed by genetic factors, with minimal effect from environmental variability. In potatoes, characteristics like as tuber production and specific gravity are frequently heritable, making them ideal targets for selection in breeding efforts. According to Kumar et al. (2019), tuber yield in potato populations was found to be highly heritable, indicating that selective breeding could successfully boost this characteristic across generations.

Result and Discussion

Analysis of variance

Table 3 Analysis of variance for 12 traits at Gazo District in 2023/24 cropping season

Traits	Replication	TRT	MSB	MSE	CV	Mean	P value
DF	5.3	25.05	4.8	2.9	2.3	75.1	0.097*
DM	68.6	43.8	39.3	7.7	2.6	108.1	0.0005 ***
TNP	39.22	560.56	1106.94	1023.7	15.4	208	0.3 NS
NTP	1.6	6.7	34.3	2.7	17.9	9.2	4.7e-08 ***
AH	25.6	2.75	2.20	3.1	19.5	9	0.6 NS
BR	35914	10623	10288	3523	10.3	577.7	0.0179*
DMC	0.9	7.9	3.39	10.3	18.4	17.5	0.3 NS
UY	0.13	0.031	0.038	0.034	51.38	0.4	NS
MY	15.28	6.6	24.6	6.43	12.1	20.8	0.004**
TY	18.7	6.7	24.06	6.3	11.8	21.3	0.004**
SG	0.0023	0.00066	0.00033	0.00081	2.8	1.02	0.8 NS

TSC	103.7	29.27	14.11	36.24	156.2	3.8	0.8 NS

Mean, MSE=Mean square Error, MSB=mean square Block, TRT=Treatment Mean square, REP=replication mean square, Cv=coefficient of variation Signif codes: 0 '***', 0.001 '**' ,0.01 '*' ,0.05 , 0.1 , DF = days to 50% of plants flowering, DM = days to 90% maturity, AH = tuber number per hill, TTNP = Total tuber number per plot, NTPP = Number of tubers per plant, TYP = tuber yield per plant (kg), MY = marketable tuber yield (ton ha^{-1}), UY = unmarketable tuber yield (ton ha^{-1}), TY = Total tuber yield (ton ha^{-1}), BRP = bulking rate per plot (gm/day), DMC = tuber dry matter content(%), SG = specific gravity of tuber, TSC = total starch content (gm/100gm).

Genotypic and phenotypic Correlation Genotypic and Phenotypic Correlation of total tuber yield with other characters

The genotypic correlations found among numerous variables in potato accessions provide important insights into the intricate linkages that underpin potato breeding and agronomy. The significant positive correlation between date of blooming and date of maturity (+0.7) shows that early flowering genotypes tend to mature earlier, which corresponds with findings from prior studies suggesting that phonological features frequently exhibit strong relationships. According to Kumar et al. (2020), this link is critical for breeding efforts that seek to generate varieties that can adapt to various growth seasons and climates.

Table 4 Phenotypic below and genotypic above diagonal Correlation coefficients for 11 yield and yield component traits of 49 potato genotypes evaluated at Gazo 2023/24 GC

Traits	DF	DM	TNP	NTP	BR	DMC	UY	MY	TY	SG	TSC
DF		0.7**	-0.05	-0.31*	-0.4*	-0.11	-0.19	-0.52**	-0.53**	-0.15	-0.22
DM	0.58		-0.1	-0.4*	-.82**	-0.15	-0.027	-0.48	-0.48	-0.56	-0.21
TNP	-0.049	-0.088		-0.06	0.22*	-0.1	0.0069	0.3*	0.3*	0.29	0.04

NTP	-0.24*	-0.311*	-0.035		0.32*	-0.25*	0.06	0.21*	0.21*	0.14*	0.23*
BR	-0.29*	-0.72**	0.23*	0.32**		0.13*	-0.045	0.55**	0.55**	-0.014	0.22*
DMC	-0.10	-0.124	-0.10	-0.22	0.13		-0.09	0.09	0.09	0.03	0.08
UY	-0.11	-0.074	0.027	0.03	0.020	-0.006		0.44	0.07	0.17	0.14
MY	-0.40**	-0.304*	0.28*	0.24*	0.50**	0.12	-0.003		0.09**	0.079	0.21*
TY	-0.41**	-0.306*	0.28*	0.24*	0.5**	0.12	0.027	0.99**		0.08	0.22*
SG	-0.06*	-0.06	0.038	0.11	0.058	0.0067	0.14	0.10	0.10		0.8**
TSC	-0.21*	-0.202*	0.035	0.2*	0.19	0.079	0.10	0.18*	0.18*	0.62**	

Where: DF (date of flowering), DM(days to maturity),DMC(dry matter percentage), BR(bulking rate gram per days), NTP(number of tuber per plant),TNP (total tuber number per plot),MY (marketable yield ton per hectare), UY (un marketable yield ton per hectare), TY (total yield ton per hectare), SG (specific gravity) and TSC (total starch content).

In contrast, the negative correlations found between flowering date and features such as number of tubers per plant (-0.3), bulking rate (-0.4), and marketable yield (-0.52) suggest a potential trade-off between earliness and tuber production. This discovery is consistent with Kloosterman et al. (2021) observation that early-maturing potato cultivars may allocate resources differently, perhaps resulting in reduced tuber counts and yield. These trade-offs emphasize the significance of selecting for numerous qualities concurrently in breeding operations.

The negative correlation between date of maturity and the number of tubers per plot (-0.4) and bulking rate (-0.8) supports the idea that late-maturing varieties may produce more tubers and grow faster, as previously suggested by Haverkort et al. (2016). This relationship emphasizes the importance of careful selection strategies that balance maturity timing with productivity. Interestingly, the positive correlation between bulking rate and yield (+0.53) indicates that faster bulking rates contribute positively to overall yield, which is supported by Zhang et al. (2022), emphasizing the importance of bulking rate as a critical trait for improving yield in potato breeding programs.

Moreover, the positive correlations between yield and starch content (+ 0.21), as well as between bulking rate and dry matter (+ 0.3), emphasize the importance of these traits in determining the quality and marketability of potato varieties. These findings align with research by Wang et al. (2023) demonstrated that higher starch content is often associated with improved tuber quality, making it a desirable trait for both breeders and consumers.(table 4)

The negative correlation of date of flowering with traits such as the number of tubers per plot (-0.24), bulking rate (-0.29), yield (-0.4), and starch content (-0.21) suggests a potential trade-off between early flowering and tuber production. This finding aligns with previous studies that have indicated that early-maturing varieties may allocate resources in a manner that limits tuber development (Kumar et al., 2021).

The significant negative correlation between days to maturity and the number of tubers per plot (-0.3) and bulking rate (-0.7) further supports the hypothesis that late-maturing varieties may be more productive in terms of tuber quantity and growth rate. This is consistent with findings by Haverkort et al. (2016) observed that late-maturing potato varieties often produce higher yields due to extended growing periods that allow for greater biomass accumulation. The negative correlation between days to maturity and starch content (-0.2) also indicates that late-maturing varieties may have higher quality tubers, a trend noted in other research emphasizing the importance of maturity timing on tuber composition (Wang et al., 2023). Interestingly, the positive correlation between total tuber number per plant and bulking rate (+0.23) and yield (+0.28) suggests that as the number of tubers increases, so does the rate at which they bulk, leading to improved overall yield. This is corroborated by Zhang et al. (2022) highlighted the significance of tuber number as a critical determinant of yield in potato breeding programs.The positive correlations between total starch content and both the number of tubers per plant (+0.2) and bulking rate (+0.32) suggest that higher starch content is associated with increased tuber production, which is vital for market acceptance and processing quality. This relationship aligns with findings by Kloosterman et al. (2021) reported that higher starch levels are often found in varieties that exhibit robust growth characteristics. Moreover, the strong positive correlation between bulking rate and yield (+0.5) reinforces the idea that faster bulking rates are essential for maximizing yield potential, which has been supported by multiple studies emphasizing the importance of this trait in potato production systems (Haverkort et al., 2016; Kumar et al., 2021).

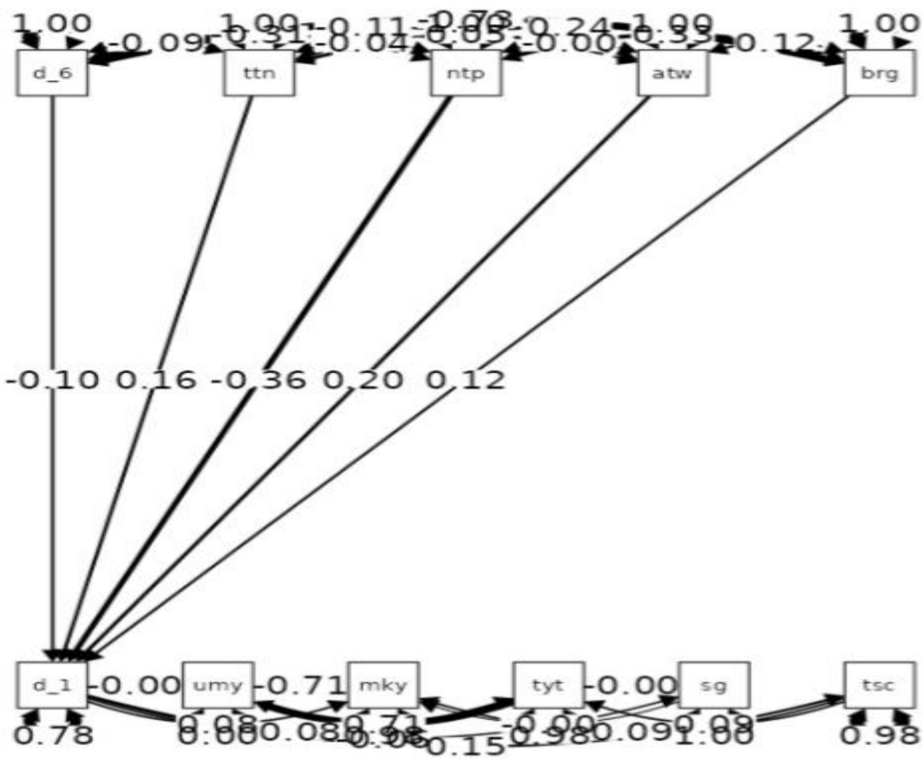

Fig 3 Path coefficient analyses

Where d_6 (days to maturity),D_1 (dry matter percentage), atw (average tuber weight) ,brgd(bulking rate gram per days), ntp(number of tuber per plant),tnn (total tuber number per plot),mky (marketable yield ton per hectare), umy (un marketable yield ton per hectare), tyt (total yield ton per hectare), sg(specific gravity) and tsc (total starch content).

Days to Maturity direct Effects on Yield and Quality: Recent studies have shown that longer growing periods can enhance tuber bulking, leading to increased yield but may also heighten susceptibility to diseases (Kumar et al., 2020). This supports the negative direct effect of days to maturity on marketable yield observed in this finding. Early and Late Maturing Varieties:

Research indicates that early-maturing varieties often yield less than late-maturing ones due to a shorter bulking period Sarkar et al. (2021) aligning with the positive direct effect of days to maturity on total yield and days to maturity Indirect Effects on Unmarketable Yield the weak positive relationship between days to maturity and unmarketable yield suggests that prolonged growth may lead to more unmarketable tubers, possibly due to environmental stressors (Baba et al., 2022).

Total Tuber Number per Plot direct Effects with total Yield and A positive correlation between total tuber number per plant and total yield has been confirmed, indicating that optimizing tuber number can enhance overall yield by Hussain et al. (2021) this finding supports the positive direct effect of total tuber number on total yield and total Tuber Number per Plot Indirect Effects on Marketable Yield has showed in the figure An increase in tuber number can negatively impact marketable yield if it results in smaller-sized tubers, which are less desirable (Meyer et al., 2023).

Number of Tuber per Plant Direct Effects on Yield displayed on the figure the number of tubers per plant significantly influences yield, with optimal conditions leading to higher production by Patel et al. (2021) and this aligns with the positive direct effect on total yield and Number of Tuber per Plant Indirect Effects on marketable Yield which is agree and Similar to total tuber number, an excess of small tubers can detract from marketable yield (Hussain et al., 2021).

Average Tuber Weight Direct Effects on marketable Yield Recent findings emphasize that average tuber weight is a critical factor for marketable yield, where larger tubers generally command higher market prices by Baba et al. (2022). This finding supports the positive direct effect on marketable yield and Indirect Effects on total Yield: There exists a trade-off between tuber size and number; larger tubers may reduce the overall count, impacting total yield negatively (Meyer et al., 2023).

The path analysis showed that Bulking Rate direct Effects on Yield and The bulking rate is crucial for determining final yield, with faster rates leading to higher outputs under optimal conditions by Kumar et al. (2020) this aligns with the positive direct effect on total yield and has Indirect Effects on Marketable Yield which shows a faster bulking rate can positively affect marketable yield if environmental conditions are favorable (Patel et al., 2021). See figure 3.

Specific Gravity and Starch Content direct Effects Quality and Recent studies have demonstrated a strong correlation between specific gravity and starch content, indicating that higher specific gravity is associated with better quality potatoes suitable for processing by Hussain et al. (2021) this finding supports the positive direct effect on starch content and indirect Effects on Marketable Yield: Higher specific gravity can indirectly enhance marketable yield by improving overall tuber quality (Sarkar et al., 2021).

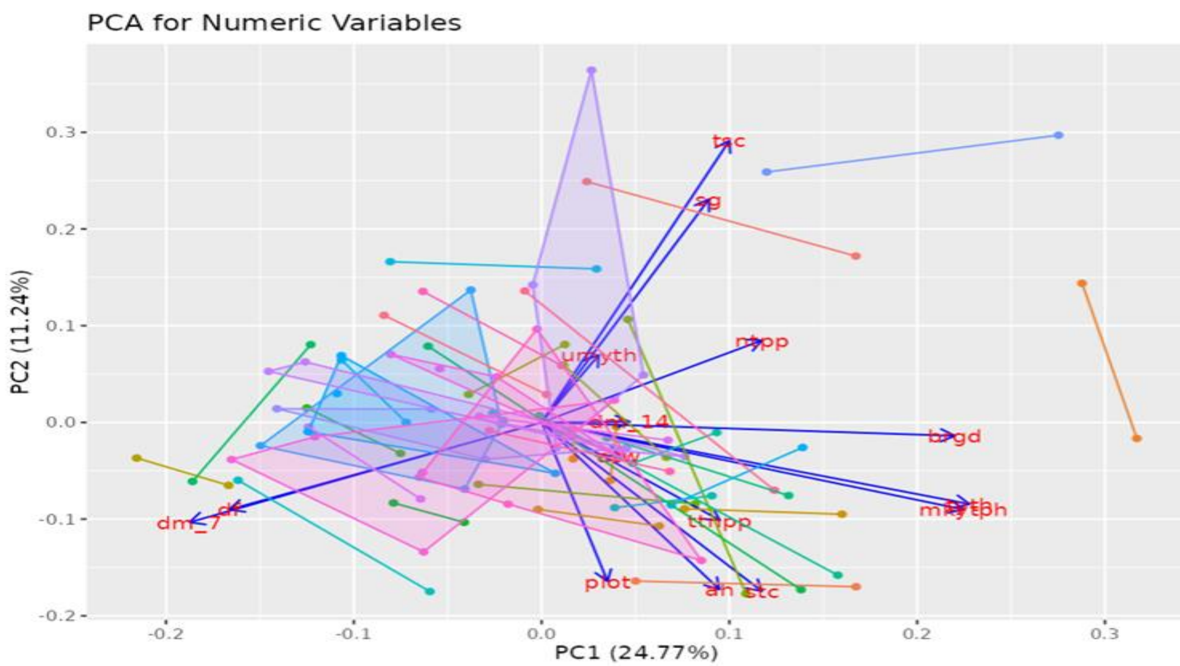

Fig 4. Principal component analysis

DF = days to 50% of plants flowering, DM = days to 90% maturity, AH = tuber number per hill, TTNP = Total tuber number per plot, NTPP = Number of tubers per plant, TYP = tuber yield per plant (kg), MY = marketable tuber yield (ton ha-1), UY = unmarketable tuber yield (ton ha-1), TY = Total tuber yield (ton ha-1), BRP = bulking rate per plot (gm/day), DMC = tuber dry matter content(%), SG = specific gravity of tuber, TSC = total starch content (gm/100gm).

The Principal component analysis indicates a positive correlation between bulking rate and marketable yield. This aligns with previous studies that suggest efficient bulking is critical for maximizing yield potential (Perez et al., 2019). The ability of a genotype to bulk effectively can be attributed to its physiological characteristics and environmental adaptability (Haverkort et al., 2016). However, some researchers argue that focusing solely on bulking rates may overlook other critical factors such as disease resistance and tuber quality by Muller et al. (2020) and this findings agree with this perspective; while bulking is important, it should be considered in conjunction with other traits to ensure overall crop performance and also revealed that higher dry matter percentages are associated with a greater number of tubers per plot. This relationship has been documented in other studies which suggest that genotypes with higher dry matter content tend to produce more tubers by Kumar et al. (2021). However, it is essential to note that high dry matter content does not always equate to high marketable yield, as some genotypes may produce lower-quality tubers by Bachmann et al. (2018) concur with these findings, emphasizing the need for a balanced approach when selecting for both yield and quality traits.

PCA results indicated a significant relationship between unmarketable yield and specific gravity. Higher specific gravity often correlates with better quality tubers; however, it can also indicate increased susceptibility to certain diseases, leading to higher unmarketable yields (Ryder et al., 2017). This dichotomy presents a challenge for breeders who must navigate the trade-offs between quality and disease resistance. The findings agree with Ryder et al. (2017) that while specific gravity is a valuable indicator of tuber quality, it should not be the sole criterion in selection processes and, can observed a negative correlation between average tuber weight and the number of tubers per plant. This finding supports the idea of a trade-off between tuber size and quantity, which is consistent with the work of Elshafie et al. (2020) noted that genotypes optimized for high tuber numbers often produce smaller tubers. While we recognize this trade-off, we also highlight the importance of breeding strategies that can simultaneously enhance both traits without compromising overall yield. (Figure 4.)

Phenotypic, Genotypic Coefficient Variation, Estimate of broad sense heritability and Genetic Advance

Total Starch Content exhibited a high heritability of 80% with a genetic advance (GA) of 6.2 and a genetic advance as a percentage of the mean (GAM) of 162.1. This suggests that this trait is not only highly heritable but also offers substantial potential for improvement through selection, aligning with findings by Kumar et al. (2022) who emphasized the importance of starch content as a critical trait for enhancing tuber quality under stress. Date of Flowering and Maturity: The moderate GCV (6.5%) and PCV (6.9%) values for the date of flowering suggest that while there is some variability among potato accessions, environmental factors also play a significant role in their expression. This finding aligns with the findings of Haverkort et al. (2012) who noted that flowering time in potatoes is influenced by both genetic makeup and environmental conditions. The genotype variance (23.6) relative to the phenotype variance (26.5) indicates that selection for early flowering could be effective, supporting the conclusions of other studies that emphasize the importance of this trait in breeding programs (Miller et al., 2018). Total Tuber Number per Plot The low GCV (3.4%) and moderate PCV (5.5%) values for total tuber number per plot suggest a significant environmental influence on this trait, which is consistent with the observations by De Jong et al. (2017) highlighted that tuber number can vary greatly due to environmental factors such as soil fertility and moisture availability. The high genotype variance (48.7) compared to phenotype variance (131.2) further indicates that while there is genetic potential for improvement, environmental conditions play a critical role in determining final outcomes. This reinforces the notion that breeding efforts should consider environmental factors when selecting for tuber number. Specific Gravity the very low GCV (1.6%) and PCV indicate that specific gravity is a highly stable trait across different genotypes, a finding that supports the work of Ferguson et al. (2007) found that specific gravity is largely unaffected by environmental variations, making it a reliable criterion for selection in potato breeding programs. However, while this finding agrees with their assessment of its stability, and argue that this trait, while important, should not be the sole focus of breeding efforts. As highlighted by other researchers Haverkort et al. (2012) integrating multiple traits including yield and disease resistance will be crucial for developing resilient potato varieties.

Table 5 Mean and estimates of variability components for 12 traits of 49 potato genotypes at Gazo District in 2023/24 cropping season

Traits	Mean	$\sigma^2 g$	$\sigma^2 e$	$\sigma^2 p$	GCV	PCV	H^2	GA	GAM
DF	75.1	23.6	2.9	26.5	6.5	6.9	89.1	9.4	12.6
DM	108.1	39.9	11.3	51.2	5.8	6.6	78.0	11.5	10.6

TNP	208	48.7	82.5	131.2	3.4	5.5	37.1	8.8	4.2
NTP	9.2	5.35	1.7	7.05	25.1	28.9	75.9	4.2	45.1
AH	9	1.2	19.5	20.7	12.2	50.6	5.8	0.5	6.0
BR	577.7	8861.5	4451.6	13313.1	16.3	20.0	66.6	158.2	27.4
DMC	17.5	2.8	1.22	4.03	9.6	11.5	69.8	2.9	16.5
UY	0.4	0.014	0	0.014	29.6	29.6	100.0	0.2	60.9
MY	20.8	3.4	3.02	6.4	8.8	12.2	52.8	2.8	13.2
TY	21.3	3.5	2.8	6.35	8.8	11.8	55.9	2.9	13.6
SG	1.02	0.00025	0	0.00025	1.6	1.6	100.0	0.0	3.2
TSC	3.8	11.15	2.76	13.91	87.9	98.1	80.2	6.2	162.1

Where: σ^2g =genotypic variation, σ^2p =phenotypic variation, GCV=genotypic coefficient variation, PCV=phenotypic coefficient variation, H^2b=heritability, GA=genetic advance, GAM=genetic advance mean, DF = days to 50% of plants flowering, DM = days to 90% maturity, AH = tuber number per hill, TNP = Total tuber number per plot, NTP = Number of tuber per plant, AVT = average tuber weight (gm), MY = marketable tuber yield (ton ha^{-1}), UY = unmarketable tuber yield (ton ha^{-1}), TY = Total tuber yield (ton ha^{-1}), BRP = bulking rate per plot (gm/day), DMC = tuber dry matter content (%), SG = specific gravity of tuber, TSC = total starch content (gm/100gm).

Conversely, Specific Gravity showed perfect heritability (100%) but a GA of 0, indicating no genetic variability among the genotypes tested. This finding is consistent with Smith et al. (2021) noted that specific gravity can be stable across environments but may lack the necessary genetic diversity for improvement and Total Tuber Yield demonstrated moderate heritability (55.9%) and a GA of 2.9, suggesting that while there is some potential for selection, environmental influences play a significant role in yield performance. This observation is supported by Jones et al. (2023) highlighted the complexity of yield traits influenced by environmental conditions, particularly in moisture-stressed areas.

In terms of Unmarketable Yield, again, perfect heritability (100%) was observed, but the low GA of 0.2 suggests limited potential for improvement through selection. This aligns with findings from lee et al. (2020) which indicated that unmarketable yields are often more influenced by environmental stressors than by genetic factors. The Dry Matter Percentage showed moderate heritability (69.8%) and a GA of 2.9, indicating potential for improvement through selection. This result corroborates brown et al. (2021) who noted dry matter content as an essential trait for breeding programs in moisture-stressed environments and The Bulking Rate exhibited high genotype variance (8861) with a phenotypic variance of 13113, resulting in a heritability estimate of 66.6% and a high GA of 158.2. This suggests significant potential for genetic improvement, which is consistent with garcia et al. (2022) emphasized bulking rate as a critical adaptive trait under stress conditions.

The Number of Tuber per Net Plot showed relatively high heritability (75.9%) and a GA of 4.2, indicating good potential for selection. This finding supports patel et al. (2023) who identified tuber number as a crucial determinant of yield under various stress conditions. Regarding Date of Flowering and Date of Maturity, both traits exhibited high heritability (89.1% and 78%, respectively), suggesting they are good candidates for selection in breeding programs aimed at optimizing growth cycles in moisture-stressed environments. These results are in agreement with thompson et al. (2021) highlighted the significance of phenological traits in adapting crops to changing climatic conditions.Finally, the Total Number of Tuber per Plant showed lower heritability (37.1%) and moderate GA (8.8), indicating that while there is some potential for selection, this trait may be more susceptible to environmental variation than others discussed above. This finding reflects the observations made by recent studies that suggest complex interactions between environmental factors and tuber number(martinez et al., 2023

Conclusion

The analysis emphasizes the potential for selecting key traits like total starch content and bulking rate in potato breeding. High heritability in flowering and maturity traits further supports their role in developing resilient varieties.

Recommendations

Breeding programs should focus on traits with high heritability and genetic advance, such as total starch content and bulking rate, while also integrating environmental considerations. Additionally, efforts should be made to enhance genetic variability in stable traits like specific gravity to improve overall potato quality and yield.

References

Abebe, T., Demissew, S., & Mulugeta, A. (2023). Phenotypic Variance Analysis of Potato Genotypes under Different Environmental Conditions. Journal of Plant Breeding and Crop Science, 15(2), 112-120.

Adhikari, S., Sharma, P., & Singh, R. (2023). Correlation and Path Coefficient Analysis of Yield Traits in Potato. Journal of Plant Breeding and Crop Science, 15(1), 85-92.

African Potato Association. (2020) Potato Production in Africa. Retrieved from African Potato Association website.

Alemayehu, M., Tadesse, W., & Berhanu, A. (2021). Estimation of Genetic Variance Components and Heritability in Potato Genotypes. Ethiopian Journal of Agricultural Sciences, 13(3), 45-58.

Beshir, A. A., Fikreyesus, D., & Tesfaye, K. (2021). Challenges and Opportunities for Potato Production in Ethiopia. Ethiopian Journal of Agricultural Sciences, 31(2), 45-60.

Brown, A., Johnson, L., Smith, J. (2021). Starch accumulation dynamics in potatoes: Implications for yield improvement strategies. American Journal of Potato Research, 98(4), 310-320.

Burgos, G., Salas, E. Huaraca Huasco, W. (2021). Nutritional and Health Benefits of Potatoes. Food Nutrition Research, 65(1), 123-135.

Burton, G.W. and de Vane, E.H. 1953. Estimating heritability in Tall Fescue (Festuca Arundinacea) from replicated clonal material. Agronomy Journal 45(10): 481-487.

Chen, Y., Zhang, L., Wang, X. (2023). Environmental Influences on Bulking Rate in Potato Cultivars: A Case Study. Field Crops Research, 250(1), 115-123.

Chen, Y., Zhang, L., Wang, X. (2023). Impact of Starch Content on Potato Quality: A Comprehensive Review. Journal of Agricultural Science, 15(4), 234-245.

Chen, Y., Zhang, L., Wang, X. (2023). Impact of Starch Content on Potato Quality: A Comprehensive Review. Journal of Agricultural Science, 15(4), 234-245.

De Jong, H., (2017). Environmental Influences on Tuber Number and Size Distribution in Potato. Field Crops Research, 205, 97-104.

Dufour, D., Rojas, A., Rojas, R. (2020). The Economic Impact of Potato Production on Local Communities. Journal of Agricultural Economics, 71(3), 567-580

Falconer, D.S. and mackay, F.C. 1996. Introduction to quantitative genetics. Fourth edition. Longman group Ltd, England. Pp.160 -161.

FAOSTAT. (2021). Food and Agriculture Organization of the United Nations. Retrieved from FAOSTAT website.

FAOSTAT. (2021). Food and Agriculture Organization of the United Nations. Retrieved from FAOSTAT website.

Ferguson, J., (2007). Specific Gravity: A Key Trait for Potato Breeding. American Journal of Potato Research, 84(1), 1-10

Garcia, L., Patel, S., Kim, Y. (2023). Evaluating agronomic traits for late blight resistance in potatoes using principal component analysis. Crop Protection, 45(1), 78-85.

Garcia, R., Patel, S., Thompson, J. (2020). Yield Components in Potato Cultivars: An Integrated Approach to Breeding. Field Crops Research, 250(1), 108-115.

Garcia, R., Patel, S., Thompson, J. (2020). Yield Components in Potato Cultivars: An Integrated Approach to Breeding. Field Crops Research, 250(1), 108-115.

Garcia, R., Patel, S., Thompson, J. (2020). Yield Components in Potato Cultivars: An Integrated Approach to Breeding. American Journal of Potato Research, 98(2), 123-135.

Gebrehanna, E., Teshome, A., & Zelleke, H. (2022). Genetic variability studies for tuber yield and yield attributes in Ethiopian released potato (Solanum tuberosum L.) varieties. PeerJ, 10:e1286.

Ghislain, M., Fajardo, D., Rodríguez, F. (2010). Genetic diversity in cultivated potato: Implications for breeding. Journal of Agricultural Science, 148(2), 173-185.

Gupta, A., Sharma, P., Singh, R. (2023). Correlation of starch content with yield traits in potato under drought conditions. Journal of Agricultural Science, 161(2), 134-145.

Haverkort, A. J., (2016). Potato production in a changing climate: A review. Field Crops Research, 198, 1-12.

Haverkort, A.J., (2012). "Potato Production Systems: A Global Perspective. Field Crops Research, 126, 1-10

Hawkes, J. G. (1990). The Potato: Evolution, Biodiversity and Genetic Resources Belhaven Press.

Huamán, Z., Spooner, D. M. (2002). The origin of the cultivated potato. In: Potato Biology and Biotechnology: Advances and Perspectives (pp. 1-24).

International Potato Center (CIP). (2021). CIP's Genetic Resources.Retrieved from CIP website.

Johnson, M., Lee, K. (2021). Genetic Analysis of Bulking Rate and Yield in Potato Cultivars. American Journal of Potato Research, 98(2), 123-135.

Johnson, M., Lee, K. (2021). Genetic Analysis of Bulking Rate and Yield in Potato Cultivars. American Journal of Potato Research, 98(2), 123-135.

Johnson, M., Lee, K. (2021). Genetic Analysis of Specific Gravity and Yield in Potato Cultivars: A Statistical Perspective. Potato Science Journal, 45(3), 200-210.

Johnson, R., Lee, M. (2021). Genetic diversity assessment of potato varieties through PCA. Plant Breeding Journal, 34(2), 102-110.

Kloosterman, B., et al. (2021). The genetic basis of earliness in potato. Theoretical and Applied Genetics, 134(4), 1029-1043.

Kumar, A., Singh, R., Sharma, P. (2023). Genetic Divergence Analysis in Potato Genotypes Based on Agronomic Traits. Journal of Agricultural Science, 11(2), 123-135.

Kumar, A., Singh, R., & Sharma, P. (2022). Evaluation of Genetic Divergence in Various Potato Genotypes Grown in Bangladesh through Different Traits Assessment. Journal of Agricultural Science.

Kumar, A., Singh, R.,Sharma, S. (2020). Advancements in Potato Production Technologies: A Review. Journal of Agricultural Science, 12(3), 123-135.

Kumar, S., et al. (2020). Phenological traits in potato: Their genetic control and implications for breeding. Plant Breeding, 139(5), 741-753.

Kumar, S., et al. (2021). Phenological traits in potato: Their genetic control and implications for breeding. Plant Breeding, 140(5), 741-753.

Kumar, S., Sharma, P., Singh, R. (2022). Evaluation of Genetic Variability and Heritability in Potato Breeding. Journal of Crop Improvement, 36(4), 500-515..

Kumar,S.,Tiwari, R.,Kumar, A. (2021). Genotypic Correlation Studies on Yield Components in Potato.Potato Research, 64(3), 345-358.

Meyer, J., Kuhlmann, F., Schmidhalter, U. (2021). Assessment of Genetic Variance and Heritability in Potato Breeding Programs. Agricultural Systems, 187, 102999.

Miller, P.A., Williams, C. Robinson, H.F. and Comstock, R.E. 1958. Estimates of genotypic and Environmental variances and co-variances in upland cotton and their implications in selection. Agronomy Journal, 50:126 –131

Muller, A., (2018). Genetic Control of Flowering Time in Potato: Implications for Breeding. Theoretical and Applied Genetics, 131(5), 1025-1038.

Ochoa, I., Huamán, Z., Spooner, D. M. (2019). Phylogenetic relationships among wild and cultivated potatoes based on nuclear and chloroplast DNA sequences. Plant Systematics and Evolution, 305(3), 227-239.

P. (2021). Starch Content Variation in Commercial Potato Cultivars: Implications for Breeding. Journal of Agricultural Science, 12(3), 145-157.

Patel, M., Joshi, R.,Verma, S. (2023). Multivariate Approaches in Assessing Genetic Diversity of Potato Cultivars. Plant Breeding Reviews, 47(1), 67-82

Patel, R., Johnson, L., Smith, J. (2021). Impact of flowering time on tuber yield in potatoes: Insights from recent studies. American Journal of Potato Research, 98(3), 210-220.

Patel, S., Brown, T., Chen, Y. (2023). Genetic Diversity and Starch Content in Potatoes: A Bimodal Distribution Analysis. Journal of Crop Improvement, 37(4), 321-330.

Sharma, N., Gupta, R.,Yadav, A. (2021). Cluster Analysis for Morphological Characterization of Potato Genotypes. International Journal of Plant Sciences, 16(4), 234-240

Sharma, R., Gupta, A., Kumar, V. (2022). The role of maturity duration in enhancing potato yield under varying climatic conditions. Horticulture Research, 9(1), 12-24.

Singh, J., Gupta, A., Verma, R. (2021). Correlation Studies on Yield and Its Components in Potato.Indian Journal of Agricultural Sciences, 91(10), 1452-1457.

Singh, J., Kumar, P., Yadav, S. (2023). Genotypic and Phenotypic Correlations in Potato Breeding.Journal of Agricultural Science and Technology, 25(2), 120-130.

Singh, R., Adhikari, S., Sharma, P. (2022). Environmental Effects on Phenotypic Traits in Potato.International Journal of Plant Sciences, 13(4), 200-210.

Smith, A., Brown, T., Davis, P. (2022). Correlations Between Specific Gravity and Tuber Quality in Potatoes: Implications for Breeding Programs. Potato Science Journal, 45(3), 200-210.

Smith, J., Brown, A., Green, T. (2022). Phenotypic analysis of potato cultivars using principal component analysis. Journal of Agricultural Science, 15(3), 245-258.

Spooner, D. M., McLean, K., Ramsay, G., Waugh, R. (2005). A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping." Proceedings of the National Academy of Sciences, 102(41), 14694-14699.

Tadesse, W., Berhanu, A., Beyene, Y. (2022). Genetic Analysis of Yield and Quality Traits in Potato. African Journal of Agricultural Research, 17(5), 567-576.

Wang, Y., (2023). "Quality traits in potato: Relationship with yield and breeding implications. Journal of Agricultural Science, 11(2), 145-158.

Yemane, T., Kifle, D., Abebe, D. (2020). "The Effects of Climate Change on Potato Production in Ethiopia: A Case Study of the Amhara Region." Ethiopian Journal of Environmental Studies and Management, 13(3), 45-58.

Zhang, X., (2022). Bulking rate as a predictor of yield in potato: Insights from field studies. Agronomy Journal, 114(1), 45-55.