DOI: 10.34101/ACTAAGRAR/1/15256

The effects of climate change and drought stress on potato production – A review

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SUMMARY

Potato (Solanum tuberosum) is the fifth most important cultivated crop according to its growing area and fourth by its production volume. Originated from the Andes of South America throughout the last five centuries spread over the world and became a global staple food. Over the years potato production has greatly evolved due to advancement in agrotechnology reflecting in higher yields contrary to the worldwide decreasing production area. The wide range of potato's ability for adaptation allows it to thrive in many different soil types and climates making it a main contributor in food security. Nonetheless rising temperatures, extreme weather events, water scarcity driven by climate change imposes serious challenges and threats for global potato production.

This review presents the short history of potato cultivation, statistics of present and past production and agroecological needs for ideal farming. The review also attempts to explore the impact of climate change on potato growing spotlighting on drought and heat sensitivity. To deal with these climate change induced challenges several mitigation options are proposed just as foliar applications of salicylic acid, hydrogen peroxide, silicon and micronutrients to elevate perseverance against abiotic stresses.

Keywords: *potato; climate change; drought; heat stress*

INTRODUCTION

Potato *(Solanum tuberosum* L.*)* was first cultivated in the Andes, South-America around 7000 YBP, however tubers of wild species might had been consumed at least thousands of years before (Bentley, 2016). Long before the Spanish conquistadors set foot on the South-American shores the Andes cultures had already developed an efficient potato cultivation system (Love et al., 2020). Probably the first European encounter with the potato was Francisco Pizzaro's expedition in 1502 (Smith, 2012). The versatile crop was introduced to Europe during the time of Spanish colonization of Latin-America. In official literature potato was first mentioned in 1552 by López de Gómara, however the European potato production started a decade earlier on the Canary Islands (Hawkes et al., 1993). Later in the 16th century the potato conquered the British Islands and in the 17th century arrived to the Old-Continent. The Great Potato Famine also should be mentioned, which happened in Ireland between 1845–52, and was a consequence of monocultural, agronomic mismanagement, which led to a wide-ranged late blight infection (*Phytophthora infestans*) (Bradshaw et al., 2009). In the 18th–19th century potato became an important food crop, especially in poor European regions. In North America it was spread by European immigrants, who had taken the tubers with them. In the 19th century potato was introduced to many sub-tropical and tropical countries, mostly by European colonists. In more recent times the potato has appeared on countries with drier and warmer climates and became a dominant plant in such territories as India, Bangladesh, Central America, Argentina, North Africa, etc. (Beukem and van der Zaag, 1990).

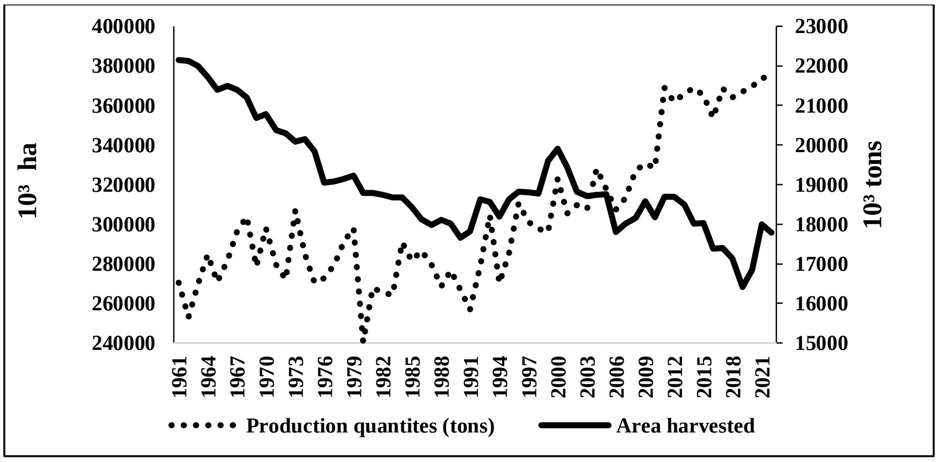
Potato production in numbers

Due to its yield potential and nutritional value, potato plays an important role in mass feeding as a staple food and also a major industrial commodity. Since 1961 to 2022 the potato production area worldwide decreased from 22.1 million to 17.7 million hectares, while the produced amount of tubers has increased from 270.5 to 374.7 million tons during the same period (*Figure 1*). There reason behind the growing tendency is the increase in the yield potential, which has increased by 59% since 1961.

Between 2000 and 2022 the biggest potato producer countries were: China, India, Russia, Ukraine, USA, Germany, Poland, France, Bangladesh and The Netherlands (*Figure 2*). During the same period of time Asia led the worldwide production by a share of 46.2%, Europe was second with 34.3% and America was the third with a share of 12.5% (*Figure 3*).

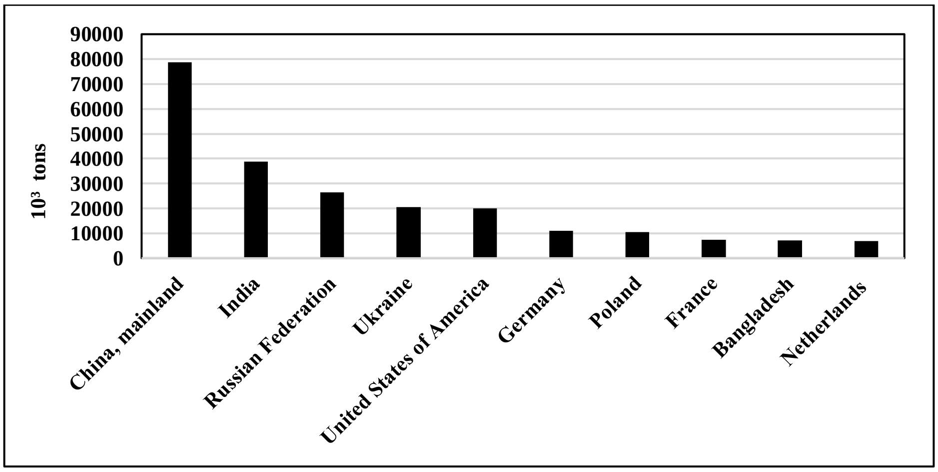
DOI: 10.34101/ACTAAGRAR/1/15256

Figure 1. **Production quantities and harvested area of potatoes in World (1961–2022)**



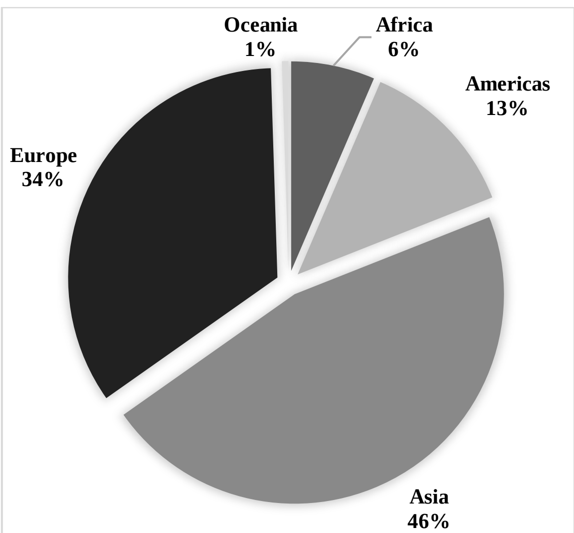
Data source: FAOSTAT (2024)

Figure 2. **Top 10 potato producers of the world 2000–2022 (tons)**



Data source: FAOSTAT (2024)

Figure 3. **Regional share of potato production during 2000–2022**



Data source: FAOSTAT (2024)

In the year of 2022 potato had the fifth largest growing area worldwide, with 17.7 millions of hectares of harvested area. According to produced quantities potato was the fourth largest following corn, wheat and rice, although potato had the highest yield/unit with 21 tons/hectares performance (*Table 1).* Worth mentioning the fact that 85% of the total biomass of the potato is edible while the average ratio of cereals approximately 50% (Lutaladio et al. 2009).

Table 1. **Most important crops in 2022 (Worldwide) according to produced quantity and harvested area**

Crop	Produced quantity (million tons)	Harvested Area (million hectares)	Yield (Tons/ha)
Corn	1163.4	203.4	5.7
Wheat	808.4	219.1	3.6
Rice	776.4	165	4.7
Soy Beans	348.8	133.7	2.6
Potato	374.7	17.7	21

Data source: FAOSTAT (2024)

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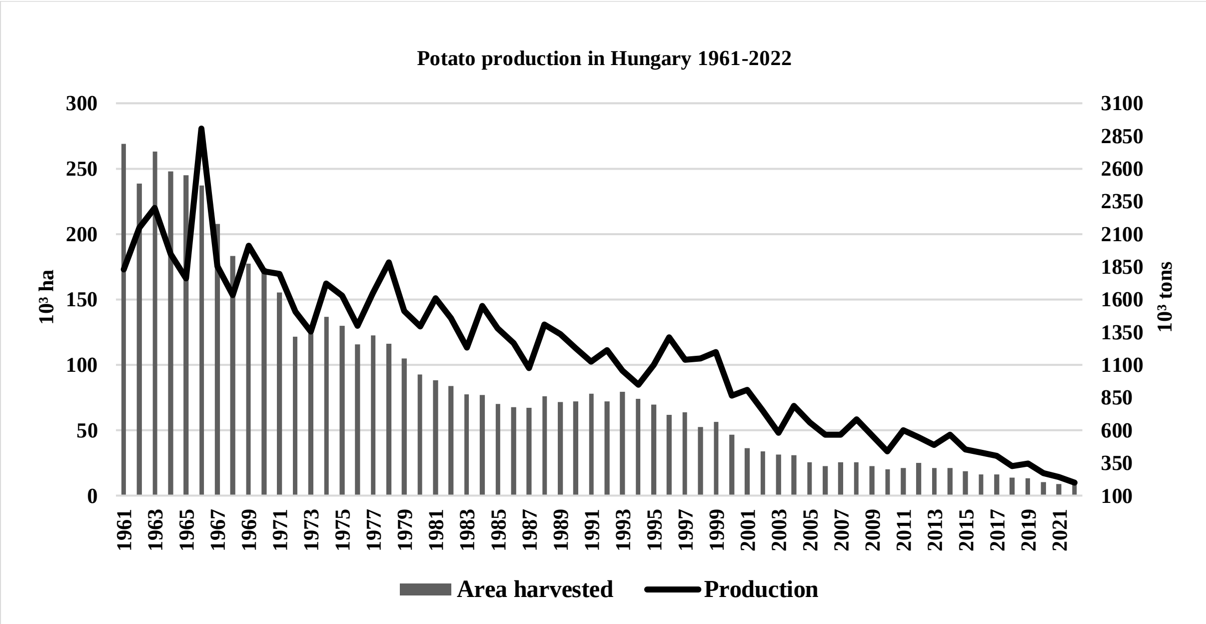
In Hungary both the harvested area and the production has drastically decreased since 1961. (*Figure 4*) Hungarian potato production shrunk to such a degree, which itself cannot cover the demand of the local market and the country has to import potato to supply the needs for this staple product.

Figure 4. **Potato production in Hungary 1961–2022**



Data source: FAOSTAT (2024)

RESULTS AND DISCUSSION

Although potato has evolved 2500–3500 meters above sea level it has a high level of adaptability for that reason it can be cultivated in various climates and soil types (Sárvári, 2022). Nonetheless potato can adapt to wide range of circumstances, but a line can be drawn where potato can be grown effectively. Best areas for growing are those where the average temperature during the hottest months is approximately somewhere between 15–21 degree Celsius. According to these information Northwest-Europe is perfectly suitable for potato cultivation, and also can be said Hungary is at the southern boarder of the potato cultivation area (Sárvári, 2022). The most suitable for potato growth is the cool temperature, while potato does not perform well in hot conditions (Haverkort, 1990). For vegetative growth 18–25 degree Celsius, for tuber initiation and bulking 4–18 degree Celsius is the most beneficial for optimal development (Reddy et al., 2018). The stem development starts at 7–8 degree Celsius, while the root development already starts at 3–4 degree Celsius. During the vegetative period the potato needs 1300–1500 degree Celsius of heat sum (Sárvári, 2022).

For optimal growth the plant needs 350–550 mm water during vegetation period based on soil type, variation and climate (Reddy et al., 2018). The crop needs balanced water distribution throughout the growing season. The maximal water need occurs at the phenological phases of tuber initiation and bulking, which is around 300–350 mm. The potato can be cultivated in different types of soils with a pH ranging between 5 to 7.5. Between these pH values the crop could perform the best, especially if the soil has a high puffer capacity. The soil should at least has a medium supply of nutrients with mildly acidic to a neutral pH range (Sárvári, 2022). The most suitable for the plant is a good quality loamy type with a high organic matter content (Reddy et al., 2018).

Climate change and potato

Climate change defined by Intergovernmental Panel On Climate Change. (IPCC) as "Any change in climate over time whether due to natural climate variability or as a result of human activity“ (Pielke, 2004). It is a controversial scientific topic, but data shows clear evidence of changes. According to the IPCC's prediction the global temperature will increase somewhere between 1.1 to 6.4 degree Celsius. Beside the raising temperature weather anomalies, extreme weather events such as storms, heath weaves, cold spells and drought can have a significant effect on potato growing and on potato yields. On territories where potato growing is impossible or limited due to cold weather temperature increase could be beneficial for future potato cultivation by establishing new growing areas. However, potato production is likely to increase in different territories with increased temperature due to the longer growing season nevertheless possible water scarcity can largely affect attainable yields (Daccache et al., 2011). Therefore, there is a possibility for present rainfed growing areas will also need irrigation to preserve current yields,

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which will increase irrigation water need and will make potato growing more expensive (Daccache et al., 2011). Beside climate change globally increases temperatures its influence on regional weather hardly predictable nevertheless increasing climatic variability and weather extremes most likely will have a significant effect on crop production and arable farming (Harkness et al., 2020).

Negative effects of temperature changes

According to Hijmans (2003), growing temperatures will have a decreasing effect on potato yield, however the degree of yield decrease will vary depending on the growing area. Temperatures higher than 30 degrees Celsius can cause various problems: slower tuber initiation and growth, brown spots on the tubers, lower rates of starch partitioning, shorter dormancy of the tubers (Levy and Veilleux, 2007). These aforementioned effects will likely negatively affect tuber numbers and weight. On places where high temperature is closely a limiting factor for potato cultivation crop yields will suffer serious decreases (Hijmans, 2003). At places where frost damage can occur, growth be can be reduced and tubers can be damaged (Haverkort and Verhagen, 2008).

Drought sensitivity

There is a probability that water resources can be decreases due to climate change. Also extreme raining events flash flooding can happen even in places, where yearly precipitation predicted to decrease (Haverkort and Verhagen, 2008). Continuous water availability is a crucial factor for potato growing. Potato is a water-efficient crop, although very susceptible for drought due to the fact that most potato breed have shallow root system, which makes difficult to absorb water from deeper soil layers (Van Loon, 1981). There is a positive correlation between root length and tuber yield in drought conditions (Lahlou and Ledent, 2005). Potato efficiently uses water nonetheless without balanced water distribution potato needs irrigation. In many different regions due to overall reduced amount of rainwater makes irrigation mandatory (Cantore at al., 2014). Drought can have a harsh effect on potato plant both on a physiological and morphological level of the plant such as decrease of tuber yield and tuber number, decrease of leaf area, stomatal conductance, photosynthetic rate. (Rodríguez-Pérez et al., 2017; Schafleitner et al., 2007). Drought causes overall weak plant performance and loss of tuber yield. The main influencing factor of tuber loss is the severity and duration of drought periods as well as phenological state of plant (Stark et al., 2013; Aliche et al., 2018; Plich et al., 2020). The potato in the early growth stages is more exposed to drought induced damages. In early development stages drought can reduce leaf area, photosynthetic rate, lowers the rate of assimilation which leads to lower performance in tuber initiation, tuber bulking and overall tuber yield (Evers et al., 2010; Obidiegwu et al., 2015). Drought can cause severe effects during stolon initiation and tuber formation (Aliche et al., 2020). Drought induces stomatal closure, which is a mechanism evolved to conserve water, however it is a useful survival mechanism, but also prevents CO_2 diffusion, that makes the Calvin-cycle substrate limited and inhibits assimilation (Pinheiro, 2011). Quality traits also influenced by drought such as starch content (Meise et al., 2019). Water restrictions reducing starch accumulation (Rudack et al., 2017; Ma et al., 2024). Michel et al. (2019), found in his study leaf area index (LAI) was significantly reduced by drought in three breeds Moonlight, Karaka, Russet Burbank. Drought reduces chlorophyll content. Hossain et al. (2014) compared 5 different potato cultivars in well-watered, moderate drought and in severe drought conditions, the found that well-watered plants showed the highest SPAD index values, second were plants under moderate drought conditions, while plants in severe drought conditions delivered the lowest SPAD index values.

Heat sensitivity

Heat stress induced by high temperatures both influences the yield and quality of potato tubers, by causing tuber deformities, second-growth, elongation, chain tuberization, gemmations, etc (Rykaczewska, 2013). Heath stress in the course of plant growth can shorten the dormancy interval of potato tubers (Levy, Veilleux, 2007). According to Rykaczewska (2015), drought stress combined with heat stress reduced the yield of certain stress sensitive breed by 50%, while less sensitive cultivars suffered a yield decrease of 25%. The effects of heat stress on potatoes are the most severe when occurs together with drought, resulting in significant yield loss (Levy, 1986). Lazarević et al. (2022), found in their experiment that LAI significantly decreased by increasing temperatures. According to Zhang et al. (2022) heat stress increased plant height by 64% and SPAD index values by up to 65% while reduced LAI and severely reduced the largest tuber's mass by 93%.

Mitigation options of drought and heat stress on potato

Foliar application of salicylic acid

Foliar treatment with salicylic acid is useful to ease drought symptoms on potatoes, hence it is a good treatment to mitigate water deficit (Acevedo et al., 2023). Metwaly and El-Shatoury (2017) designed an experiment which was based on randomized complete block design with three replications. Irrigation water in the quanity of 700, 1000 and 1300 m^3/0,42 hectares were applied in the main plots, while salicylic acid as foliar application (0.0, 0.1, 0.2 and 0.3 g per liter.) were randomly assigned in the sub plots and applied 2 times during vegetative growth period. Throughout the experiment they found that the harmful effects of drought on the growth and productivity of potato can be alleviated by foliar application of salicylic acid. According to El-Areiny et al. (2019), the foliar application of salicylic acid to potato plants gave, significantly improved values of both yield and quality

DOI: 10.34101/ACTAAGRAR/1/15256

compared to untreated plants. Salicylic acid foliar spray treatment improved water stress resistance characteristics in potatoes. Salicylic acid foliar application improved water use efficiency, electrolytic leakage, relative water content in plants under stress conditions (Hasan et al., 2023).

Foliar application of hydrogen peroxide:

Moussa et al. (2012) set up an experiment where four cultivars were used: Anushka, Dora, Vivaldi, Universal. The plants were treated two times per week in four different concentrations of peroxide (zero, 20, 40 and 60 mM). The starch percentage of tubers was significantly increased, with the increasing amount of peroxide, however the highest percentage of tuber dry matter content was produced by the plant which was sprayed with the 40 mM hydrogen peroxide concentration. Lopez-Delgado et al. (2005), found in their experiment that by spraying potato plant two times per week, from 21 to 90 days after planting, with 5 and 50 mM hydrogen peroxide (H_2O_2) solutions showed significantly higher tuber starch accumulation by 6.7% and 11.0% respectively and stem diameters 27.0% and 21% higher compared to the control. Hydrogen peroxide can be effectual to improve the quality of potato tubers. Yaseen et al. (2014) concluded foliar application of hydrogen peroxide on potato plants positively affected tubers starch content. Spraying potato plants with hydrogen peroxide at the rates of 50 or 75 mM starting from 40 days of planting two times per week until maturity stage led to enhancement both dry matter and tuber starch.

Foliar application of silicon

Foliar-applied silicon had a positive effect on the osmotic adjustment, antioxidant enzymes (CAT and/or SOD) activities and photosynthetic apparatus maintenance and also decreased H_2O_2 concentration in leaves of drought-stressed potato plants. Foliar silicon application increased tuber dry weight and helped to maintain fresh tuber yield of potato plants under water deficit (Pilon et al., 2014). The application of foliar silicon has been shown to effectively enhance plant growth and boost the yield of early potato crops under drought conditions. During periods of water deficiency, the silicon-based bio-stimulant Optysil (Na_2SiO_3) was applied at the BBCH 14–16 leaf development stage, leading to significant improvements in the growth and productivity of early-season potatoes (Wadas and Debski, 2021). Wadas and Dębski (2021) noted that the use of the silicon-based biostimulant Optysil resulted in an increased assimilation area and enhanced leaf dry weight, as well as higher contents of chlorophyll-a, chlorophyll-b, and carotene. According to Crusciol et al. (2009) foliar silicon application reduced stalk lodging and increased mean tuber weight and tuber yield. According to Seleiman et al. (2023) negative effects of drought on quality and productivity traits of potatoes could be mitigated application of silicon.

Foliar application of micronutrients

The application of micronutrients through foliar treatment on potato plants has been shown to significantly increase tuber yield, the number of tubers per plant, and the dry matter percentage. This suggests that targeted foliar application of nutrients such as iron, manganese, copper, and zinc can enhance both the quantity and quality of the potato harvest (Al-Jobori, and Al-Hadithy 2018). Combined foliar application of Zn + Mn on potato plants significantly increased mean weight of tuber, mean tuber yield per plant, and total tuber yield. Zn + Mn foliar treatment during the vegetative growth stage caused an enhancement in mean weight of tuber, mean tuber yield per plant, and total tuber yield (Jawad and Fadhly 2016). Toor et al. (2020) concluded in their review article as: the most important limiting factor in crop production is drought, however foliar application of Zn has been shown effective solution to mitigate and minimalize adverse effects of drought. Seleiman et al. (2023), found that zinc has a positive effect on stress tolerance, yield and tuber quality of potato, under drought conditions

CONCLUSIONS

Potato production has a divers history and notable role as a staple food globally. From its evolution in the Andes to its international prominence, the flexibility of the crop has allowed it to prosper in various soil types and climates. The data illustrates an ascending trend in potato yields, underlines its potential as a vital plant for food security. Nonetheless, challenges such as extreme weather event, water scarcity, and rising temperatures jeopardize its future cultivation. To alleviate these hurdles, multiple agronomic practices, including foliar treatments of salicylic acid, hydrogen peroxide, micronutrients, and silicon, have shown promise in boosting drought and heat resistance in potato crop. As climate variability continues to intensify, integrating novel agricultural solutions and improving crop resilience will be crucial for upholding potato production. The current research in this field not only emphasizes the pivotal role of understanding the physiological responses of potatoes to abiotic stressors but also highlights the need for sustainable practices to secure a reliable food supply by tackling these obstacles.

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