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EFFECT OF DROUGHT AND SALINITY STRESS ON PROLINE ACCUMULATION IN POTATO (*SOLANUM TUBEROSUM* L.) GENOTYPES

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Abstract. The study of the mechanisms of plant resistance to unfavorable factors of various natures is one of the priority areas; it will allow us to get closer to understanding their nature and thereby effectively control ways to increase plant productivity. The purpose of this work was to study the activity of proline synthesis in potatoes under the influence of drought and salinity. As a result of the research, genetic variability in the accumulation of proline in potato samples exposed to abiotic stress factors was revealed. An increase in proline content was observed under both drought and salinity conditions. Moreover, with a more significant effect of drought stress, the proline content in leaves increased more significantly compared with a less significant effect of this factor. Based on cluster analysis of the results of changes in proline synthesis activity, a dendrogram was compiled that included 4 clusters. Under salt stress conditions, these genotypes had relatively low proline content. Thus, in our studies, exposure to abiotic stress factors led to a significant increase in the amount of free proline in potato plant tissues. Considering the fact that proline functions as an osmoprotector and antioxidant, it is clear that increasing its amount is aimed at protecting the plant from the negative effects of stressors.

Keywords: *Potatoes, drought, salinity, resistance, proline.*

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1. Introduction

The beginning of the 21st century was marked by a shortage of global water resources, environmental pollution and an increase in soil and water salinity. Abiotic stress is a major factor limiting plant growth and it will soon become even more severe

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as desert lands cover more and more areas of the world (Vinocur & Altman, 2005). As population growth outpaces food reserves, significant changes in agricultural practices are needed around the world.

The potato plant (*Solanum tuberosum* L.) from the nightshade family is of great importance as a food product throughout the world (Zaheer & Akhtar, 2016; Xu *et al*., 2023). This is an important source of carbohydrates, proteins, vitamins, minerals (Beals, 2019). Taking the third place in terms of use as food products after wheat and rice, potatoes are very sensitive to long-term water deficit at the stage of growth and development (Evers *et al*., 2010; Nasir & Toth, 2022).

Although potatoes have a wide range of distribution, the yield potential of varieties varies greatly depending on the region. Azerbaijan unites agricultural regions with very different ecological characteristics. For this reason, in our country, we should use varieties with high general adaptability and not varieties with special adaptability in certain areas.

In recent years, a number of works have been published showing a complex of physiological changes occurring in plants in response to stress (Gervais *et al*., 2021). At the biochemical level, in response to drought stress, the synthesis and accumulation of physiologically active substances in the tissues of potato genotypes is observed (Chen & Murata, 2008). As a result, leaf cells can absorb more water from the soil in order to save water in the leaf. The mechanism of drought resistance of plants on a morphological, physiological and molecular basis is described (Farooq *et al*., 2009).

Salt stress is also an important abiotic factor affecting growth and plant secondary metabolism (Hasanuzzaman & Fujita, 2022). Faried and his colleagues note that soil salinization negatively affects the growth and productivity of potato plants, especially in arid and semi-arid climates (Faried *et al*., 2002). A large amount of Na^+ accumulated in plant cells reduces the ability of plants to absorb water from the soil. Joint osmotic and ionic stresses reduce the expansion of cells and tissues, cause an imbalance of nutrients, thereby negatively affecting the growth, development and survival of plants (Carillo *et al*., 2019). Plants have protective mechanisms of adaptation to salt stress, such as synthesis of physiologically active substances, resistance to antioxidant stress and oxidation of membrane lipids (Gao *et al*., 2015).

One of the first stress-induced responses of plants is the accumulation of proline (2-pyrrolidinecarboxylic acid) - a stress metabolite, the content of which increases strongly under stress, which is associated with the breakdown of chlorophyll and proteins. Currently, it has been established that proline - a polyfunctional compound - plays an important role in maintaining cellular metabolism, showing osmo-regulatory, stress-protective and signaling effects, but is also an antioxidant involved in the neutralization of some active forms of oxygen (Hayat *et al*., 2012).

According to the researchers, the increase in the content of proline is probably the result of its *de novo* synthesis, since the expression of genes encoding the key enzymes of its biosynthesis increased under drought conditions.

In drought-resistant wheat varieties, proline content increased under the influence of drought (Ahmed *et al*., 2013).

The accumulation of proline in the body of plants is important both for the survival of plants under stress conditions, as well as for recovery during the period of rehydration (Ashraf & Fooland, 2007). In some studies, the ability of cells to accumulate proline is considered as a selective trait used in assessing the drought resistance of varieties and species (Chaves & Oliveira, 2004).

Under salt stress, in response to an imbalance of inorganic ions and water regime in the plant, there is an increase in the accumulation of proline in plants, as well as substances of a phenolic nature, such as low molecular weight soluble phenolic compounds (Siripornadulsil *et al*., 2002; Blokhina *et al*., 2003).

There are reports in the literature that under conditions of salt stress, proline performs a number of stabilizing functions: it participates in the process of osmoregulation, reducing the water potential of the cell by increasing the accumulation of osmotically active organic substances and ensuring the flow of water into the plant from saline soil, has protective properties, interacting with proteins, increases the solubility of the latter and protects them from denaturation under stress, changes the state of water in biological membranes, restoring their hydration (Diamant *et al*., 2001; Yousfi *et al*., 2010) and takes part in the detoxification of ROS (Meena *et al*., 2019).

Numerous studies of the effect of salinity on the plant organism have shown the antioxidant role of proline (Ahmad *et al*., 2010; Fan, 2012; Moukhtari *et al*., 2020).

There is a positive correlation between an increase in proline content in the cell and the ability of plants to survive salinity (Haves & Oliveira, 2004). According to researchers, the accumulation of proline during osmotic stress is associated with an increase in synthesis and a decrease in its degradation (Abraham *et al*., 2003). The kinetics of accumulation of this substance depends on the intensity and duration of stress (Zhao *et al*., 2021).

Currently, the effect of individual stress factors on plants is being intensively studied. However, in nature, plants are usually exposed to various combinations of abiotic stresses, such as the combined effects of drought and salinity (Mittler, 2006). The greatest accumulation of proline was observed under combined stress (Ahmed *et al*., 2017). It has been suggested that water stress in saline soils exacerbates the toxic effects of stress by limiting water uptake by roots and the ability of plants to withstand drought (Grewal, 2010).

An increase in the content of free proline under stress conditions is the result of NaCI-dependent expression of genes encoding the enzymes of its biosynthesis: pyrroline-5-carboxylate synthetase and pyrroline-5-carboxylate (Goharrizi *et al*., 2020).

Considering the above, the purpose of this research was to study changes in the amount of proline in potatoes under conditions of abiotic stress - drought and salinity.

2. Materials and methods

During the research, a sustainability assessment was carried out to drought and salinization of a collection of potato plants of strategic importance for Azerbaijan. As shown in Table 1, the object of the study was 50 local and introduced potato genotypes, where the activity of proline accumulation under the influence of abiotic factors was studied.

To create drought stress sucrose solution was used at an osmotic pressure of 3.5 and 7 atm, salt stress was created with a 0.2 M NaCl solution at an osmotic pressure of 9 atm. During the research, the amount of proline in the leaves of 50 potato samples subjected to abiotic stress was determined. The amount of proline was determined by the Bates et al. (1973) method.

$$C=\frac{E \cdot K \cdot V}{m}$$

C - concentration of proline (μM/g raw mass);

E - optical density;
K - coefficient (calculated according to the calibration curve);
V - extract volume, (ml);
m - volume of crushed material (g).

Statistical analysis was carried out using the statistical computer program PAST (PAleontological ST) atistics (Hammer, 2001).

Table 1. The study used 50 local and introduced potato genotypes

No	Code	Name of of samples	№	Code	Name of of samples
1	SF1	Agata	26	SF26	Murlie
2	SF2	Agila	27	SF27	Murovdag
3	SF3	Agilo	28	SF28	Neptun
4	SF4	Alious	29	SF29	Olivea-A
5	SF5	Allergiya	30	SF30	Oqonyok
6	SF6	Anna Karella	31	SF31	Orkestr
7	SF7	Anna lona	32	SF32	Qelebe
8	SF8	Anna Sh.	33	SF33	Qretola
9	SF9	Aranda	34	SF34	Sarishin
10	SF10	Arinda	35	SF35	Sarqunmira
11	SF11	Arizona A.	36	SF36	Sartala
12	SF12	Arizona B-clas	37	SF37	Sevinj
13	SF13	Berhina B-c	38	SF38	Silvina
14	SF14	Carrera	39	SF39	Sipropetu
15	SF15	Chanlibel	40	SF40	Sirvina
16	SF16	Colombo	41	SF41	Slavyanka
17	SF17	Emir	42	SF42	Sloretta
18	SF18	Fabula	43	SF43	Soraya
19	SF19	Gedabay	44	SF44	Shovgi
20	SF20	Impola	45	SF45	Suipatte
21	SF21	Kamal	46	SF46	Telman
22	SF22	Larise	47	SF47	Turan
23	SF23	Manague	48	SF48	Ugur
24	SF24	Manaque	49	SF49	Uniko
25	SF25	Marotona	50	SF50	Vagif

3. Results

As a result of our research, genetic variability of proline accumulation in potato samples exposed to stress factors was revealed. The dynamics of changes in the content of proline when exposed to drought stress are presented in Figure 1. A significant variation of proline content indicators was observed in all studied variants. In the control, the amount of proline varied between 2.3-5.3 μM/g, the minimum value of which was noted in genotype SF3 and the maximum value in genotype SF42.

The study of the reaction of potato plants to drought stress was carried out when exposed to osmotic solutions of medium and high concentrations of sucrose. In all variants of the experiment, an increase in the amount of proline was observed. With a slight effect of drought stress (3,5 atm), the amount of proline changed in the range of 4.3-30 μM/g. The minimum value of this indicator was noted in the SF4 genotype, the maximum - in the SF40 genotype. The increase in proline compared to the control was

2-9 times. The amount of free proline in genotype SF40 exceeded the control plant by 9 times.

At higher sucrose concentrations, the proline content in leaves increased more significantly. Thus, in conditions of severe drought, the value of this indicator exceeded the control by 4.1-9.5 times. Compared to the control, the smallest increase was observed in the SF29 genotype and the largest in the SF41 genotype. In general, the amount of proline varied in the range of 9.5-50.4 μM/g, which corresponds to the experimental variants SF33 and SF41, respectively.

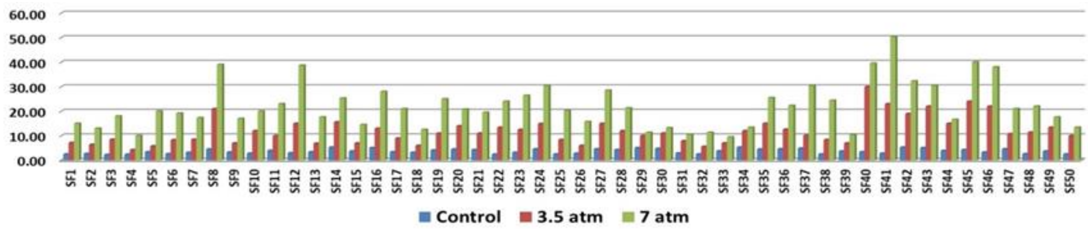

Figure 1. Amount of free proline in potato genotypes under drought conditions (3.5 and 7 atm)

Figure 2 shows that studies on proline synthesis under the influence of salinity in potatoes found that its amount in plant leaves varies from 7.2 to 37.7 μM/g. The lowest value was noted in genotype SF33, which was 2.5 μM/g, exceeding the control indicator by 1.5 times. The highest level of proline under the action of salt stress, which was 32.5 μM/g and exceeded the control by 7.25 times, was recorded in genotype SF45.

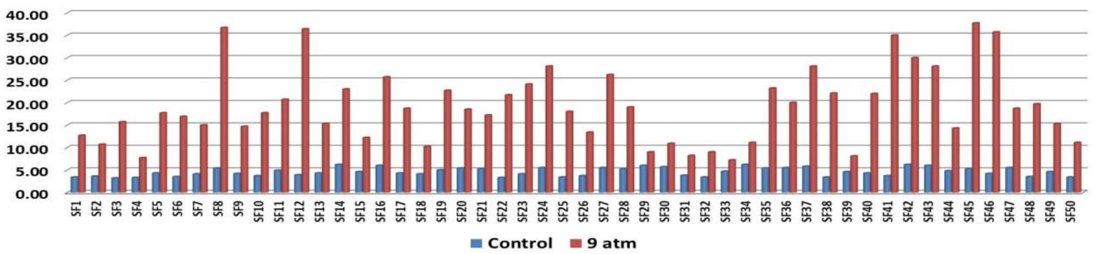

Figure 2. Amount of free proline in potato genotypes under salinity conditions (9 atm)

Cluster analysis was conducted using the Euclidean genetic distance index based on the UPGMA method of the PAST statistical program package. From Figure 3 it can be seen that, based on the results of changes in the amount of proline under stress, the dendrogram grouped the studied genotypes into 4 clusters.

The first cluster of the dendrogram included the genotype FS40, identified as divergent. In drought conditions, at 3.5 atm, the proline content reached the highest level in comparison with other genotypes, amounting to 30 μM/g and at 7 atm - the average value (39.5 μM/g). In conditions of salt stress, the amount of proline had an average value of 22 μM/g. The second cluster of dendrograms combined 5 samples of potatoes.In genotypes grouped in this cluster, the amount of proline under stress was at the maximum level. Thus, during drought, the amount of proline varied within 3.5 atm, within 15-24 μM/g., at 7 atm - within 38-50 μM/g. In the conditions of salt stress, the content of proline was characterized by a high indicator, being in the range of 35-37.7 μM/g. genotypes were included in the third cluster of dendrograms. In the genotypes grouped in this cluster, the indicators of the amount of proline under stress conditions were moderate.

Thus, under conditions of drought at 3.5 atm, the average value of the amount of proline in these samples varied within 11-22 μM/g and at 7 atm - within 24-30.4 μM/g. The amount of proline under salt stress was at the level of 21.7-30 μM/g. The fourth cluster represented the largest group of the dendrogram, including 33 genotypes. Genotypes grouped in this cluster had a low level of proline under abiotic stress. Thus, during drought at 3.5 atm, the proline quantity index varied within 5.6-15 μM/g and at 7 atm - within 9.5-24.4 μM/g. Under salt stress, proline content was low and fluctuated between 7.2-22.1 μM/g.

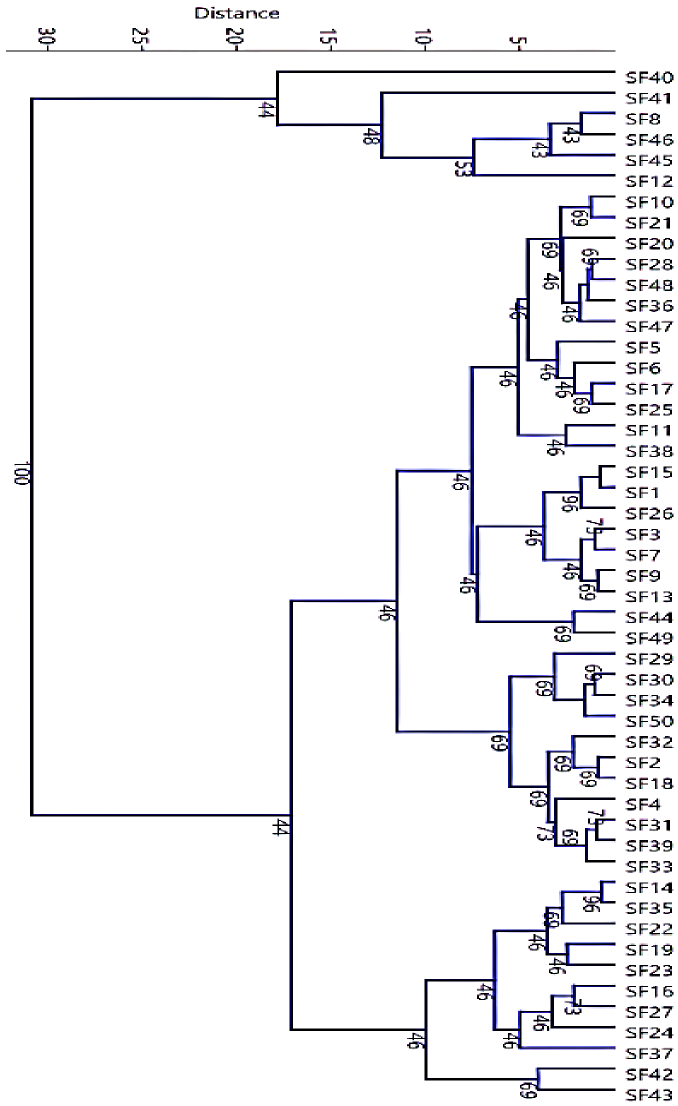

Figure 3. Dendrogram, built on the variation of proline content in potatoes

PCA (Principal Component Analysis) is used to reduce the size of the data obtained during the analysis. Of course, during this process, some features of the data will be liquidated. The main goal here is to preserve the stability of changes and reduce the number of errors to a minimum. In addition, since PCA reduces multidimensional data, it allows data visualization. From Figure 4 it is clear that, as in the PCA cluster, the studied genotypes were divided into 4 main groups according to changes in the amount of proline under stress conditions.

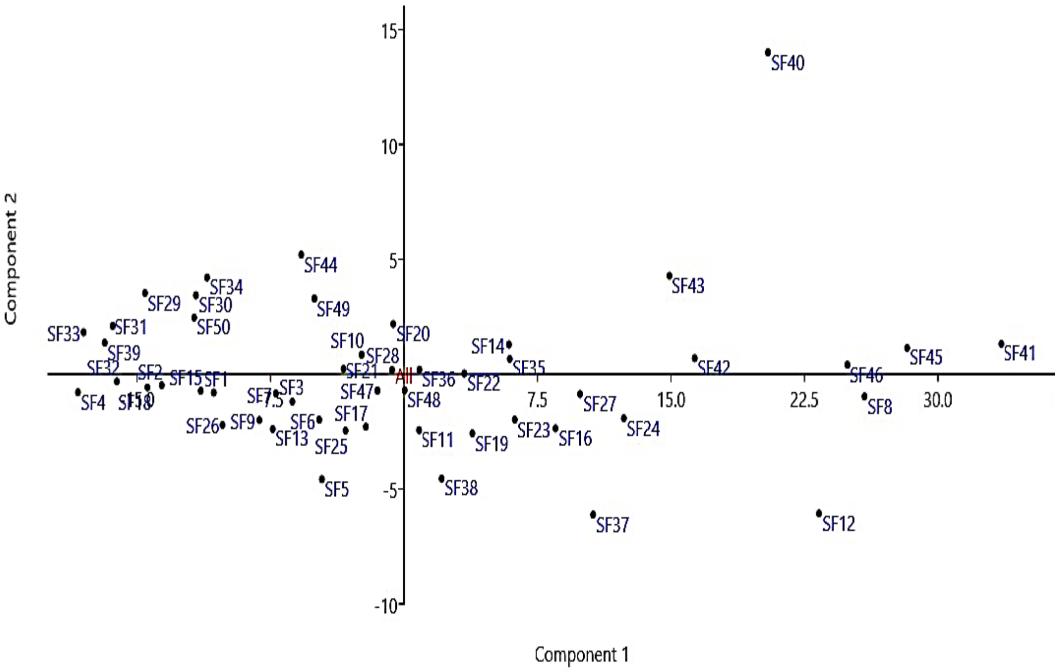

Figure 4. PCA, built on the variation of proline content in potato proline

4. Discussion

Thus, in our studies, exposure to a stress factor led to a significant increase in the amount of free proline in the tissues of potato plants. The activation of proline synthesis in potato leaves under the influence of drought and salinity stress noted in our studies is consistent with the results of the work of other authors. High proline accumulation in potato leaves after drought stress was noted in studies by Sprenger et al. (2016). An increase in the level of proline in the leaves of all studied potato lines under conditions of water deficiency was noted by Knipp and Honermeier (2006). An increase in the amount of proline in potato leaves under drought conditions was noted in the work of Samy (2021). In work Mansur and Ali (2017) the opinion is expressed that the accumulation of proline plays an important role in the salt resistance of plants. This supposed role in adaptation to salt is based on the data that salt-tolerant plants have a higher proline content compared to sensitive genotypes. Rodriguez-Delfín and colleagues (2012) under conditions of salt stress in potato leaves and tubers note a significant increase in proline content. The accumulation of proline in potatoes under salt stress conditions was noted in the work of Sanwal and colleagues (2022).

Considering the fact that proline functions as an osmoprotector and antioxidant, it is clear that increasing its amount is aimed at protecting the plant from the negative effects of stressors. There is an opinion that the ability of proline to neutralize AFC is possibly one of its most important functions (Chourasia *et al*., 2010). Based on data from the literature (Gill & Tuteja, 2010), it can be assumed that in drought conditions, proline could reduce the concentration of AFC in the cell and thus increase the efficiency of the antioxidant system as a whole. The accumulation of proline during osmotic stress is associated with an increase in its synthesis and a decrease in its degradation (Abdelaziz *et al*., 2018).

5. Conclusion

One of the top priorities is the research of how plants resist different types of adverse circumstances; this will help us better understand these aspects and control strategies to boost plant output. The aim of this study was to investigate how salinity and drought affected the activity of proline synthesis in potatoes. The response of potato plants to drought stress was assessed at sucrose osmotic pressure of 3.5 atm and 7 atm; salt stress was created with a 0.2 M NaCl solution at an osmotic pressure of 9 atm. The study's findings demonstrated genetic heterogeneity in proline accumulation in potato samples subjected to abiotic stressors. Both salinity and dryness were associated with an increase in proline content. Furthermore, the proline content in leaves rose more dramatically when drought stress had a greater impact than when it had a less significant effect. A dendrogram including four clusters was created using cluster analysis of the data pertaining to variations in proline synthesis activity. The first cluster included one genotype identified as divergent. The second cluster united 5 samples characterized by high proline content. The third cluster of the dendrogram included 11 genotypes in which the amount of proline under stress conditions was moderate. The fourth cluster was the largest group in the dendrogram, containing 33 genotypes. These genotypes have comparatively low proline levels when exposed to salt stress. Accordingly, in our investigations, the amount of free proline in potato plant tissues increased significantly as a result of exposure to abiotic stressors. Given that proline serves as an antioxidant and osmoprotector, it is obvious that raising its levels is intended to shield the plant from the damaging effects of stresses.

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