EIP-AGRI Focus Group

Soil salinisation

MINIPAPER: Quality aspects of plants in response to salinity

ALBINO MAGGIO, ARJEN DE VOS, NADIA CASTANHEIRA, STEPHAN JUNG, JORGE ZAMBUJO, MARCELLO MASTRORILLI

funded by European Commission

1 Introduction

The effects of salinization on crop yield and quality have been thoroughly documented for most crops in a variety of environments (Zörb et al., 2019). However, while high salinity in the soil and/or irrigation water will unavoidably reduce yield compared to non-salinized conditions, there is evidence that quality parameters of the commercial products may actually improve upon salinization. Establishing a functional link between salinization and product quality under specific cultural and environmental conditions can shift, at least partially, the salinization problem from *challenge* to *opportunity*. Soil salinity may improve quality parameters in field crops, but mostly in fruits and vegetables (De Pascale et al., 2001; Rouphael et al., 2018). Moderate salt stress may positively impact fruits physical properties, including firmness and texture. Additionally, the accumulation of secondary metabolites may define product flavor and biofunctional properties which may have beneficial health implications.

Long and short-term effects of salinization on quality parameters should also be considered. The quality profile may be largely affected by short-term salt stress "shocks" whereas long-term modifications affect soil physico-chemical properties (De Pascale et al., 2012).

In the following sections we will describe a few case studies in which the effect of salinization on quality parameters has been documented. As we will show, in some cases the body of experimental evidence is considerable and sufficient to define a specific, stable and reproducible link between salinization and product quality, which can support the definition of a *salinity label* that intrinsically defines high quality products (*SalQual*™). Research tailored to specific agricultural contexts should aim at exploring opportunities to add market value to locally adapted varieties which are (more) tolerant to salt stress so as to compensate yield reductions. Minor salt tolerant crops could also be considered to foster agriculture activities in salinized environments.

2 Salinity and product quality - Case studies

Plants adaptation to saline growing conditions involves adjustments in their molecular, biochemical and physiological processes that consequently change the physical properties of the commercial products and lead to the accumulation of secondary metabolites that will alter their nutritional profile. In this section we show some case studies where crops maintained or even improved their quality parameters when grown in saline conditions. In most cases, the observed improved quality has not been exploited to commercial value. Therefore, adequate marketing strategies should be developed to offer these products to target consumer niches, which appreciate these qualities.

2.1 Salinized tomatoes taste better and contain functional molecules with nutritional value

Beneficial effects of salinity on bioactive compounds have been reported for tomato (Segura et al., 2009). Vitamin C and carotenoids may increase by 35% upon moderate salinization (Dorais et al., 2008). Similar effects have been observed for the general antioxidant activity (Krauss et al., 2006). Lutein, β-carotene, lycopene have been shown to increase upon salinization (Ehret et al., 2013) depending also on the fruit developmental stage. Anthocyanins also may increase at moderate-high salinity (EC 3.5 and 5.5 dS m^{-1}) (Borghesi et al., 2011). Fruits carotenoids and lycopene contents increase up to an EC of the irrigation water of EC 4.4 dS m^{-1} (De Pascale et al., 2001). Salinity may also improve flavour and taste of tomato fruits. Moderately high salinity levels up to 6.0 dS m^{-1} conferred high reducing sugars and titratable acidity contents. (Moya et al., 2017). The increase in soluble sugars and acids is also correlated to physiological responses mediating plant adaptation to saline environments (De Pascale et al., 2001), which also establishes a quite tight link between growth and quality traits under salinity. Many of these stress induced molecules act as

funded by European Commission

osmotic protectants, scavengers of Reactive Oxygen Species (ROS), gene regulators and mediators of adaptation mechanisms, all of which are activated and required in response to salt stress. With respect to the pattern of Na^+ accumulation in tomato fruits, there is scattered information probably because most Na^+ accumulates in shoots and roots. This aspect requires further research.

For tomato and other species for which the existence of positive links between salt stress and quality parameters is known, there are opportunities to penetrate the market with adequate branding strategies, including educating consumers on the nutritional quality of such high-value products. Although some tomato varieties are already cultivated in salinized areas and known by consumers (e.g. Pachino tomatoes from Sicily), their functional properties are still not fully valued: salinized tomatoes not only taste better, but they are also *naturally* enriched of healthy functional molecules.

2.2 *Salty* potatoes are ready for the market

Saline farming from the Netherlands has identified potato varieties that are more tolerant to salinity then previously assumed. These varieties are suitable for cultivation under moderate salinity (EC 4-8 dS m^{-1}) and even produce considerable yields under high saline conditions (EC 8-12 dS m^{-1}). At these salinity levels the sodium content of the tubers is well below the recommended daily intake of sodium. Most people add more salts to a “non-saline potato” (to the boiling water or directly on the cooked potato to give it more taste) than what a potato cultivated on saline soil contains. A professional panel test has assessed that a potato variety that was cultivated under saline conditions was more tasteful than the same variety cultivated under non-saline conditions. The positive effects on taste and flavour were not associated to different minerals and secondary compound levels, which were similar in saline and non-saline soils. This is also true for the shelf live - salinity appears to have little influence on this parameter. Depending on the potato variety, the sugar content can increase under increasing salinity levels. This can be an added value for baked or salad potatoes, but may have negative consequences in the production of potato chips.

There is a good market for “saline potato” in the Netherlands, because of a combination of the improved taste and effective product branding. Consumers like the story of growing potato under saline conditions, they appreciate the potential of saline agriculture for global food security and are willing to pay an additional price for that. Outside Europe, this improved taste seems to be less important. High yield under saline conditions is most important for farmers.

Results from the literature also show an increase in sodium concentration of the tubers with increasing salinity, which also causes an increase in water-soluble carbohydrates, starch and total non- structural carbohydrates in leaves (Ghosh et al., 2001). Other studies show a decrease in dry matter and starch content, as well as an increase is sugar content of the tubers with increasing salinity (Jha et al., 2017). Different potato varieties also show different trends in vitamin C, total soluble sugars, sucrose and starch accumulation under salinity stress (Zhang et al., 2005). A decrease in vitamin C and an increase in sodium concentration with increasing salinity can be seen as undesirable effects, whereas the greatest added value of increasing salinity is the improved taste.

2.3 Prickly pears can stand salinized environments maintaining their high nutritional value

Cactus prickly pear (*Opuntia ficus‑indica* (L.) Mill) is tolerant to drought and high temperatures, it adapts well to poor soils and is very water-use efficient. These characteristics make cactus pear an interesting crop in the frame of global desertification, limited water resources and soil/water salinity (Potgieter and D’Aquino, 2017;). Prickly pear fruit and cladodes are known for several nutritional and medicinal properties, including high levels of antioxidants, phenolic compounds, pigments, vitamins and fibers, and pectin. They are also known as a source of chemical compounds for cosmetic purposes and a source of natural pigments for the food industry (Shedbalkar et al., 2010). The secondary metabolites betalains are used as colorants in the food industry but they also possess beneficial properties for human health, including anti-inflammatory, antioxidant and chemo-preventive properties and positive effects on metabolic, cardiovascular and gastrointestinal health (Stintzing and Carle, 2004). Prickly pears can be grown under high salinity and drought conditions. This crop is

funded by European Commission

described as moderately tolerant to salinity and plants grown in saline conditions do not significantly reduce their yield with some genotypic differences. Quality parameters such as ascorbic acids, flavonoids and mineral concentrations of fruit juice of cactus pear cultivated in saline soils and irrigated with saline water (EC 4-7 dS m^{-1}) are not affected by salinity (Centofani et al., 2017). Results from the literature indicate that *Opuntia* can be cultivated under saline conditions without affecting its high nutritional and nutraceutical value. Some studies report that under salinity, Na^+ accumulates mostly in roots, although increased Na^+ levels have been found in fruit juice at EC 4-7 dS m^{-1} (Centofani et al., 2017). More knowledge is needed on the accumulation of sodium in commercial products.

Prickly pears are mainly consumed fresh, yet the increased knowledge on their nutritional value, the possibility to cultivate them in marginal lands, and the increasing worldwide demand for this fruit is driving new challenges for the cactus pear industry. Fruits are widely appreciated for their biological attributes nevertheless the peel is less used and it is where the antioxidant pigments (betalains) and pectins are predominantly found. It is possible to produce oil out of peel with appreciable amounts of polyunsaturated fatty acids, mainly linoleic acid, α-tocopherol, sterols, β-carotene and vitamin K1 (Ramadan and Mörsel, 2003). Furthermore, the extraction of pigments and bioactive compounds from peel can be further developed. These compounds have anti-inflammatory and antimicrobial activity that can be used in food and pharmaceutical industries. Moreover, there is an increasing interest in processed products since these have an extended shelf-life and consents products diversification.

2.4 *Salads* from halophyitic buck´s horn plantain and ice plant – new tastes for costumers

The term halophytes is generally used to describe (wild) salt tolerant plants, which dominate natural habitats with a high concentrations of soluble salts. These plants do not necessarily prefer these environments. However, halophytes outcompete salt sensitive plants (glycophytes), since they have developed various strategies to adapt to saline environments. Most agricultural plants are glycophytes and do not tolerate well salinity. There is a high number of plants species, which can be categorised as halophytes. Here two examples of known, but rarely used plants/crops, which could be an alternative food product grown on salt affected soils.

Buck´s horns plantain, Erba stella or Minutina (*Plantago coronopus*) is a halophyte which is known especially in Italy. It has a nutty and salty taste, more flavourful than most green salads, generally used as salad or steamed vegetable. The sodium concentration of buck´s horns plantain ranges between 3,4 – 3,8% when grown on a mildly salt affected soil (EC 4,8 dS m^{-1}). Buck´s horns plantain is known to contain high levels of vitamins A and C. However, there is lack of scientific data to confirm this. Compared to other green salads it can be kept in the fridge for longer time. It is already well known in some regions (Northern Italy, Canary Islands) and it can also be found in some farmer markets across other European countries. Since it can be used as a green salad and presents a “new” taste to the assortment of green salads, the biggest issue is getting to know the product to consumers. Branding could be a way to do this. A big plus towards most other green salads is its firmness and in most cases its long shelf life. Another big plus is the fact that it is quite winter hard and keeps growing with temperatures just above zero. Therefore, it could be an addition to the small assortment of green salads, which grow without additional heating in winter. Since it is relatively unknown, it presents an opportunity for farmers so to place these products in a specific market niche for costumers searching for new taste.

Ice plant (*Mesembryanthemum crystallinum* L.) is a halophyte and a potential high value crop. The ice plant is able to accumulate relatively high amount of Ca. Although, Ca is regarded as an important mineral element for human nutrition, two-thirds of the world´s population lacks sufficient amounts of Ca (White and Broadley, 2009). The same is true for Mg and Zn. Like most Caryophyllales plants, ice plants accumulate unusually high amounts of these elements. Salinity does not affect the carotenoid concentration of ice plants, whereas in other halophytes carotenoid concentrations can be negatively affected by increasing salinity (Aghaleh et al., 2009; Qiu et al., 2003; Redondo-Gomez et al., 2010). Ice plants taste more and more salty with increasing soil salinity. When eating the leaves raw they also have an uncommon but pleasant mouthfeel, caused by its high leaf succulence The sodium concentration in these plants ranges between 7,4-9,6%

funded by European Commission

(depending on the time of harvest) when irrigated with diluted sea water of EC 4 dS m^{-1} and was raised to concentrations as high as 13,8-17,9% when irrigated with sea water of EC 35 dS m^{-1} (Atzori et al., 2017). The market could be ready to appreciate this crop well, since it presents a new and interesting texture combined with a high nutritive value (Atzori et al., 2017).

2.5 Naturally antioxidants enriched rice in salinized fields

Rice is a moderately salt tolerant cereal. In brown rice varieties, which are more tolerant to saline stress, Na accumulates to values of 0.0097% in plant tissues, while the more sensitive varieties can present Na content of 0.0180% when exposed to salinity levels of the order of EC 5-6 dS m^{-1}. In the more tolerant rice varieties, crude protein and potassium values are higher than those recorded in more sensitive cultivars, whereas they have similar levels of starch and amylose. In saline soil, with and EC of 5-6 dS m^{-1}, rice grain cooking and eating quality may be adversely affected independent of the plant salinity tolerance, but they have an increased protein level which improves the nutritional value of the grain. The increased softness of cooked rice due to the reduction in amylose content is offset by the increased protein content that acts as a barrier to water absorption of rice during cooking. Also for rice, it has been observed that moderate salinity can enhance antioxidant contents including tocotrienols and γ-oryzanol (Tung and Ng, 2016). It has also been reported that salt stress increased nutritional quality of mature grains, i.e., total phenolic content, anthocyanins, proanthocyanins and antioxidant activities in several rice cultivars (Chunthaburee et al., 2015).

3 Knowledge gaps and potential innovations, sustainability of innovations

High salinity in the soil and/or irrigation water will unavoidably reduce yield of conventional crops compared to non-salinized conditions. The effects on salinization on crop yield are well documented; however there is limited information on the quality parameters improvements of commercial products grown in salinized environments. Quality improvements may occur up to a critical threshold after which the added value in terms of quality will not compensate the yield decay caused by high salinity. These thresholds are species- and environment-specific and should be further explored to assess opportunities to create added market value where saline agriculture is the only possible. In the following tables we addressed some of the main knowledge gaps and potential innovations identified on the effects of salinity on product quality (Table 1). One potential innovation for marketing is the definition of a *salinity label* (e.g. *SalQual*™) that may help consumers in associating salinized products to higher nutritional and health quality. Operational groups focused on salinization problems in agriculture can support farmers and facilitate their adaptation to a changing environment (Table 2).

Table 1. Knowledge gaps, challenges, opportunities

TOPIC	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
Crop and salinity stress	Limited knowledge on the physiological and molecular basis of salinity tolerance and agronomic implications	Elucidating the physiological and molecular basis of crop tolerance to salinity and functionalize this knowledge to optimize agronomic management of saline agricultural systems	Needs of a multidisciplinary approach, complex and expensive	Development of salt tolerant varieties
Crop	Scarce	1. Profiling the nutritional	Need to define	Value areas that

funded by European Commission

TOPIC	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
quality and salinity	information on quality improvements of salinized products	content of crops grown under saline conditions	environmental and genetic factors that may interact with salt stress response and affect the nutritional profile of commercial products Need of an accurate inventory of salt-affected areas at regional, national and EU levels	are/will be affected by salinization; monitoring and controlling the progression of salinization; anticipating and delaying transitions to irreversible salinization problems
		2. Defining a threshold of commercial return for quality traits improvements vs. yield loss in saline environments	Need to define agronomic determinants that guarantee quality standards	Mapping salt tolerant species/cultivars vs. saline conditions and cultivation protocols
		3. Profiling the biosynthesis of biofunctional molecules that may have beneficial health implications	Complex interactions between salinity and other environmental factors may limit a stable/constant accumulation of functional molecules	Identification of new active molecules and characterization of their beneficial effects on human health; profiling synergistic effects of different molecules and their multi-functionality as food, feed and nutraceutical uses
Crop quality and salinity	Scarce information on the accumulation of sodium in commercial products	Improving knowledge on dietary Na^+ uptake in emerging agricultural systems under climate change	Health concerns	Develop market products that do not need seasoning
Market	How can we increase awareness on the quality of these products?	Educate consumers on quality aspects of salinized products – develop a *salinity label* that intrinsically defines a higher quality product (e.g. *SalQual*™)	Lack of consumers awareness on the quality/benefits of these products Price of the products	Differentiation of these products in terms of higher nutritional quality associated with health benefits

TOPIC	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
Market	How to better develop a market for halophytes?	Definition of a *salinity label* attesting higher quality (e.g. *SalQual*™)	Decreased/reduced land value due to negative perception Increase farmer's acceptance to grow "unknown" halophytes	Agricultural business on salinized land Farmland will not be abandoned

Table 2. Ideas for EIP-AGRI innovative projects/Operational Groups

TITLE	CONTEXT	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/ IMPACTS
1. Agronomic profiling of salt tolerance and product quality traits in European crops exposed to soil salinity	Show cases for the introduction of new tolerant crop varieties and/or varieties with better quality traits	Selection of species/cultivar suited to saline environments Small- and short-time experiments Context-specific analyses of salinization progression vs environmental parameters and quality improvements Training of farmers to farming systems under salinization processes Demonstration on different crop varieties (technical aspects and market opportunities)	Farmers Researchers Advisors Agribusiness Local authorities NGO associations /consumers	New market opportunities Screening for potentially labelling and branding foods Skills and knowledge transfer to farmers Rural cohesion in the territories Increased farmers returns Increased knowledge on ecosystem services Agro-ecological landscape preservation
2. Diversifying and promoting cropping systems	Territories where crop diversification should be increased	Introducing new crops in areas with monoculture/crop rotation Measuring ecosystem services Promoting local/regional distribution of the new crops Develop an environmental label	Farmers Society Participatory approach Advisors Researchers	Creating alternatives for areas where conventional agriculture has to face serious environmental constrains (salinity) and eventually abandonment/desertification Valuing agro-ecosystem services

funded by European Commission

4 Conclusions

Avoiding increasing soil salinity is a common goal most people can agree on. However, natural soil salinization, competition for water resources, and climate change are among the critical factors that will eventually lead to salinization of most susceptible areas. Ways have to be found to use salt affected agricultural land to produce high quality products that may penetrate market niches, increase farmers' income and contain land abandonment. There is available knowledge and practice with regard to the quality aspects of saline agriculture products. Emphasizing product quality of old and new crops could be a market opportunity for farmers to compensate for decreasing yields in salt affected areas.

funded by European Commission

References

Aghaleh, M., Niknam, V., Ebrahimzadeh, H., Razavi, K. (2009) Salt stress effects ongrowth, pigments, proteins and lipid peroxidation in Salicornia persica and S.europaea. Biol. Plant. 53: 243–248.

Atzori, G., de Vos, A. C., van Rijsselberghe, M., Vignolini, P., Rozema, J., Mancuso, S., & van Bodegom, P. M. (2017) Effects of increased seawater salinity irrigation on growth and quality of the edible halophyte Mesembryanthemum crystallinum L. under field conditions. Agricultural Water Management. 187: 37-46.

Borghesi, E., González-Miret, M.L., Escudero-Gilete, M.L., Malorgio, F., Heredia, F.J., Meléndez-Martínez, A.J., 2011. Effects of salinity stress on carotenoids, anthocyanins, and color of diverse tomato genotypes. J. Agric. Food Chem. 59, 11676–11682.

Centofanti, T., Bañuelos, G., Zambrano, M.C., Wallis, C.M. (2017) Desert Plant for Saline and Drought Stricken Farmland: Assessment of Opuntia cactus Nutritional Characteristics. J Environ Bio Res. 1(1): 1-8.

Chunthaburee, S., Sanitchon, J., Pattanagul, W., Theerakulpisut, P, 2015. Effects of salt stress after late booting stage on yield and antioxidant capacity in pigmented rice grains and alleviation of the salt-induced yield reduction by exogenous spermidine. Plant Production Science, 18: 32-42.

De Pascale, S., Maggio, A., Fogliano, V., Ambrosino, P., Ritieni, A., 2001. Irrigation with saline water improves carotenoids content and antioxidant activity of tomato. J.

De Pascale, S., Orsini, F., Caputo, R., Palermo, M.A., Barbieri, G., Maggio A., 2012. Seasonal and multiannual effects of salinisation on tomato yield and fruit quality. Functional Plant Biology 39: 689-698.

Dorais, M., Ehret, D.L., Papadopoulos, A.P., 2008. Tomato (Solanum lycopersicum) health components: from the seed to the consumer. Phytochem. Rev. 7, 231–250.

Ehret, D.L., Usher, K., Helmer, T., Block, G., Steinke, D., Frey, B., Kuang, T., Diarra, M., 2013. Tomato fruit antioxidants in relation to salinity and greenhouse climate. J. Agric. Food Chem. 61, 1138–1145.

Ghosh, S. C., Asanuma, K., Kusutani, A., Toyota, M. (2001). Effect of salt stress on some chemical components, and yield of potato. Soil Sci. Plant Nutr. 47, 467–475. doi: 10.1080/00380768.2001.10408411 Hortic. Sci. Biotechnol. 76, 447–453.

Jha, G., Choudhary, O.P., Sharda, R. (2017). Comparative effects of saline water on yield and quality of potato under drip and furrow irrigation. Cogent Food & Agriculture 3, 1369345.

Krauss, S., Schnitzler, W.H., Grassmann, J., Woitke, M., 2006. The influence of different electrical conductivity values in a simplified recirculating soilless system on inner and outer fruit quality characteristics of tomato. J. Agric. Food Chem. 54, 441–448.

Potgieter, J., D'Aquino, S. (2017) Fruit production and post-harvest management, In: Inglese P, Mondragon C, Nefzaoui A, et al., Crop Ecology, Cultivation and Uses of Cactus Pear, Rome: The Food and Agriculture Organization of the United Nations and the International Center for Agricultural Research in the Dry Areas, 51–72.

Qiu, N., Lu, Q., Lu, C., 2003. Photosynthesis, photosystem II efficiency and thexanthophyll cycle in the salt-adapted halophyte Atriplex centralasiatica. New Phytol. 159: 479–486.

Ramadan, M.F., Mörsel, J.T. (2003) Recovered lipids from prickly pear [Opuntia ficus-indica (L.) Mill.] peel: a good source of polyunsaturated fatty acids, natural antioxidant vitamins and sterols. Food Chemistry 83: 447-486.

funded by European Commission

Redondo-Gomez, S., Mateos-Naranjo, E., Figueroa, M.E., Davy, A.J. (2010) Salt stimulation of growth and photosynthesis in an extreme halophyte Arthrocnemum macrostachyum. Plant Biol. 12: 79–87.

Rouphael ,Y., Petropoulos, S.A., Cardarelli, M., Colla, G. 2018. Salinity as eustressor for enhancing quality of vegetables. Scientia Horticulturae 234 (2018) 361–369.

Segura, M.L., Contreras, J.I., Salinas, R., Lao, M.T., 2009. Influence of salinity and fertilization level on greenhouse tomato yield and quality. Commun. Soil Sci. Plant Anal. 40, 485–497.

Shedbalkar, U.U., Adki, V.S., Jadhav, J.P., Bapat, V.A. (2010) Opuntia and other cacti: applications and biotechnological insights. Trop Plant Biol 3(3): 136-150.

Stintzing, F.C.; Carle, R. (2004) Functional properties of anthocyanins and betalains in plants, food and in human nutrition. Trends Food Sci. Technol. 15: 19–38.

Tung, Y.-H., Ng, L.-T. , Effects of soil salinity on tocopherols, tocotrienols, and γ-oryzanol accumulation and their relation to oxidative stress in rice plants.

White, P.J. and Broadley, M.R. (2009) Biofortification of Crops with Seven Mineral Elements Often Lacking in Human Diets-Iron, Zinc, Copper, Calcium, Magnesium, Selenium and Iodine (Research Review). New Phytologist 182: 49-84.

Zhang, Z., Mao, B., Li, H. et al. (2005). Effect of salinity on physiological characteristics, yield and quality of microtubers in vitro in potato. Acta Physiol Plant 27: 481.

Zörb C., Geilfus C.-M., Dietz K.-J., 2019. Salinity and crop yield Plant Biology, 21 (Suppl. 1), 31–38.

funded by European Commission