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Four Species with Crop Potential in Saline Environments: The SALAD Project Case Study †

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Abstract: With sea levels rising due to climate change, salinity intrusion will increase and new crops, specifically appropriate to such particular ecological conditions, are needed. In the project "SALAD—Saline Agriculture as a Strategy to Adapt to Climate Change", the possibility of growing tomato (*Solanum lycopersicum*), potato (*Solanum tuberosum*), quinoa (*Chenopodium quinoa*), and New Zealand spinach (*Tetragonia tetragonioides*) in saline conditions is explored, together with their market upscaling opportunity. The crops are described in terms of their origin and distribution, botanical description and edible use. Moreover, the state of the art of the four crops' response under saline conditions is reviewed.

Keywords: saline agriculture; salt-tolerant crops; tomato; potato; quinoa; New Zealand spinach; SALAD project

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1. Introduction

The current food system feeds the great majority of the world population and supports the livelihoods of over one billion people. Yet, it is both a major driver of climate change and increasingly vulnerable to it because of its intrinsic dependency on natural resources. With sea levels rising due to climate change, salinity intrusion will increase and not only affect agricultural production, but also the living conditions of farmers, the quality of natural resources and whole ecosystems. In salt-affected areas, the world's major crops are not adequate to supply the calories, proteins, fats, and nutrients people need. New crops are needed that are specifically appropriate to such particular ecological conditions. In the recent funded project "SALAD—Saline Agriculture as a Strategy to Adapt to Climate Change", the possibility of growing four crops in saline conditions is explored, together with their market upscaling opportunity. The main objective of the SALAD project is to improve the climate resilience of agricultural production in the current and potential salt-affected areas and promote the use of innovative salt-tolerant crops and cultivation techniques to improve food security and sustainability in the context of climatic changes, by boosting transnational cooperation between knowledge institutes, farmers, and entrepreneurs, consumers, and the public sector, around and beyond partner regions. The case study species to be studied in the project are tomato (*Solanum lycopersicum*), potato (*Solanum tuberosum*), quinoa (*Chenopodium quinoa*), and New Zealand spinach (*Tetragonia tetragonioides*). The four crops are currently not at the same stage of development and awareness among the general public, with quinoa and potato crops already extensively screened for their performance in saline conditions, tomato showing very promising quality improvements of the fruits under saline conditions, and New Zealand spinach is still at an early stage of research. Regarding the salt tolerance of the four species, potato and tomato crops are glycophytes, characterized by a high difference among varieties, whereas quinoa and New Zealand spinach are halophytes, or "salt-loving" species. The four crops are here introduced in terms of their origin and distribution, their botanical description, and edible use. Moreover, the state of the art of the four crops' response under saline conditions is reviewed.

2. Tomato Crop

2.1. Origin, Distribution, and Botanical Description

Tomato (*Solanum lycopersicum* L.) is an important food and industrial crop, cultivated all over the world. The species originated in western South America and Central America and numerous varieties of the tomato plant are widely grown in temperate climates across the world, with greenhouses allowing for their production during all seasons of the year. Tomatoes are fruits, botanically classified as berries. They are commonly used culinarily as a vegetable ingredient.

2.2. Tomato Response to Salinity

This species is classified as a moderate-salinity-tolerant species [1], and its salt tolerance has been studied since the 1970s [2]. Salt-sensitive and salt-tolerant genotypes (i.e., ecotypes from the Galapagos Islands) were investigated by [3] assessing a far stronger salt resistance in the Galapagos ecotypes, which were surviving in a full-strength seawater nutrient solution, EC roughly corresponding to 50 dS m^{-1}. The salt-resistant genotypes were firstly used in breeding programs with the aim of transferring genetic information to cultivated tomato, but the process did not give the expected results and, to date, creating new salt-tolerant tomato cultivars with breeding programs faces many obstacles, mainly because traits related to salt tolerance are not combined in a single donor genotype [4]. Several trials were also performed to determine the seawater tolerance of cultivated tomato, assessing, in the meantime, the characteristics of fruits; even if seawater irrigation generally reduced the crop yield, according to the tested variety, in particular, 10 to 20% seawater (roughly EC of 8 dSm^{-1} to 14 dS m^{-1}) increased the nutritional value of the product. In particular, fruit dry matter and total soluble solids were reported by several authors to increase with the use of seawater concentrations of 10–12% compared to control. In addition to that, the concentration of reducing sugars (RS) and titratable acidity (TA) also increased in the berries exposed to seawater irrigation, resulting in tastier fruits than control ones [5]. Similarly, glucose, fructose, and citric and ascorbic acid increased proportionally to salinity, with glucose concentrations up to 139% and fructose up to 101% higher compared to the control treatment [6].

3. Potato Crop

3.1. Origin and Distribution, and Botanical Description

The potato is a starchy tuber used as a root vegetable, native to the Americas. The plant was introduced to Europe in the 16th century by the Spanish and today, potatoes are a staple food in many parts of the world and an integral part of much of the world's food supply, being a rich source of carbohydrates, proteins, dietary fiber, ascorbic acid, riboflavin, and minerals [7]. Following millennia of selective breeding, there are now over 5000 different types of potatoes.

3.2. Potato Response to Salinity

The potato crop is classified as a moderately salt-sensitive crop since the threshold value of soil salinity of saturated soil extract (EC_e) is 1.7 dS m^{-1} and irrigation water salinity (EC_w) is 1.1 dS m^{-1} [7]. Yet, the results of field experiments suggest that there is more potential for conventional crop production under "moderate saline" conditions than is generally assumed, with numerous cultivars (i.e., 'Miss Mignonne', 'Achilles', 'Foc', 'Met', and '927') not showing yield losses at EC up to 4.1 dS m^{-1} [8], with some varieties showing greater levels of salt tolerance compared to others. Moreover, 'Désirée' was irrigated with saline water (EC 6.6 dS m^{-1}) in the Negev Desert without loss of yield [9], even if the combination of salinity and heat instead led to a reduced tuber yield. Under saline conditions, leaf water and osmotic potentials were observed to decline significantly, even if a positive turgor was maintained by plants throughout the entire growth period, thanks to the fact that plants mainly adjusted osmotically due to chloride and proline [10]. Potato leaves are very sensitive (especially to salt applied at the beginning of tuber formation) and are severely damaged by overhead irrigation with saline water that may induce toxicity, exhibited as leaf burn along the margins [9]. Especially on tubers, high salinity levels (EC greater than 10 dS m^{-1} in the root zone) may cause coarse russeting and furrowing of the tubers, accompanied by severe browning of the surface [9].

4. Quinoa Crop

4.1. Origin and Distribution, and Botanical Description

The species originated in the Andean region of northwestern South America. Today, its cultivation has spread to more than 70 countries, including Kenya, India, the United States, and several European countries. It is an herbaceous annual and it is grown as a crop primarily for its edible seeds, which are rich in protein, dietary fiber, B vitamins, and dietary minerals.

4.2. Quinoa Response to Salinity

Quinoa is a facultative halophytic plant species with the most tolerant varieties being able to cope with salinity levels as high as those present in seawater [11]. Of the almost 2500 existing quinoa accessions, more than 200 have been tested under saline conditions, and shown to differ in their response to salinity [11]. The natural variability in a number of traits (i.e., inflorescence type, seed color, seed size, life-cycle duration, salinity tolerance, saponin content, and nutritional value) allows quinoa to adapt to diverse environments [12]. Generally, optimal plant growth has been observed at NaCl concentrations of 100–200 mM (~10–20 dS m^{-1}) and biomass production, seed yield, and harvest index were proved to be higher under moderately saline conditions (10–20 dS m^{-1}) than under non-saline conditions [13,14]. Several studies to identify mechanisms of salt tolerance in quinoa have been conducted over the last few years, identifying many factors, among which are the efficient control of Na^+ sequestration in leaf vacuoles, a higher ROS tolerance, a better K^+ retention, and the accumulation of compatible solutes, such as proline and total phenolics [12].

5. New Zealand Spinach Crop

5.1. Origin and Distribution, and Botanical Description

Tetragonia, or New Zealand spinach, is a widespread species native to eastern Asia, Australia, and New Zealand that has been introduced in many parts of Africa, Europe, North America, and South America. Sandy shorelines represent its natural habitat. It is a halophyte that grows well in saline ground and it is often cultivated as a leafy vegetable.

5.2. New Zealand Spinach Response to Salinity

Several trials have shown that Tetragonia may withstand an EC of the growing medium of 10 dS m^{-1} [15,16]. Other studies identified a salt-induced growth response at salinity levels of 50–100 mM NaCl (EC 5–10 dS m^{-1}) [17,18] and even higher salinity thresholds (i.e., 18 dS m^{-1}) have been assessed in hydroponic conditions [18], regardless of the type of salinity tested (i.e., NaCl solution vs seawater at comparable EC) [19]. Salinity was also correlated to an increased nutritional value of the edible leaves due to the enhanced accumulation of mineral elements and a decrease in nitrates in saline conditions compared to control ones [18].

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