Agronomic Performance and Adaptability of Potato Varieties in Pishin: Multivariate Analysis for Sustainable Agriculture

Fazal Rehman Khan1[1], Nimra Gul[*1,3], Syed Abdul Malik[1], Mohammad Idrees[1], Mohammad Naseem[1], Ikhlaq Ahmed[1], Fazal Rabi[1], Syed Shamsullah[2], Zafran Khan[3]

[1]Directorate of Agriculture Research, Potato, Pishin, Balochistan

[2]Directorate of Agriculture Research Viticulture Pishin

[3]Department od Plant Breeding and Genetics, University of Agriculture, Faisalabad

*Corresponding author's email: nimratahir122@gmail.com

Abstract

Balochistan, a region characterized by its vast deserts and subtropical climate, holds a unique position in Pakistan's agricultural landscape. Amidst its diverse cultivation practices, the potato (*Solanum tuberosum* L.) is one of the most important crops in the world and a crucial source of Vitamin C. Its high nutritional value has earned it a place in global agriculture and food security. Balochistan's agriculture, embodying both a challenge and opportunity in optimizing crop yield under the region's distinct environmental conditions. This study evaluates the adaptability and performance of five commercial potatoes (*Solanum tuberosum* L.) varieties cultivated under the subtropical desert climate of Pishin, Balochistan, Pakistan. Across two cropping seasons Employing a Randomized Complete Block Design (RCBD) with three replications, the research focused on key growth and yield parameters, including yield per plot, tuber growth percentage, average number of tubers per plant, plant height on ridges, and emergence percentage. To effectively analyze the complex interplay of these multiple growth parameters and reduce the dimensionality of dataset, Principal Component Analysis (PCA) was employed, enabling the identification of the most significant variables influencing variety performance. Among the varieties tested, "Kuroda" and "Asterix" exhibited exceptional adaptability and performance. "Kuroda" showed a yield increase from 7.03 kg to 14.33 kg per plot and a tuber growth percentage improvement from 46.53% to 88.27% in the second year, underscoring its potential for boosting productivity under subtropical desert conditions. Principal Component Analysis (PCA) indicated that the first two components accounted for over 95% of the variance, highlighting the criticality of yield and growth traits in variety success. Our findings advocate for the strategic selection of high-performance potato varieties as a key lever for enhancing yield and adaptability in desert climates, thereby reinforcing food security and agricultural sustainability in Balochistan and similar regions worldwide.

Keywords: Potato, Tuber, Emergence, Adaptability, Sustainability

1 INTRODUCTION

The potato (*Solanum tubersum* L.) stands as a prominent tuber crop globally, with its origins likely tracing back to Peru, South America. It is thought that its spread worldwide was facilitated by military campaigns, trade, and transport [1]. Presently, the world hosts over 5,000 varieties of potatoes, with a significant number found predominantly in South America [2]. Globally, the potato is esteemed for its nutritional value, versatility in usage in both unprocessed and processed forms, and accessibility for consumers with lower incomes. It offers a substantial source of water, carbohydrates, vitamins, minerals, proteins, and fats, providing 390 KJ per 100g of baked potato [2]. Positioned as the world's third most significant crop in terms of production and consumption after rice and wheat, potatoes are a staple for nearly a billion people worldwide in various forms [3]. Recent figures show global potato production reached 381.7 million tonnes across 19.1 million hectares in 2014, with Pakistan contributing 2.9 million tonnes from 0.15 million hectares during the same timeframe [4].

The global importance of potatoes lies in their potential to contribute to food security. With the world's population expected to reach 9 billion by 2050, the demand for food, particularly nutritious food, will increase dramatically. Potatoes, being highly efficient in terms of space and time, can produce more food more quickly on less land and in harsher climates than any other major crop, thus playing a critical role in feeding the growing global population [5]. Varieties that excel in a wide range of environmental conditions are essential to this effort, as they can be cultivated in diverse geographic regions and under varying climate conditions. Moreover, the adaptability of potato varieties to different environmental stressors, such as drought, salinity, and pests, is crucial for sustaining production in the face of climate change. Climate change poses significant risks to agricultural productivity, including increased incidence of extreme weather events and new patterns of pests and diseases. Developing and cultivating potato varieties with enhanced resistance to these stressors can help mitigate the impacts of climate change on crop yields and food availability [6].In addition to food security and climate resilience, the economic importance of the potato cannot be overstated. For many smallholder farmers in developing countries, potatoes represent a vital source of income.

Cultivating varieties that are high-yielding, disease-resistant, and suited to local conditions can significantly improve farmers' livelihoods. Furthermore, as potatoes are a labor-intensive crop, they also provide employment opportunities within communities [7].

In Pakistan, the potato is a key food source and is readily available year-round. Pakistan cultivates three potato crops: spring, summer, and autumn, across its diverse agro-ecological zones, from plains to mountainous regions [8]. Potato farming is favored due to its relatively low labor demands and quick turnaround from planting to harvest (under 90 days), positioning it as an advantageous crop for local farmers. However, despite suitable growing conditions, ease of cultivation, and minimal labor requirements, potato yields in Pakistan lag behind those in other developing nations due to various challenges. These include abiotic stresses such as cold stress, drought, salinity, soil issues, imbalance fertilizer application, and inadequate quality of irrigation water. Additionally, biotic factors like low-yielding strains and various fungal, nematode, bacterial, and viral infections significantly hinder potato growth and yield in the country [9]. Potato cultivation is widespread across Pakistan, yet the vast majority of its production, accounting for 94%, primarily occurs in Punjab, contributing 93.6% to the total. This is followed by Khyber Pakhtunkhwa with 5.17%, Balochistan at 1%, and Sindh at a minimal 0.33%. The country hosts two principal potato growing clusters: one situated in Okara, Punjab, and the other in Hunza, Gilgit Baltistan [10]. It is estimated that 24,000 square kilometers (kha) are dedicated to agricultural cultivation, with potatoes occupying about 1,300 kha. This is notably smaller than the areas allocated for potato cultivation in other South Asian countries [9]. Between 1900 and 2014, annual potato production in Pakistan fluctuated between 0.7 and 3.8 million tonnes (MT), hitting a low in 1991 with 0.7 MT and peaking at 3.8 MT in 2013, before a slight decrease to 2.9 MT in 2014 [11]. A comparison over a five-year span (2010-2014) reveals that India leads in potato production within South Asia, followed by Bangladesh, with Pakistan ranking third, ahead of Nepal. During this period, India and Bangladesh saw consistent growth in both the area harvested and potato output. Conversely, Pakistan experienced fluctuations in its potato cultivation area and production, with an increase from 138 kha in 2010 to 175 kha in 2013, then a drop to 159 kha in 2014. Similarly, production peaked at 3,802 kilotonnes in 2013, then decreased to 2,901 kilotonnes in 2014. In 2020, the potato yield was approximately 4.55 million tons, harvested from an area of 234,400 hectares. Subsequently, in the 2021-22 period, data from the Ministry of National Food Security & Research (MNFS&R) indicates a significant rise in production to 7.74 million tons, marking an almost 50% increase from the previous year's output [11].

The extensive cultivation and consumption of potatoes across diverse ecological zones, including the unique terrains of Balochistan, underscore their significance in ensuring food security and agricultural sustainability [12]. This ubiquity is largely due to the remarkable adaptability of potatoes to varied climates and soils, a trait that is especially pertinent in Balochistan's varied microclimates, ranging from arid deserts to cooler mountainous regions. Coupled with their high yield potential and nutritional value, the performance and adaptability of different cultivated varieties of potato in areas like Balochistan constitute a pivotal area of study within agronomy and crop science [13]. Researchers and farmers are keen to optimize yield, nutritional content, and resistance to pests and diseases under the changing environmental conditions characteristic of this region.

From a nutritional standpoint, the potato is a rich source of carbohydrates, fiber, vitamins, and minerals, essential for the diverse diets of Balochistan's population [14]. However, the nutritional content can vary significantly among different varieties, making the development and promotion of varieties with higher levels of essential nutrients critical. Such efforts can improve the nutritional outcomes of potato-consuming populations, particularly in areas of Balochistan where food diversity is limited and malnutrition is a concern. Emphasizing the cultivation of nutrient-rich potato varieties in Balochistan not only addresses immediate nutritional needs but also aligns with long-term goals for food security and the sustainable development of the region's agricultural sector [15].

The performance and adaptability of different cultivated varieties of potato (*Solanum tubersum* L.) are of paramount importance for several compelling reasons, spanning from ensuring global food security to addressing the challenges of climate change [16]. As one of the most widely consumed crops worldwide, the potato plays a crucial role in the diet of millions, offering not just sustenance but also significant nutritional benefits. The crop's adaptability to a wide range of climates and soil types makes it a key agricultural asset, particularly in regions where other staple foods might struggle to thrive [2]. Adaptability in potatoes is often evaluated through agronomic performance indicators such as tuber yield, size, and quality, alongside resilience to environmental stressors like drought, temperature extremes, and soil conditions. Genetic improvement programs have increasingly focused on enhancing these traits to meet the dual challenges of rising global food demand and climate change. For instance, varieties with enhanced drought tolerance or resistance to diseases such as late blight (caused by Phytophthora infestans) are of particular interest, given their potential to sustain production under adverse climatic conditions [17].

This paper aims to explore how the potato industry in Pakistan has responded to climate change, particularly through the adoption of enhanced varieties as a strategy for adaptation. Principal Component Analysis (PCA) emerges as a valuable statistical tool in this context, enabling the identification of superior potato varieties. This research focuses on identifying performance and adaptability of different cultivated varieties of potato. Using PCA, aiming to inform breeding strategies for improving performance in agro-ecological zones. This effort is critical for developing climate-resilient potato capable of enduring future environmental challenges.

2 MATERIALS AND METHODS

2.1 Description of the Study Area

The field experiment was conducted at the Surtal Farm, Pishin, Balochistan, Pakistan, under irrigation conditions during the 2021/2022 and 2022/2023 cropping seasons. Situated at an elevation of 1555.52 meters (5103.41 feet) above sea level, the farm experiences a Subtropical desert climate, characterized by limited precipitation and significant temperature variations. The average annual temperature at the farm is 24.8ºC (76.64ºF), which is 3.91% higher than the national average. Annually, the farm receives an average precipitation of 12.68 millimeters (0.5 inches), distributed over approximately 24.82 rainy days, accounting for 6.8% of the year.

Google maps

July, the warmest month, sees temperatures reaching up to 39.86ºC (103.75ºF), whereas January, the coldest month, experiences temperatures as low as 6.27ºC (43.29ºF). February is marked as the wettest month with about 38.81mm (1.53 inches) of rainfall, in contrast to September, which is the driest month, recording minimal precipitation of 0.11mm (0.004 inches). This setting in Balochistan province offers a unique opportunity to explore agricultural practices tailored to desert climates with extreme temperature fluctuations and scarce rainfall.

2.2 Experimental design

This study assessed the performance of commercial potato employing a 2-factor factorial under Randomized Complete Block Design (RCBD) with three replications to ensure the reliability of results. A total of five potato varieties (Sarpo-mira, Kuroda, Asterix, Saturna, Flamba) were evaluated, with each plot measuring approximately 1/4 acre (about 1011.8 square meters). The experimental setup included a plant spacing of 25 cm within rows (plant-to-plant) and a row spacing of 75 cm (row-to-row), with a recommended seed rate of 1100 to 1200 kg per acre. To facilitate management and ensure uniformity, a 1-meter spacing separated each plot from adjacent replications. With plot dimensions of 50.59 meters in length and 20 meters in width, the layout accommodated 27 rows per plot, hosting an estimated 203 plants per row. This structured approach was optimized for observing the growth and yield of potatoes under a balanced fertilizer regimen of NPK, with ratios of 200-150-100 kg per hectare of Nitrogen, Phosphorus, and Potassium, respectively, to ensure optimal nutrient availability.

Data collection focused on key growth and yield parameters, including yield per/plot/kg, tuber growth (%), average number of tubers/plant, plant height on ridges (cm), emergence percentage.

2.3 Statistical Analysis

Analysis of variance will be used to study the genetic differences among potato varieties genotypes against NaCl stress [18]. Principal component biplot will be made for multi-trait selection [19]. Furthermore, to perform principal component analysis (PCA), XLSTAT version 2012.1.02 (copyrighted by Addinsoft from 1995 to 2021), was utilized as the analytical tool for these respective analyses.

3 RESULTS

3.1 Analysis of Variance

In our study on different cultivated varieties of potato (*Solanum tubersum* L.), we conducted a thorough analysis of several key traits over a period of two years. The ANOVA for different agronomic traits (Yield, Tuber size, Average weight, Plant height, and Emergence rate) of potato varieties in Balochistan demonstrate statistically significant differences across varieties, years, and their interaction terms, as indicated by very low p-values (all $p < 0.05$. F-statistic for variety in the Yield analysis is 239.20 with a p-value of 0.0000, suggesting strong evidence there is no difference in yield across varieties. This pattern is consistent across all traits, indicating that the performance of potato varieties significantly varies, and these differences are consistent over years. The interaction term (variety × year) is also significant in all cases except for replicates, indicating that the performance of varieties changes differently over years. Such findings are critical for selecting the most adaptable and high-performing potato varieties for sustainable crop production in Balochistan (Table 3.1).

TABLE 3.1 | Mean squares results of variance analysis for various characteristics.

Source of Variation	DF	Yield per/plot/kg	Tuber Growth (%)	Average Number of Tubers/Plant	Plant Height on Ridges (cm)	Emergence Percentage
Replication	2	0.156	0.4	1.300	0.66	0.09
Variety	4	15.699**	608.6**	48.617**	216.61**	73.60**
Year	1	707.131**	28423.9**	300.833**	9889.21**	2240.78**
Variety × Year	4	1.800**	1.9**	1.583**	30.00**	0.30**
Error	18	0.066**	0.1**	0.226**	0.10**	0.01**
Total	29					

The degrees of freedom (DF) and mean square values for yield per/plot/kg, tuber growth (%), average number of tubers/plant, plant height on ridges (cm), and emergence percentage across replication, varieties, year, variety by year interaction, and residual error.

Descriptive statistics reveal a wide variation in yield performance across the varieties, with the average yield per plot standing at 7.03 kg and a notable range from a minimum of 0.96 kg to a maximum of 14.33 kg. The tuber growth percentage also varied significantly, indicating varied adaptability and growth potential among the varieties, with an average growth rate of 46.53% and extremes ranging from 0.53% to 88.27%. Furthermore, the average number of tubers per plant was 5.70, showcasing a broad spectrum from 0.33 to 13.33, which reflects the influence of genetic and environmental factors on tuber production. The plant height on ridges showed an average of 24.62 cm, with a substantial variation from 2.15 cm to 50.50 cm, indicating diverse growth habits among the potato varieties. Lastly, the emergence percentage, critical for early growth stages, averaged at 13.21%, with values ranging from 1.05% to 26.60%, highlighting the variability and importance of selecting varieties with high emergence rates for optimal field establishment (Table 3.2).

TABLE 3.2 | Descriptive statistics results for various characteristics.

Trait	Mean	Min	Max
Year	1.50	1.00	2.00
Yield per/plot/kg	7.03	0.96	14.33
Tuber Growth (%)	46.53	0.53	88.27
Average Number of Tubers/Plant	5.70	0.33	13.33
Plant Height on Ridges (cm)	24.62	2.15	50.50
Emergence Percentage	13.21	1.05	26.60

3.2 Box Plot

In the detailed investigation of annual variations in potato adaptability and yield performance, boxplots separated by year illuminated the dynamic responses of five potato varieties to environmental and agronomic conditions across two years. These analyses revealed marked differences in how each variety adapted and performed from Year 1 to Year 2, offering valuable insights into their resilience and productivity. Specifically, varieties "Kuroda" and "Asterix" stood out for their robust performance across several key metrics. In Year 1, while most varieties showed moderate performance, "Kuroda" and "Asterix" were already leading in terms of yield and tuber growth. The transition to Year 2 underscored their superior adaptability, with both varieties exhibiting significant improvements in all measured traits, particularly in yield per plot and tuber growth percentage. This year-over-year enhancement highlights "Kuroda" and "Asterix" as exceptionally adaptable and productive, suggesting their potential for reliable performance in fluctuating environmental conditions. The analysis thus underscores the critical importance of annual monitoring and variety selection in optimizing potato crop outcomes (Figure 1).

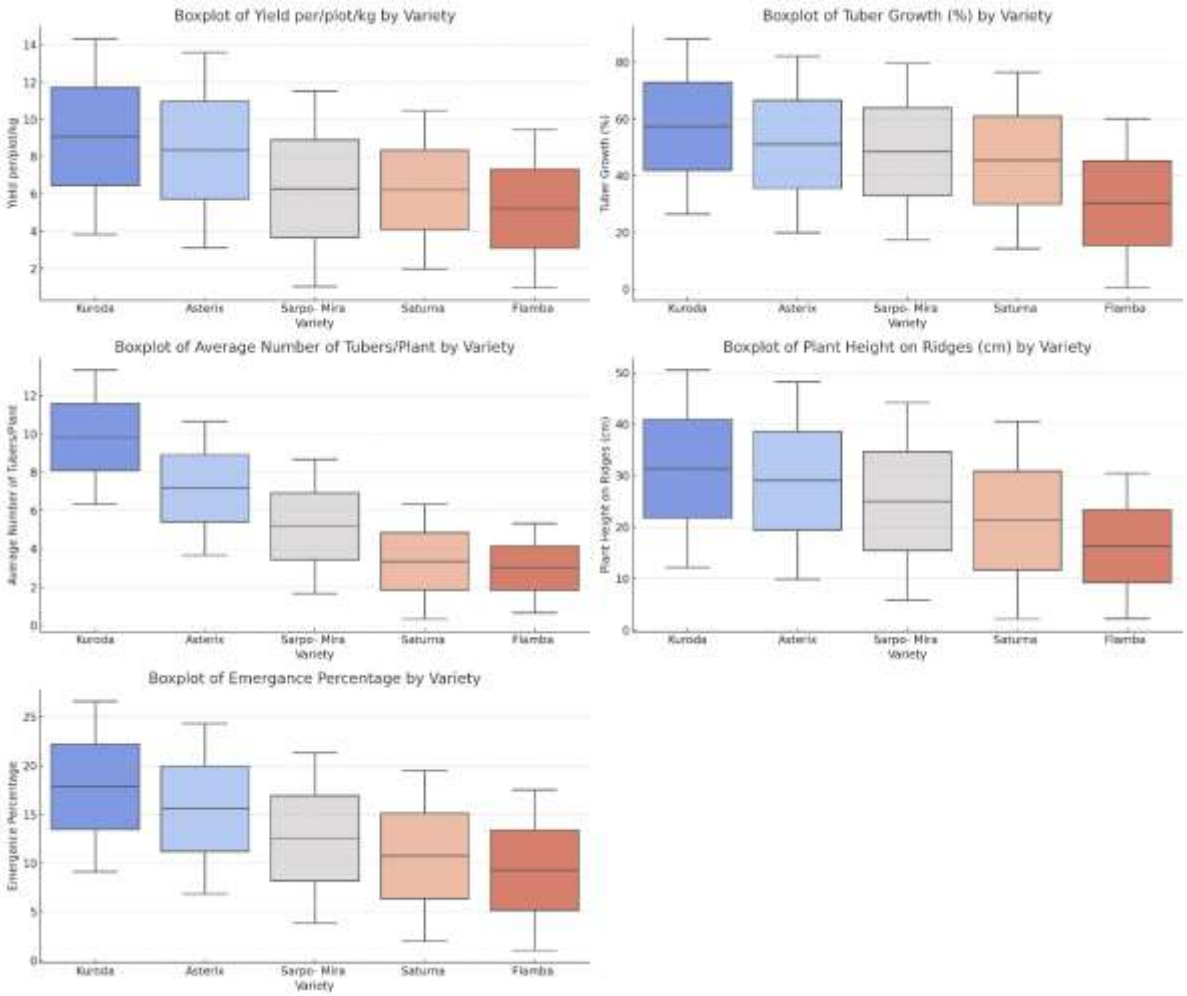


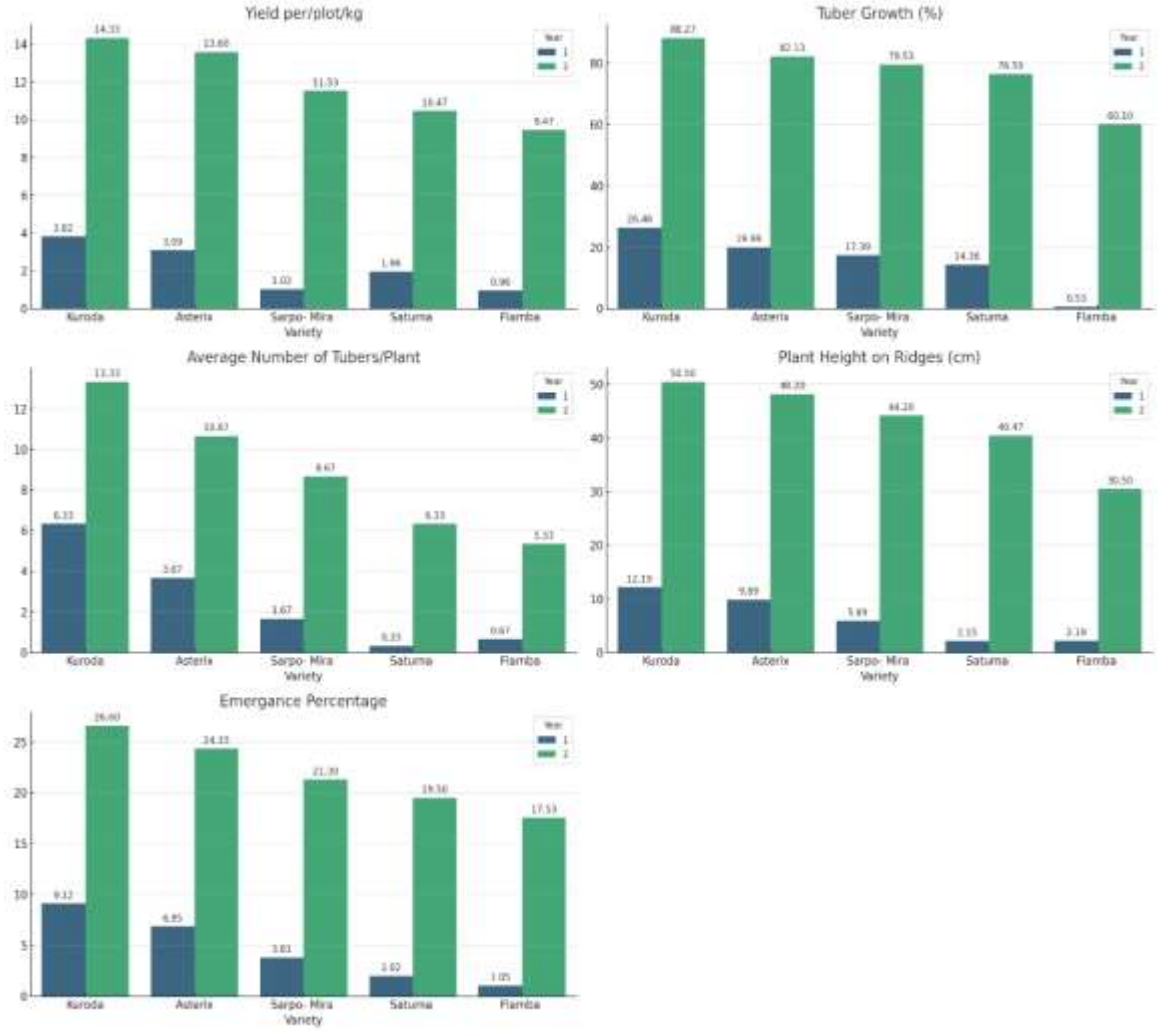
Fig. 1: Box plots representing response of different varieties.

3.3 Bar Graphs

The analysis of potato (*Solanum tubersum* L.) varieties over two consecutive years offers detailed insights into the traits essential for assessing their performance and adaptability. When examining yield per plot, Kuroda and Asterix stood out in the second year with impressive yields of approximately 14.33 kg and 13.6 kg, respectively, demonstrating a significant increase from their first-year yields. This highlights the potential impact of environmental adaptations or agricultural practices on yield improvements. Tuber growth percentage showed a remarkable variance, with Kuroda and Asterix again leading in the second year, recording growth rates of 88.27% and 82.13%, respectively. Such figures

suggest a robust genetic potential for growth under conducive conditions. The average number of tubers per plant was notably higher in Kuroda in the second year at 13.33, indicating its superior tuber production capability among the varieties studied. Plant height on ridges also varied significantly, with Kuroda reaching up to 50.5 cm in the second year, indicating a vigorous growth habit that could influence both yield and ease of harvest. The emergence percentage, a critical factor for initial growth success, was highest for Kuroda in the second year at 26.6%, underscoring the variety's strong start compared to others (Figure 2).

Fig. 2 | Bar graphs representing response varieties.



3.4 Scree plot

In the analysis of cultivated potato varieties (*Solanum tubersum* L.) across two consecutive years, Principal Component Analysis (PCA) was employed to elucidate the underlying structure of the data and assess the contribution of various traits to the overall variance. The scree plots derived from PCA revealed a pronounced variance concentration in the initial components, highlighting the dominance of a few traits in explaining the observed variability among the varieties. For Year 1, the first principal component alone accounted for 91.00% of the total variance (Figure 3a), with the second component adding a further 4.88%. Similarly, in Year 2, the first component explained a slightly higher percentage of the total variance, at 95.35%, with the second contributing an additional 4.13% (Figure 3b). These findings suggest a significant consolidation of variance within the first two components, indicating that the majority of the variation in potato growth and development traits across the studied varieties can be captured succinctly by these components. This concentration of variance is indicative of the potential for dimensionality reduction in the dataset, enabling a more focused analysis on the key factors driving the observed differences in potato performance and adaptability over the two years.

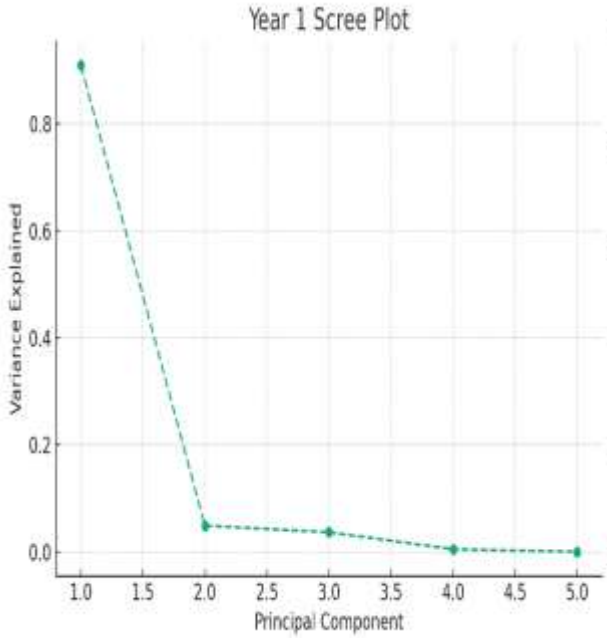


Fig. 3a Scree plot for year 1

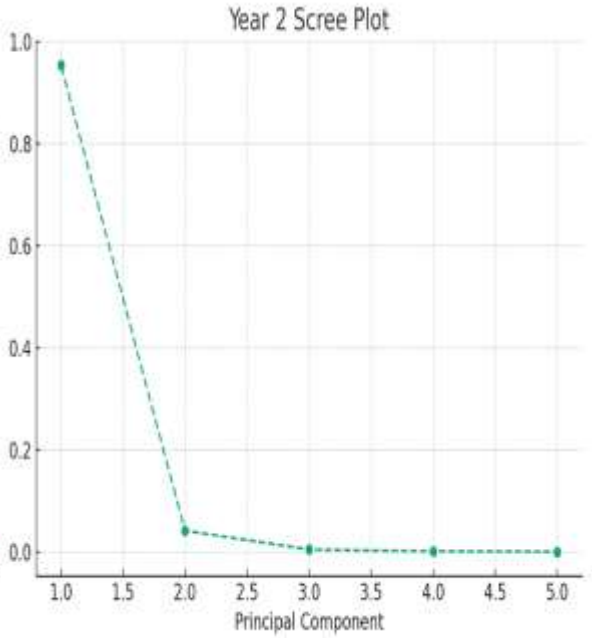


Fig. 3b Scree plot for year 2

3.5 PCA Biplot

In both years, the biplots vividly illustrate the distribution of the varieties in the space defined by the first two principal components, effectively capturing the dynamics of yield per plot, tuber growth percentage, average number of tubers per plant, plant height on ridges, and emergence percentage.

In both Year 1 and Year 2, the biplots revealed that certain varieties exhibited a pronounced alignment towards the principal components, indicating a stronger influence of the assessed traits on these varieties. Notably, the variety "Kuroda" consistently positioned closer to the vectors representing key growth and yield metrics in the PCA space, suggesting its superior performance across multiple traits, including yield per plot, tuber growth percentage, and average number of tubers per plant. This positioning is reflective of "Kuroda" adaptability and robustness, making it a standout variety in both years.

The first two principal components, capturing a significant portion of the variance (95.88% in Year 1 and 99.48% in Year 2), underscore the pivotal roles of these traits in defining the phenotypic landscape of the potato varieties. Kuroda proximity to these critical vectors in the biplot not only highlights its exceptional performance but also suggests that it exemplifies the trait combinations most conducive to high yield and growth under the conditions studied. Therefore, based on the PCA biplot analysis, "Kuroda" emerges as the best-performing variety, demonstrating a potent combination of the measured traits that are key determinants of successful cultivation.

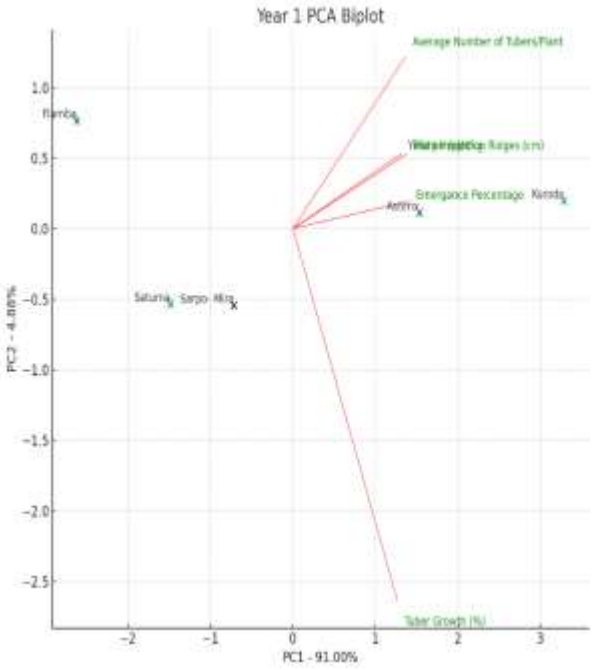


Fig. 4a Biplot representation of varieties

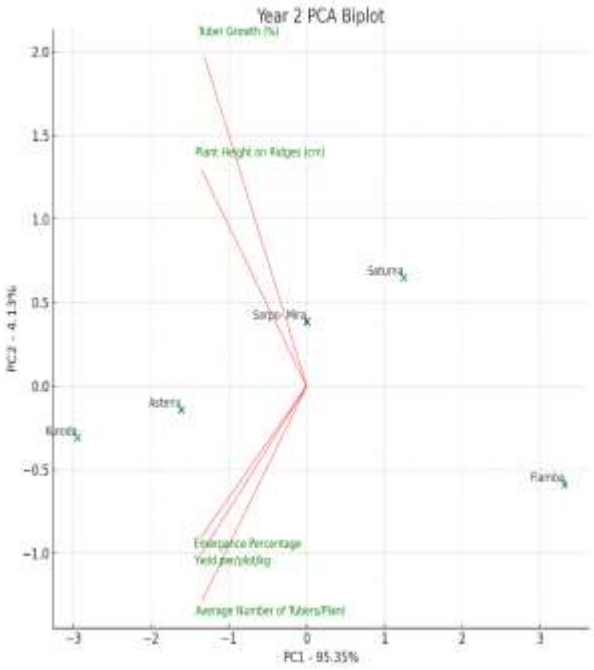


Fig. 4b Biplot representation of varieties

4 DISCUSSIONS

In the study focused on evaluating the performance and adaptability of five commercial potato varieties in the subtropical desert climate of Pishin Surtal Farm, Balochistan, Pakistan, across two cropping seasons, the results underscored the critical importance of selecting appropriate varieties for maximizing yield and adaptability in challenging environments.

The ANOVA for all the agronomical traits of potato varieties in Balochistan demonstrate statistically significant differences across varieties and years. The interaction term (variety×year) is also significant in all cases except for replicates, indicating that the performance of varieties changes differently over years. Such findings are critical for selecting the most adaptable and high-performing potato varieties for sustainable crop production in Balochistan. Notably, the varieties "Kuroda" and "Asterix" emerged as superior in terms of yield and growth characteristics, with "Kuroda" showing a remarkable increase in yield per plot and tuber growth percentage in the second year. This suggests a strong genetic potential and adaptability to the environmental conditions prevalent in subtropical desert climates, where extreme temperatures and limited water availability pose significant challenges to crop production.

Reflecting the challenges highlighted by [20], reveals the intricate effects of environmental and temporal factors on potato crop performance. They found that the interaction between potato variety and planting location, as well as the year of cultivation, significantly influenced tuber production outcomes, highlighting the importance of genetic and environmental synergy for optimal yield. This aligns with our findings in Balochistan, where "Kuroda" and "Asterix" varieties demonstrated exceptional adaptability and productivity, potentially due to their favorable genetic interaction with the unique subtropical desert climate of the region. Such parallels suggest that the success of potato cultivation in varying climates critically depends on selecting varieties with genetic traits that are adaptable to specific local conditions, a strategy that could significantly enhance agricultural productivity and sustainability.

The study by [21] provides further context to our findings by showcasing the significance of selecting potato varieties that meet both agronomic and economic criteria. In their research, the Gudane and Bubu varieties were preferred by farmers in the West Hararghe Zone for their high yields and favorable qualities such as disease resistance and marketability. This preference underscores the broader applicability of our study's results, where varieties like "Kuroda" exhibited superior performance under challenging environmental conditions. They emphasis on variety selection for enhancing the seed value chain and economic returns mirrors our conclusion that choosing high-performance potato varieties is crucial for improving yield and adaptability in diverse climates, including the desert conditions of Balochistan.

The findings from [22] enrich our discussion by illustrating the variability in yield and quality among different potato varieties in various Ethiopian locales. Their research underscores the significant impact of environmental conditions and varietal characteristics on potato production. The high yields and marketable tuber production achieved by specific varieties in certain locations resonate with our observation of "Kuroda" and "Asterix" varieties' adaptability and high yield in Balochistan's subtropical desert climate. Habtamu et al.'s study accentuates the necessity of tailoring potato variety selection to local environmental conditions, a principle that is central to our study's findings and recommendations for enhancing potato crop performance in arid and semi-arid regions.

Together, these studies underscore the complexity of factors influencing potato yield and adaptability. They highlight the critical need for careful variety selection based on genetic characteristics, environmental adaptability, and economic viability to meet the challenges of sustainable potato production in diverse global contexts.

5 CONCLUSIONS

Our comprehensive study on the adaptability and performance of five commercial potato varieties under the challenging conditions of a subtropical desert climate in Pishin, Balochistan, over two consecutive cropping seasons has yielded significant insights into potato agronomy and crop science. The findings clearly demonstrate that among the evaluated varieties, "Kuroda" and "Asterix" exhibit superior performance in terms of yield, tuber growth, and adaptability to environmental stressors. These varieties have shown a remarkable ability to thrive in conditions characterized by extreme temperature fluctuations and minimal rainfall, highlighting their potential as resilient food sources in desert climates and similar agro-ecological zones. The utilization of Principal Component Analysis (PCA) has efficiently distilled the complex interplay of growth parameters into a coherent understanding of variety performance, emphasizing the dominance of yield per plot, tuber growth percentage, and average number of tubers per plant as key determinants of adaptability and productivity.

This research underscores the importance of selecting high-yielding, adaptable potato varieties as a strategy to enhance agricultural sustainability and food security in regions facing the dual challenges of climate change and arable land scarcity. "Kuroda," with its standout performance across multiple metrics, exemplifies the genetic and agronomic traits desirable for achieving high productivity in adverse conditions. As the global demand for food increases and climate variability intensifies, the insights from this study contribute valuable knowledge towards optimizing potato cultivation practices, with implications for policy, agricultural development, and the broader goal of ensuring a reliable food supply for future generations.

Future research should focus on expanding the genetic diversity of potato varieties tested in similar environmental conditions, alongside exploring the impact of advanced agronomic practices and technologies on enhancing crop resilience and yield.

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REFERENCES

[1] Spooner, D.M., et al., A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping. Proceedings of the national academy of sciences, 2005. 102(41): p. 14694-14699.
[2] Zaheer, K. and M.H. Akhtar, Potato production, usage, and nutrition—a review. Critical reviews in food science and nutrition, 2016. 56(5): p. 711-721.
[3] Anwar, D.M., et al., Determinants of potato prices and its forecasting: A case study of Punjab, Pakistan. 2015.
[4] Pronk, A., et al., Report Topsector Potato India and Ethiopia 2015/16. 2017, Wageningen Plant Research.
[5] Devaux, A., P. Kromann, and O. Ortiz, Potatoes for sustainable global food security. Potato research, 2014. 57: p. 185-199.
[6] Hijmans, R.J., The effect of climate change on global potato production. American journal of potato research, 2003. 80: p. 271-279.
[7] Scott, G.J., M.W. Rosegrant, and C. Ringler, Global projections for root and tuber crops to the year 2020. Food policy, 2000. 25(5): p. 561-597.
[8] Khan, N.P. and J. Akhtar, Competitiveness and policy analysis of potato production in different agro-ecological zones of Northern Areas: Implications for food security and poverty alleviation. The Pakistan development review, 2006: p. 1137-1154.
[9] Majeed, A., et al., Late blight of potato (Phytophthora infestans) I: Fungicides application and associated challenges. Turkish Journal of Agriculture-Food Science and Technology, 2017. 5(3): p. 261-266.

[10] Majeed, A. and Z. Muhammad, Potato production in Pakistan: challenges and prospective management strategies–a review. Pak. J. Bot, 2018. 50(5): p. 2077-2084.
[11] Otieno, H.M. and E.K. Mageto, A review on yield response to nitrogen, potassium and manure applications in potato (*Solanum tubersum* L.) production. Archives of Agriculture and Environmental Science, 2021. 6(1): p. 80-86.
[12] Winston, H.Y., The Indus basin of Pakistan: The impacts of climate risks on water and agriculture. 2013: World bank publications.
[13] Aksoy, E., et al., Recent advances in potato (*Solanum tubersum* L.) breeding. Advances in Plant Breeding Strategies: Vegetable Crops: Volume 8: Bulbs, Roots and Tubers, 2021: p. 409-487.
[14] Khan, A., et al., Intraspecific variations in exotic potato (Solanum tuberossum) genotypes revealed by multivariate approaches. FRESENIUS ENVIRONMENTAL BULLETIN, 2021. 30(6): p. 5735-5741.
[15] Burlingame, B., B. Mouillé, and R. Charrondiere, Nutrients, bioactive non-nutrients and anti-nutrients in potatoes. Journal of food composition and analysis, 2009. 22(6): p. 494-502.
[16] Zsögön, A., et al., Enhancing crop diversity for food security in the face of climate uncertainty. The plant journal, 2022. 109(2): p. 402-414.
[17] Haverkort, A., et al., Societal costs of late blight in potato and prospects of durable resistance through cisgenic modification. Potato research, 2008. 51: p. 47-57.
[18] Steel, R.G.D. and J.H. Torrie, Principles and procedures of statistics. Principles and procedures of statistics., 1960.
[19] Pearson, E.S., " Student" as statistician. Biometrika, 1939. 30(3/4): p. 210-250.
[20] Kena, K., et al., Adaptability and performance evaluation of potato (*Solanum tubersum* L) varieties under irrigation in west and Kellem Wollega zones. J Advan Plant Sci, 2018. 1: p. 213.
[21] Zewdu, A., et al., Participatory Evaluation and Selection of Improved Irish Potato Varieties at Daro Lebu and Oda Bultum Districts of Western Hararghe Zone, Oromia Regional State, Ethiopia. Bioinformatics, 2017. 5(6): p. 82-89.
[22] Gebreselassie, H., M. Wahassu, and B. Shimelis, Evaluation of potato (*Solanum tubersum* L.) varieties for yield and yield components in Eastern Ethiopia. Evaluation, 2016. 6(5).