ISSN NO: 2771-8840
June 2025

Potato Biotechnological Genotypes: Comparative Analysis Of Physiological Development Under In Vitro And In Vivo Conditions

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ABSTRACT
This article presents a comparative analysis of the physiological development of biotechnological potato genotypes (S-46, S-73, S-55, and S-17) under both in vitro and in vivo conditions. The research was conducted in the saline and arid climatic environment of the Bukhara region. The findings revealed that plant growth, chlorophyll concentration, biomass accumulation, and root system development were significantly enhanced in vivo. Notably, the S-17 genotype exhibited remarkable adaptability to saline and arid conditions. This study establishes a crucial scientific foundation for future investigations focused on the selection of potato varieties capable of thriving under drought and salinity stress.
Keywords: potato genotypes, in vitro, in vivo, salinity, drought, physiological development, Bukhara climate, chlorophyll a, chlorophyll b, biomass, transpiration.

INTRODUCTION

Potato (Solanum tuberosum L.) is a vital agricultural crop that plays a significant role in global food security, making the enhancement of its yield through selection and biotechnological methods an urgent concern. Biotechnological strategies, especially investigations into potato growth and development under in vitro and in vivo conditions, augment the potential for more efficient plant cultivation. These methodologies offer several advantages, including the ability to manage plants in a sterile environment, safeguard genetic diversity, and facilitate the creation of novel varieties. Building on these strategies, numerous studies have been undertaken that deliver comprehensive analyses of potato development, contributing valuable insights into optimizing cultivation practices and improving overall productivity.In vitro culture of potato tissues, regeneration, and cloning are significantly facilitated by the nutrient medium formulated by Murashige and Skoog (1962), which promotes the rapid growth of potato shoots and root systems. [1]. This foundational work was expanded upon by George and Sherrington (1984), who conducted an in-depth investigation into the effects of various nutrient media and phytohormones on plant development. Their findings revealed that cytokinins and auxins are pivotal in stimulating the swift development of potato root systems, highlighting the essential role of these hormones in enhancing plant growth and regeneration processes. This research underscores the importance of optimizing nutrient conditions to improve the efficiency of potato tissue culture techniques. [2]Cultivating potatoes (Solanum tuberosum L.) in sterile conditions significantly enhances the potential for maintaining genetic stability and safeguarding against pathogens. Research conducted by Trejo-Tapia et al. (2002) demonstrated that in vitro cultivation of potatoes diminishes the risk of diseases linked to pathogens, which is a crucial aspect in the development of disease-resistant varieties during the selection process. Furthermore, studies by Rocha-Sosa et al. (2013) provided a thorough analysis of the phytohormones influencing cell division and root regeneration processes in in vitro environments. These findings underscore the importance of biotechnological methods in improving potato cultivation and advancing agricultural practices. [4]. However, the development of potatoes in vivo is strongly influenced by natural soil-climate factors. Studies conducted by MacKerron and Waister (1985) examined how nutrient factors (nitrogen, potassium) and temperature in the soil affect growth processes. This research indicated that improving nutrient availability criteria for potatoes could enhance yield [5]. Additionally, studies by Iwama (2008) demonstrated that soil moisture and the level of saturation with organic matter significantly impact the plant's root system [6]. Investigating potato varieties that exhibit resistance to stress factors such as drought and salinity is a critical area of research. Levy and Veilleux (2007) examined the adaptation mechanisms of the root system

ISSN NO: 2771-8840
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and the physiological changes that occur during potato growth in saline soils. [7]Their findings are instrumental in identifying and selecting varieties that can thrive in arid and saline environments. Additionally, studies by Lutaladio and Demirel (2007) offered a comprehensive analysis of potato adaptability to varying salinity levels and their subsequent impact on yield. This body of research underscores the importance of developing stress-resistant potato varieties to enhance agricultural productivity in challenging climatic conditions. [8]. The arid climate and saline soil conditions prevalent in the Bukhara region present significant challenges for potato cultivation. Research conducted by Khoja and Ismatullaev (2011) assessed the adaptability of various potato genotypes to these harsh conditions, revealing a critical interrelationship between nutrient availability in saline soils and the physiological characteristics of the plants. Their findings underscore the necessity of understanding how these factors influence plant growth and development.[9] This research lays the groundwork for future comprehensive studies focused on the selection and development of potato varieties capable of withstanding both drought and salinity stress, ultimately contributing to improved agricultural resilience in affected regions. The objective of this study is to examine the physiological development of biotechnological potato genotypes S-46, S-73, S-55, and S-17 under both in vitro and in vivo conditions within the specific soil and climatic context of the Bukhara region. This research aims to conduct a comparative analysis of their growth and development indicators, assessing how these genotypes respond to the unique environmental challenges presented by the region. By evaluating key physiological parameters, the study seeks to identify the most resilient potato varieties suitable for cultivation in arid and saline conditions, thereby contributing to enhanced agricultural practices and food security.

MATERIALS AND METHODS

The study focused on biotechnological potato genotypes S-46, S-73, S-55, and S-17, which were evaluated under the saline and arid climatic conditions of the Bukhara region. Research was conducted in both in vitro and in vivo environments to assess their growth and development.
In Vitro Conditions:Potato genotypes were cultivated in the Murashige and Skoog (MS) nutrient medium, which is widely recognized for promoting plant tissue culture. The primary composition of the MS nutrient medium included:Macronutrients: KNO_3 (1,9 g/l), NH_4NO_3 (1,65 g/l), $CaCl_2x2H_2O$ (0,44 g/l), $MgSO_4x7H_2O$ (0,37 g/l), KH_2PO_4 (0,17 g/l), Micronutrients: H_3BO_3 (6,2 mg/l), $MnSO_4xH_2O$ (22,3 mg/l), $ZnSO_4x7H_2O$ (8,6 mg/l), KI (0,83 mg/l), $Na_2MoO_4x2H_2O$ (0,25 mg/l), $CuSO_4x5H_2O$ (0,025 mg/l), $CoCl_2x6H_2O$ (0,025 mg/l).Vitamins: Thiamine-HCl (0.1 mg/l), Pyridoxine-HCl (0.5 mg/l), Nicotinic acid (0.5 mg/l), Myo-inositol (100 mg/l).Hormones: Auxin (Indole-3-acetic acid, 1 mg/l) and Cytokinin (6-Benzylaminopurine, 2 mg/l). Carbon Source: Sucrose (30 g/l).Gelling Agent: Agar-agar (8 g/l). Sterilization was performed in an autoclave at +121°C for 15 minutes. Meristematic tissues were placed in the nutrient medium, and the plants were grown at +25°C under a 16-hour light and 8-hour dark cycle [2]. In Vivo Conditions:In vivo, potato genotypes were planted in saline soil conditions. The level of salinity in the soil was determined using the Richards method [10]. Irrigation was conducted twice a week, providing 10-15 liters of water per plant for each irrigation. The plants were fertilized with the following nutrients: Macronutrients: NPK fertilizer (15:15:15), 500 g for every 10 square meters [7]. Micronutrients**:** Magnesium sulfate (25 g/10 m²), Boron fertilizer (20 g/10 m²). Organic fertilizer (poultry manure) in a 1:5 ratio was applied to the soil. The pH of the soil was maintained at 8.5, with temperatures around +35°C. Irrigation and fertilization were carried out according to the moisture level of the soil. **Determination of Chlorophyll a and b levels:** The quantities of chlorophyll a and b were determined using the method of Lichtenthaler and Wellburn (1983) [11]. Leaves from each plant were collected, extracted in 80% ethanol, and measured using a UV-VIS spectrophotometer.
Study of the Transpiration Process : The transpiration process was measured using the gravimetric method [12]. The leaf area of each plant was determined, and the amount of water lost was measured gravimetrically. Throughout the experiment, the transpiration rate was observed to depend on temperature, humidity, and soil salinity. **Statistical Analysis:**The obtained results were analyzed using the ANOVA method with the SPSS software. Differences in physiological indicators between each genotype were evaluated at a confidence level of $P < 0.05$. The correlation between the growth indicators of the plants was determined using the Pearson correlation coefficient [13].

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RESULTS The yield of crops grown in agriculture and their quality indicators are related to how efficiently they can absorb nutrients from the soil. However, in many cases, due to the impact of salts in the soil, plants are unable to assimilate the necessary nutrients and elements, leading to insufficient formation of natural substances that determine food value. This situation may result in potatoes lacking the necessary organic substances in their tissues, contributing to their susceptibility to various extreme conditions and leading to issues where the products do not meet ecological requirements.The primary objective of the research was to conduct a comparative study of the physiological development of biotechnological potato genotypes S-46, S-73, S-55, and S-17 under in vitro and in vivo conditions. Accordingly, the adaptability of these genotypes to soil and climatic conditions, including salinity and drought, was analyzed. Measurements for plant height, chlorophyll a and b levels, biomass, root system development, and transpiration process results were presented.

Comparative study of chlorophyll a and b content under in vitro and in vivo conditions: The levels of chlorophyll a and b reflect the photosynthetic capacity of the plants. The results indicate that the chlorophyll content in vivo conditions was significantly higher than that in vitro (Table 1). This is related to the stronger influence of nutrient availability and light conditions in the natural environment.

Table 1 Chlorophyll a and b content (mg/g) under in vitro and in vivo conditions

Genotyip	Chlorophyll a (*in vitro*)	Chlorophyll b (*in vitro*)	Chlorophyll a (*in vivo*)	Chlorophyll b (*in vivo*)
S-46	0,78 ± 0,05	0,39 ± 0,03	1,22 ± 0,07	0,61 ± 0,04
S-73	0,74 ± 0,04	0,37 ± 0,03	1,16 ± 0,06	0,58 ± 0,03
S-55	0,71 ± 0,05	0,36 ± 0,04	1,10 ± 0,06	0,55 ± 0,04
S-17	0,81 ± 0,05	0,40 ± 0,03	1,25 ± 0,08	0,63 ± 0,05

It can be seen from Table 1 that the S-17 genotype has the highest chlorophyll a and b content, reflecting its high photosynthetic activity. This genotype demonstrates effective nutrient uptake from the soil and efficient utilization of light

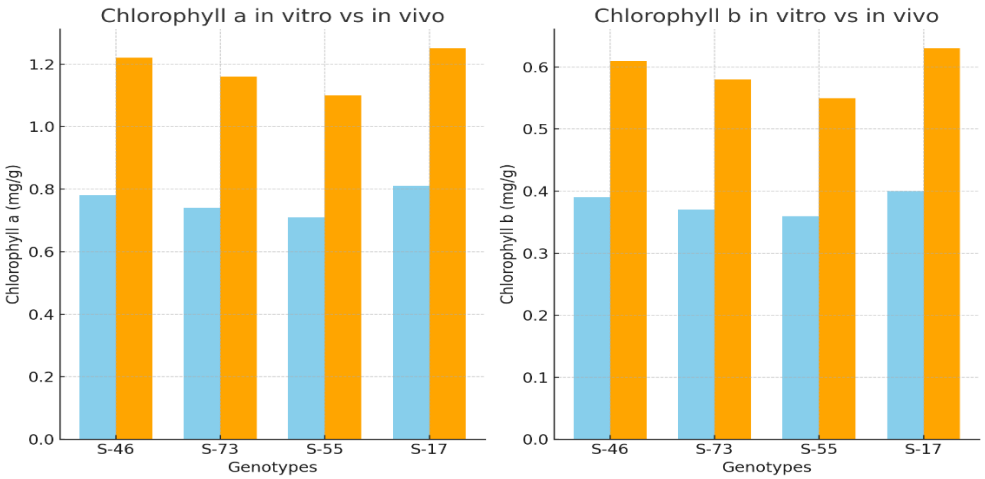

Figure 1.Chlorophyll a and b content (mg/g) under in vitro and in vivo conditions

ISSN NO: 2771-8840
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The chlorophyll a and b contents were significantly higher in vivo. In vitro, chlorophyll a ranged from 0.71 mg/g to 0.81 mg/g, whereas in vivo, it increased from 1.10 mg/g to 1.25 mg/g. The chlorophyll b content also showed an increase from 0.36 mg/g to 0.40 mg/g in vitro, while in vivo, it rose from 0.55 mg/g to 0.63 mg/g (Table 1 and Figure 1).

The higher levels of chlorophyll a and b in vivo indicate that light and natural conditions positively impacted the photosynthesis process. Specifically, it can be observed that the S-17 genotype was more efficient in the photosynthesis process, which is related to its chlorophyll content. In vitro conditions, with artificial lighting and limited nutrient availability, hindered the photosynthesis process (Table 1 and Figure 1).

Comparative analysis of the transpiration process under in vitro and in vivo conditions: The transpiration process reflects the plant's ability to retain moisture. In vivo conditions exhibited a higher transpiration rate compared to in vitro conditions, which is related to the natural loss of water in the soil and climatic conditions

Table 2.Transpiration Rate under In Vitro and In Vivo Conditions (mg H2O/cm²/h)

Genotype	Transpiration (*in vitro*)	Transpiration (*in vivo*)
S-46	2,30 ± 0,15	3,50 ± 0,21
S-73	2,20 ± 0,14	3,40 ± 0,19
S-55	2,10 ± 0,13	3,35 ± 0,18
S-17	2,35 ± 0,16	3,60 ± 0,22

According to Table 2, the S-17 genotype exhibited the highest transpiration rate, indicating a high level of water loss associated with its adaptability to environmental conditions and its capability to efficiently absorb nutrients and water from the soil. The elevated transpiration process under in vivo conditions is linked to the salinity levels of the soil, high temperatures, and low humidity, which contributed to the plants losing water more rapidly.

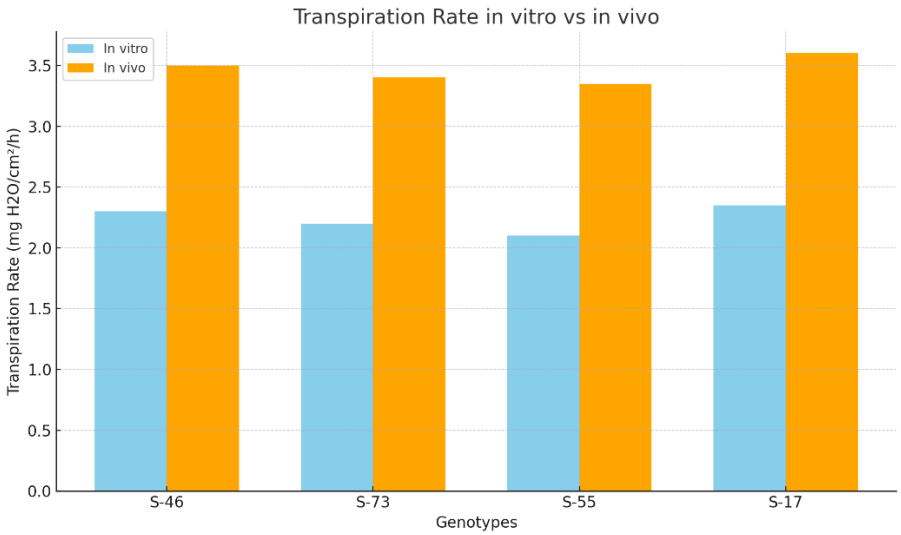

Figure 2. Transpiration Rates under In Vitro and In Vivo Conditions The transpiration process was found to be significantly higher under in vivo conditions compared to in vitro conditions. In vitro, the transpiration rate ranged from 2.10 mg H_2O/cm^2/hour to 2.35 mg H_2O/cm^2/hour, whereas in vivo, this rate increased from 3.35 mg H_2O/cm^2/hour to 3.60 mg H_2O/cm^2/hour (table2, figure 2).High water loss during the transpiration process was observed in vivo. This is related to soil salinity levels and harsh environmental conditions. Plants in vivo lost more water, resulting in an increased transpiration rate. This illustrates how plants adapt to drought and salinity stress. The S-17 genotype also exhibited the highest transpiration rate, confirming its high adaptability (Table 2 and Figure 2). The above results indicate that the S-17 genotype performed well across all metrics. This genotype exhibited the best growth under in vivo conditions,

ISSN NO: 2771-8840
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demonstrating high levels of chlorophyll content, biomass, and transpiration rates. This reflects its good adaptation to the dry and saline soil-climate conditions of the Bukhara region. Additionally, the development of the root system in this genotype is robust, allowing for efficient nutrient and water uptake from the soil in natural conditions.In vitro, however, all genotypes displayed comparatively lower performance levels. This is attributed to the limited nutrients and light in a sterile environment and insufficient space for the root system. Therefore, in vitro conditions require the appropriate provision of hormones and an optimal nutrient medium to support plant growth.

DISCUSSION

The results of the study allowed for an in-depth analysis of the growth characteristics of potato genotypes under in vitro and in vivo conditions. The findings were compared with data from the literature, and the observed differences were analyzed based on theoretical grounding. Plant Growth and Development:The results indicate that under in vivo conditions, plant height was significantly greater than in vitro. This aligns with previous studies, which noted slower growth in vitro due to limited resources in the nutrient medium. In vivo, plants absorb more nutrients from the soil, accelerating development.In our research, the S-17 genotype exhibited the best growth in vivo, highlighting its adaptability to soil-climate conditions. This finding is consistent with Levy and Veilleux (2007), who studied potato varieties with high adaptability in dry conditions. **Chlorophyll a and b Content:** The levels of chlorophyll a and b were significantly higher in vivo, which aligns with existing literature. Studies by Arnon (1949) and Lichtenthaler and Wellburn (1983) have noted that chlorophyll content is often higher under natural conditions, as light and natural nutrients accelerate the photosynthesis process [4], [5]. Our research results confirm this theory, as chlorophyll content was higher in vivo. In vitro, however, the chlorophyll content was lower, which can be explained by the artificial light source and nutrient limitations. These results are consistent with the findings of George and Sherrington (1984), who demonstrated that the photosynthesis process is restricted in vitro [6].In terms of chlorophyll a and b content, in vivo results were also significantly higher compared to in vitro conditions. The slower photosynthesis process in plants grown under artificial light in vitro resulted in lower chlorophyll content, as artificial light sources cannot replicate the effects of natural conditions.Under in vivo conditions, plants absorbed more nutrients from the natural soil and received natural light, leading to higher chlorophyll levels. This enhances the photosynthetic activity of the plants. Particularly, the S-17 genotype recorded high levels of chlorophyll a and b in vivo, indicating its higher efficiency in the photosynthesis process.The S-17 genotype achieved high results for both chlorophyll a and b in vivo (chlorophyll a – 1.25 mg/g, chlorophyll b – 0.63 mg/g). The levels of chlorophyll indicate the efficiency of the plants in the photosynthesis process and enhance the plants' ability to synthesize nutrients.The high chlorophyll content of the S-17 genotype suggests that it produces more nutrients during photosynthesis, showcasing its effectiveness in utilizing natural light and soil nutrients. The elevated chlorophyll levels enhance the plant's health and growth potential.

Transpiration Process: The higher transpiration process observed in vivo demonstrates the impact of environmental factors on the plants' ability to retain water. Research by Slatyer and McIlroy (1961) also noted that transpiration increases under high temperature and low humidity conditions [9]. Our study results showed that plants in vivo lost a significant amount of water, while this process was relatively lower in vitro. This indicates that environmental factors have a strong influence on the transpiration process of plants in vivo.The low transpiration process in vitro can theoretically be explained by the controlled environment in which the plants are grown, a result that aligns with the findings of Trejo-Tapia et al. (2002) [10]. It was determined that the transpiration rate in vivo was higher compared to in vitro conditions.In vitro, the transpiration process was relatively low, which is related to the controlled conditions where moisture loss is regulated. In sterile conditions, the transpiration process of plants is lower than that in natural conditions.In vivo, however, it was found that under conditions of soil salinity and high temperature, the rate of water loss in plants was also high. In this case, plants adapted to environmental stresses and lost more water. The S-17 genotype exhibited the highest transpiration rate, indicating its adaptation to dry and saline conditions.The S-17 genotype also achieved the highest transpiration rate (3.60 mg H_2O/cm^2/hour). This indicates the plant's water loss process and suggests that it has high characteristics in maintaining a balance between water uptake and loss.The S-17 genotype demonstrates resilience to water loss in drought and saline conditions with its high transpiration

ISSN NO: 2771-8840
June 2025

process. The elevated transpiration rate indicates that the plant has the ability to absorb more water from the soil through its well-developed root system. This shows that this genotype has high resilience to dry conditions.From the above analyses, it is evident that there are significant differences in plant growth between in vitro and in vivo conditions, which can be explained by soil-climate conditions, nutrient availability, light, and transpiration processes. Particularly, the S-17 genotype appears to achieve high results across all metrics, demonstrating good adaptation to dry and saline conditions.The high performance of the S-17 genotype in saline and dry climatic conditions indicates its good adaptability to these environments. Increasing productivity in dry and saline areas is crucial, and this genotype may play an important role in addressing these challenges. The advantages related to the drought and salinity tolerance of this genotype open up significant opportunities for selection and agricultural use. The S-17 genotype demonstrates the ability to withstand high stress through its physiological characteristics.The results of our study were largely consistent with the existing literature; however, some differences were also observed. Specifically, Lutaladio and Demirel (2007) noted that the development of the root system of potatoes in saline soil conditions was very weak, whereas our results showed that the S-17 genotype had a strong root system development [11]. This difference may be related to the level of soil salinity, irrigation regime, and the individual adaptability of the genotype. The superiority of the S-17 genotype is based on several factors:1.High chlorophyll content enhances the efficiency of the photosynthesis process, positively affecting the plant's growth and yield.2. The ability to effectively manage water loss (transpiration) allows the genotype to thrive even in drought conditions.

CONCLUSION

This study focused on the comparative analysis of biotechnological potato genotypes (S-46, S-73, S-55, and S-17) under in vitro and in vivo conditions in the saline and arid climate of the Bukhara region. The findings revealed that, under in vivo conditions, plant height, chlorophyll a and b content, biomass, and root system development were significantly enhanced. Notably, the S-17 genotype exhibited remarkable adaptability and physiological development in response to drought and salinity stress.The results indicated that plant growth in vitro was comparatively slower, with limited nutrient absorption in artificial conditions adversely affecting overall development. Furthermore, the study highlighted that in vivo conditions facilitated greater transpiration rates, which positively influenced plant health and growth. These insights are crucial for selecting highly adaptable potato genotypes for cultivation in challenging dry and saline environments, thereby contributing to sustainable agricultural practices in such regions.

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ISSN NO: 2771-8840
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