Potato Affected by Heat and Drought Stress

Subjects: Physiology

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Solanum tuberosum heat tolerance drought tolerance bulking climate change

1. Introduction

Potato (*Solanum tuberosum* spp. *tuberosum* L.) is the third most important food crop after rice and wheat, with increasing popularity in terms of human consumption. Its annual production was 388.19 million tons (MT) in the year 2019, which is expected to increase further in several regions [1]. Potato is a popular staple vegetable in many countries. Potato is also a staple food in European countries, adding carbohydrates to the human diet and nutrients and minerals [2]. As the human population continues to rise, the accessibility of food may emerge as a major concern on a worldwide scale, and thus potato can help to provide food and nutritional security [3]. This crop is also vital in light of ongoing climate change, which is already exerting intense pressure on the human population's food and grain supply. In the coming decades, climate change will become a major rising problem for governments and policymakers to devise ways to combat the adverse effects of climate change and ensure food and nutritional security [4].

About 10,000 years ago, the domestication of potato took place in the highlands of the Andes in South America [5]. In the early 16th century, explorers from European countries, such as Spain, England, and the Netherlands, introduced potatoes to Europe [6]. Potatoes are grown extensively in two primary regions. The first zone is between 45° N and 57° N, where potato is cultivated as a summer crop; while the second zone is the subtropical lowlands between the latitudes of 23° N and 34° N, where potato is cultivated during the winter [7]. In the subtropical and tropical regions, the potato is grown as a winter crop where the night temperatures remain below 22 °C. However, a temperature below 20 °C is usually required for tuberization in potato [8]. The term "tropicalization" refers to the process of breeding and developing suitable production techniques for vegetable crops that may be grown at lower latitudes [9].

The importance of potatoes in securing food and nutritional security was identified by the Food and Agriculture Organization (FAO) of the United Nations when it declared the year 2008 as the "The International Year of the Potato" [10]. This initiative was pursued to attract the world's attention toward the importance of potatoes and their

more significant role in food and nutritional security in nonconventional areas. Most developing countries are on the Asian and African continents, where the production and demand for potatoes have increased in recent years [11]. The tropicalization of the potato crop is vital, as potato serves as a cheap source of energy and nutrition. The potato can help overcome food and nutritional insecurity and contribute to improving economic growth [12].

Environmental factors such as heat, drought, salinity, flood, and cold are the major causes of adverse effects on the growth, development, and productivity of horticultural crops [13]. Abiotic stressors are the major cause of crop loss on a global scale, since they can reduce the average yield of most crops by more than 50 percent [14]. The rise in global temperature is a threat to agriculture in general. The increase in temperature poses significant abiotic stress for crop plants that adversely affects their survival, adjustment, and performance [12]. Under such a changing climate scenario, potato cultivars need to be developed that can thrive under high temperatures and give reasonably good production and productivity [15].

Heat stress negatively affects the plant's growth, and developmental, biochemical, and physiological processes, leading to a reduction in yield and productivity. The critical developmental stage affected by heat stress is the reproductive and bulking stages [16]. Similarly, plant response to drought stress is detrimental and impacts morpho-physiological, anatomical, and biochemical parameters. Climate change is detrimental to tuber and root vegetable crops, which are also considered staple foods in many countries. It has been predicted that there will be a decrease in global potato production by 18–32% due to global warming by the middle of this century [12][17]. Therefore, to cope with this climate change problem and ensure food security, it is essential to understand the responses of crops to climate change. Understanding the mechanism of plant response to abiotic stresses could be a viable strategy for developing crop varieties through selection, breeding, and biotechnological approaches, with the goal of developing varieties tolerant to heat or/and drought stress [18]. Regions in tropical areas suffer from unprecedented seasonal heat and drought stress [19][20]. These stresses lead to a detrimental effect on physiological and biochemical mechanisms in the plant that ultimately hamper the growth and development of potato plants [21] and reduce yields and tuber quality [22]. The potato crop originated in borderline subtropical/alpine climates and performed best in places with warm days and cool nights. Potato production in tropical and sub-tropical regions is challenging. However, potato breeders and physiologists are trying to develop thermo-insensitive varieties which may be suitable for tropical regions [23].

Potato cultivation is expanding to non-traditional regions with water-deficient conditions and facing heat stress. In addition, heat and drought spells are becoming more frequent in temperate zones [12][16].

2. Production and Productivity of Potato Affected by Heat and Drought Stress

Potato crop species are highly prone to different abiotic (high-temperature stress, drought, salinity, and mineral stress) and biotic stresses (insect and pest attacks) [13][24][25][26]. Heat stress is a significant issue for temperate countries and potato production locations in the semi-arid Middle East and the Sub-Saharan, subtropical, and tropical regions [27]. Temperature is the most critical uncontrollable factor affecting potato growth, development,

production, and productivity. Tropical areas experience high-temperature stress, where plants undergo several anatomical, morphological, physiological, biochemical, and molecular changes. Growth and development are seriously affected, leading to a substantial decrease in potato production [16]. Due to high temperatures, the environment of the tropical region alters the morphological features and the physiological and developmental processes of potato plants. For instance, high temperatures may cause a reduction in the leaf area index, specific leaf area, size and number of leaves, and canopy development, an increase in the plant's lateral branching and height, and a decrease in the number and size of tubers. The alarming rate of increase in temperature due to climate change causes more frequent heat stress to plants during the summer and high night temperatures in the winter, which hampers crop yield and quality in any region of the world [27]. Heat stress mediates imbalances in source–sink activity, allocation of photoassimilates, necrosis, and malformation of tubers [27]. Furthermore, the soil temperature in which the potato is grown affects the process of stolon formation, tuberization, and bulking, ultimately reducing the tuber yield [28][29].

High-temperature and water stress conditions affect the yield and quality of potato tubers, where the severity, duration, and timing of both heat and water stress adversely affect sprout emergence, stolon formation, tuberization, and final yield of the potato tubers [30]. The potato tuber yield depends on tuber bulking [29], which occurs in the late stage of growth. The production may decrease due to bulking reduction, which is affected by heat and water-deficient conditions [28]. As per Obiero et al. [30], the high-temperature treatment affects the whole plant's dry matter and potato tuber yield. They reported that high-temperature treatment (30 °C) compared to a control (temperature of 22 °C) before and after tuber initiation leads to 45% smaller tubers (less than 2.5 cm diameter).

Planting time (spring and autumn) affects potato yield [31]. High temperatures in the subtropical climate, particularly during the spring season, are more detrimental than autumn because of the combination of low humidity (higher atmospheric evaporative demand) and higher temperatures. An average yield reduction of 68% and 42% was observed in spring and autumn plantings [22]. This difference may also be due to water availability during the spring and autumn seasons [32]. Under tropical conditions, high-temperature stress negatively impacts potato tuber quality and yield through the inhibition of the transport of photoassimilates to the developing stolons [12]. It was reported by Fleisher et al. [33] that the optimum temperature for photosynthesis and biomass accumulation in potato is 20 °C. Additionally, it was reported that the optimum daily mean temperature might be as low as 13 °C [12]. An increase of every 5 °C above the optimum temperature causes a reduction in the photosynthetic rate by 25%, which ultimately affects biomass accumulation and, later, the sink activity [15][30][34].

As previously documented, potato production decreases due to heat and drought stress in most East African countries [35]. Additionally, Jarvis et al. [36] anticipated about a 15% reduction in potato yield in Africa by 2030. Across Asia, India and China are at constant drought and heat stress risk. Moreover, periods of high temperatures and drought are becoming more frequent in Central and Western Europe. US potato production was also severely affected due to drought and heat stress during the last 2–3 years. In Mediterranean regions, the problem of dry spells in potato cultivation is also a major concern [37]. Likewise, the major potato-growing areas of the world under consistent risk of drought and heat stress are highlighted in **Figure 1**.

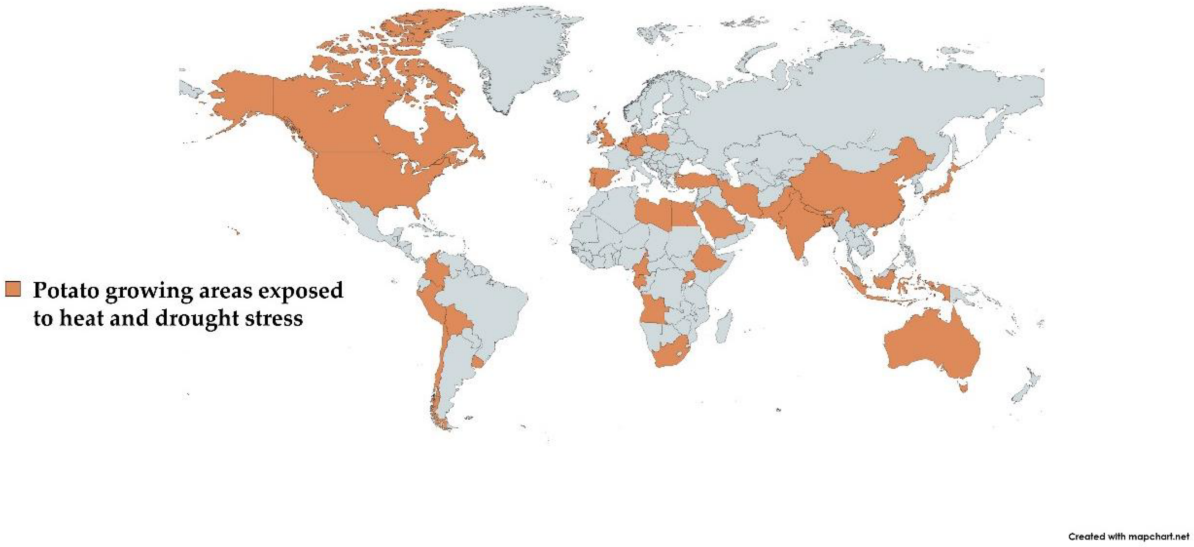

Figure 1. The area shown in brown color depicts the major potato-growing areas affected due to heat and drought stress.

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