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Ph.D. Dissertation

Effect of different rootstocks on the salt stress tolerance and fruit quality of grafted eggplants (*Solanum melongena* L.)

By

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LIST OF ABBREVIATIONS

ABA	Abscisic acid
APX	Ascorbate peroxidase
C*	Chroma
CAT	Catalase
CD	Colour differences
CIRG	Colour index of red
CRD	Completely randomized design
D.W	Dry weight
DW	Whitening index
F_v/F_m	Ratio of variable to maximum fluorescence
F.W	Fresh weight
GR	Glutathione reductase
GSH	Glutathione
H°	Hue angles
MDA	Malondialdehyde
NFT	Nutrient film technique
OP	Oxidation potential
PCA	Principal component analysis
POD	Peroxidase
PPO	Polyphenol oxidase
ϕPSII	Quantum yield of photosystem II
ROS	Reactive oxygen species
RWC	Relative water content
SOD	Superoxide dismutase
SPAD	Soil Plant Analysis Development
SSC	Soluble solids content
TSS	Total sugar content
T. W	Turgid weight
Ψw	Water potential

1. INTRODUCTION

Eggplant (*Solanum melongena* L.), a member of the *Solanaceae*, is grown in many countries. Worldwide annual production of eggplant was around 55 million tons in 2020 according to (FAO, 2020). China (36 million tons), India (13 million tons), Egypt (1 million tons), Turkey (800 thousand ton), and Indonesia (600 thousand ton) are the largest eggplant producers in the world. Iran, Italy, Japan, Spain, and the Philippines complete the top 10 (FAO, 2020). The total Hungarian production of eggplant in 2020 was 830 tons ranking it 76th in the world (FA0, 2020). There are numerous eggplant varieties that produce fruits of diverse sizes, hues, and forms. The most extensively produced type in Europe has a dark purple skin and is between 12 and 25 cm long and 6 to 9 cm wide. The fruit is popular in a variety of cuisines and is a critical component of the diet in numerous areas, including India and Bangladesh, Southeast Asia, and the Middle East.

Regarding antioxidants, eggplant ranks in the top ten vegetables, rich in minerals, antioxidants, flavonoids, phenolics, and vitamins (Mahanta and Kalita, 2020). Eggplant has been shown to have antioxidative properties, anticancer properties, it lowers cholesterol levels, and reduces the risk of obesity, diabetes, and cardiovascular disease (Padmanabhan et al. 2016). The high content of phenols, particularly chlorogenic acid, is responsible for eggplant's health-promoting properties (Padmanabhan et al. 2016). The eggplant's purple skin is high in anthocyanins. Anthocyanins have been shown to influence cognitive and motor performance, improve memory, and prevent age-related losses in brain function (Morris and Taylor 2017).

Quality characteristics include a bright white, green, violet, or variegated surface free of flaws, a dark green calyx, and the absence of seed or pulp browning (Cantwell and Suslow, 2000). However, the quick moisture loss after harvest results in peel shrinkage, sepal and pedicel browning, and loss of surface glossiness, restricting the marketability of this fruit under ambient storage conditions (Singh et al. 2016).

The primary goals of plant breeding in general have been mostly to increase yield, to confer disease resistance, make plants more resilient to mechanical damage, and to enhance the overall postharvest performance. However, due to a lack of viable selection methods, such as genetic markers, the process has been slow and inefficient thus far. Grafting is considered as a quick alternative to the somewhat sluggish breeding technique for enhancing the environmental stress tolerance of vegetable crops.

Grafting is the process of combining two plant parts (a rootstock and a scion) by means of tissue regeneration, in which the combination of plant parts achieves physical reunion to grow as a single plant. Grafting has become a necessity for intensive vegetable production since the use of chlorofluorocarbon-based soil fumigants was prohibited for environmental reasons (Colla et al. 2017). Grafting has become an increasingly popular method of agriculture for cultivating under severe environmental conditions that pose both abiotic and biotic stresses to vegetable crops. This has made it possible to expand commercial production onto the lands that would otherwise be underutilized. The use of vigorous rootstocks has been implemented not only in open field agriculture but also in protected cultivation systems, the latter of which allows for an increase in productivity and an improvement in the distribution of the costs of infrastructure and energy (Lee et al. 2010). Applying grafting has primarily increased in the cultivation of plants belonging to two families: the *Cucurbitaceae* and the *Solanaceae*. Vegetable grafting expanded rapidly in many countries for a number of reasons, such as to control soilborne pathogens (such as root-knot nematodes) and foliar pathogens; to enhance plant vigour; to extend the harvesting period; to increase yield and fruit quality; to prolong postharvest life; to increase nutrient uptake; to allow tolerance to low and high temperatures; to cope with salinity and heavy-metal stress; and to increase tolerance to drought and waterlogging (Mozafarian and Kappel 2020, Rouphael et al. 2018). In addition, in the presence of rising atmospheric temperatures, heat stress has become an increasingly serious global issue, with over 1.7 billion hectares affected presently and a steady increase in that number over the next few decades (Bayoumi et al. 2021). It is considered to be a potential tool to graft elite commercial cultivars onto selected high-temperature tolerant rootstocks (Schwarz et al. 2010).

Salinization of soil and irrigation water is an issue in agriculture across the world's arid and semi-arid regions, resulting in a significant reduction in cultivated land and plant growth and productivity. Salinity affects 20-33% of the world's agricultural and irrigated land, and the detrimental implications are expected to reach 50% by 2050 (Machado and Serralheiro 2017, Soda et al. 2016). Salinity has a variety of detrimental effects on plants, including reducing the photosynthetic rate and chlorophyll content, altering the anatomy and physiology, increasing the reactive oxygen species (ROS) generation, with adversely effect on plant development and production. Eggplant is a moderately sensitive plant to salt stress (Akinci et al. 2004), with a salinity threshold of 1.5 $dS.m^{-1}$ (Ünlükara et al. 2010).

The majority of previous studies investigated eggplant and tomato rootstock compatibility with eggplant scion individually. The objective of the present study was to compare the effect of tomato and eggplant rootstocks on fruit yield and certain quality parameters of eggplant 'Madonna' in soilless pot culture in an unheated plastic greenhouse. Moreover, current research is aimed at identifying the best rootstock type to maximize eggplant’s yield and fruit quality by conducting not only the laboratory testing, but the sensory evaluation as well.

Also, increasing customer demand for high-quality vegetable crops necessitates a careful selection of rootstock-scion combinations that produce fruits of acceptable quality and shelf life. Therefore, this work aimed to study the quality of eggplant different rootstock-scion combinations and then stored at 0 and 10 °C for nine days.

Based on literature review, there is a scarcity of evidence on the performance of grafted eggplant on fruit quality and yield under saline water irrigation. There is a need to distinguish new salinity-resistant rootstocks. This research aimed to investigate physiological responses and Na^{+}, Cl^{-} distribution and evaluate fruit yield and quality under poor water quality (high EC) irrigation.

2. OBJECTIVE TO ACHIEVE

The objectives of this research were

1. To identify the best rootstock which provides the maximum yield and quality among six different rootstocks, including Taibyou (SH), Akansau (A), Torvum (ST), Hikyaku (SI), Emperador (E), Optifort (O) and compare them with self-grafted and non-grafted plants of eggplant 'Madonna'.
    a. To check the effect of rootstocks on the browning of the pulp, fruit seeds number as essential elements of eggplant fruit quality.
    b. To test the consumer evaluation of eggplant fruits harvested from different rootstocks-scion combinations.
    c. To understand the effect of storage temperature on the postharvest fruit quality of eggplant harvested from grafted and non-grafted plants.
2. To evaluate two different rootstocks (Torvum-ST and Taibyou-SH) with non-grafted and self-grafted plants exposed to 80 mM NaCl.
    a. To compare the fruit quantity and the performance of the grafted and non-grafted plants subjected to stress conditions.
    b. To determine some photosynthesis parameters, as well as water stats, Na^+ and Cl^- content of various plant organs.

3. LITERATURE OVERVIEW

3.1 Eggplant overview

Eggplant, or brinjal (*Solanum melongena* L.), belonging to the large *Solanaceae*, is a warm-season crop cultivated in tropical and subtropical areas worldwide. The eggplant was domesticated in the area between north-eastern India and southwestern China. From its Indo-Chinese origins and domestication center, eggplant spread eastward to Japan and westward (Taher et al. 2017). The domestication of eggplant was primarily characterized by a dramatic increase in fruit size, shape, and colour diversity, as well as a reduction in plant prickliness and fruit bitterness. Gradually, eggplant cultivation spread throughout the Mediterranean basin, Central Europe, Africa, and finally America, and is now grown worldwide. There are still wild *Solanum melongena* forms in Indo-China (Taher et al. 2017). Some modern cultivars from this area have fruits that look like the fruits of wild *Solanum* species (round green berries that are 3–5 cm in diameter).

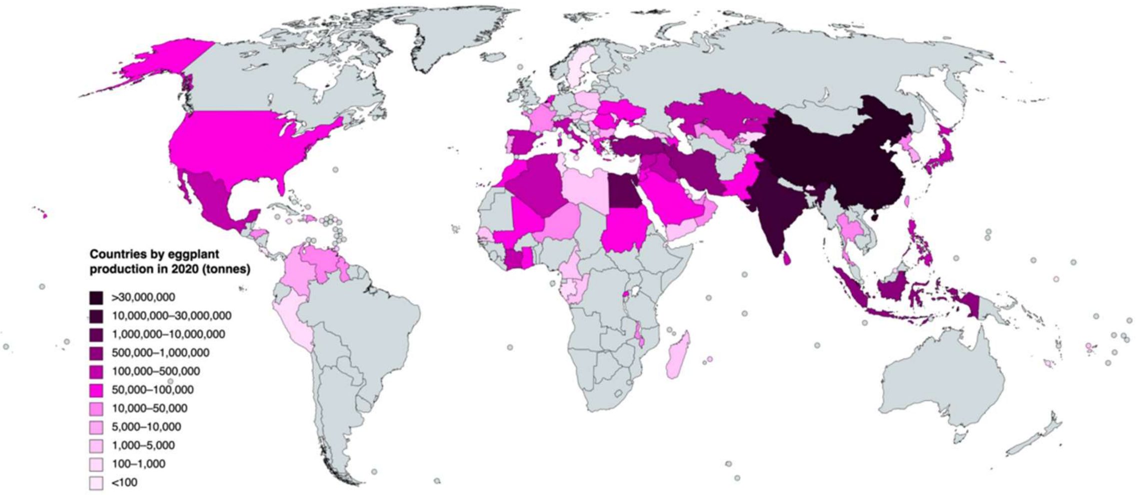


Figure 1. Countries by eggplant production in 2020 (FAO, 2020).

Based on FAO data from 2020 (Accessed on 1 January 2022), the global production of eggplant is around 56 million tons annually (Figure 1). The top producing countries are China (36 million tons), India (13 million tons), Egypt (1 million tons), Turkey (800 thousand tons), and Indonesia (600 thousand tons). The production in Hungary is around 867 tons. The average yield (18 tons per hectare) varies depending on climate, cultural system, crop duration, and grower technology (FAO, 2020).

Consumption of eggplant has increased over the years with the rise in awareness of the consumers about its health benefits. According to USDA database, eggplant is composed of 92% water, 6% carbs, 1% protein, and little fat when it is raw (www.dc.nal.usda.gov, Accessed on 1 January 2022). Season, cultivation environment (open field or greenhouse), and genotype affect nutrient composition slightly (San José et al. 2013). Regarding nutritional value, eggplant is low in calories and fats and contains mostly water, some protein, fiber, and carbohydrates. It is a good source of vitamins like B_1, B_2, B_3 B_6, B_5, C, K, and minerals like magnesium, potassium, manganese, and copper. In terms of oxygen radical absorbance capacity, eggplant ranks among the top ten vegetables. It has a high content of phenolic compounds, most notably chlorogenic acid in the fruit flesh and anthocyanins in the fruit skin. Both phenolic acids and anthocyanins have beneficial properties for human health (Mennella et al. 2012, Plazas et al. 2013, Stommel et al. 2015, Braga et al. 2016). Chlorogenic acid, the principal phenolic acid in eggplant, is reported to reduce the risk of human chronic diseases (Mahanta and Kalita 2020).

Eggplant is an important vegetable crop valued for its low-calorie value and high fiber and potassium content (Nisha et al. 2009, Raigón et al. 2008). The nutrition facts and composition of fresh and raw eggplant fruits is presented in Table 1.

Table 1. Eggplant Nutritional Composition per 100 g of Fresh and Raw Fruit (U.S. Department of Agriculture, Agricultural Research Service. 2013)

Proximate		Minerals (mg)		Vitamins		Lipids	
Water (g)	92.30	Ca	9.00	Vitamin C (mg)	2.20	Saturated (g)	0.03
Energy (kcal)	25.00	Fe	0.23	Vitamin B1 (mg)	0.04	Monounsaturated (g)	0.02
Protein (g)	0.98	Mg	14.00	Vitamin B2 (mg)	0.04	Polyunsaturated (g)	0.08
Total lipid (g)	0.18	P	24.00	Vitamin B3 (mg)	0.65	Cholesterol (mg)	0.00
Carbohydrate (g)	5.88	K	229.00	Vitamin B6 (mg)	0.08		
Fiber (g)	3.00	Na	2.00	Folate (µg)	22.00		
Total sugar (g)	3.53	Zn	0.16	Vitamin A (µg)	1.00		
				Vitamin E (µg)	0.30		
				Vitamin K (µg)	3.50		

3.1.1 Eggplant taxonomy and botanical description

Eggplants are berry-bearing vegetables belonging to the huge *Solanaceae* (nightshade), with around 3000 species scattered across approximately 90 genera (Vorontsova and Knapp 2012). *Solanum* is the largest of these genera, with around 1500 species (Frodin 2004), including globally significant crops such as potato (*Solanum tuberosum* L.) and tomato (*Solanum lycopersicum* L.), as well as several smaller crops (Frodin 2004).

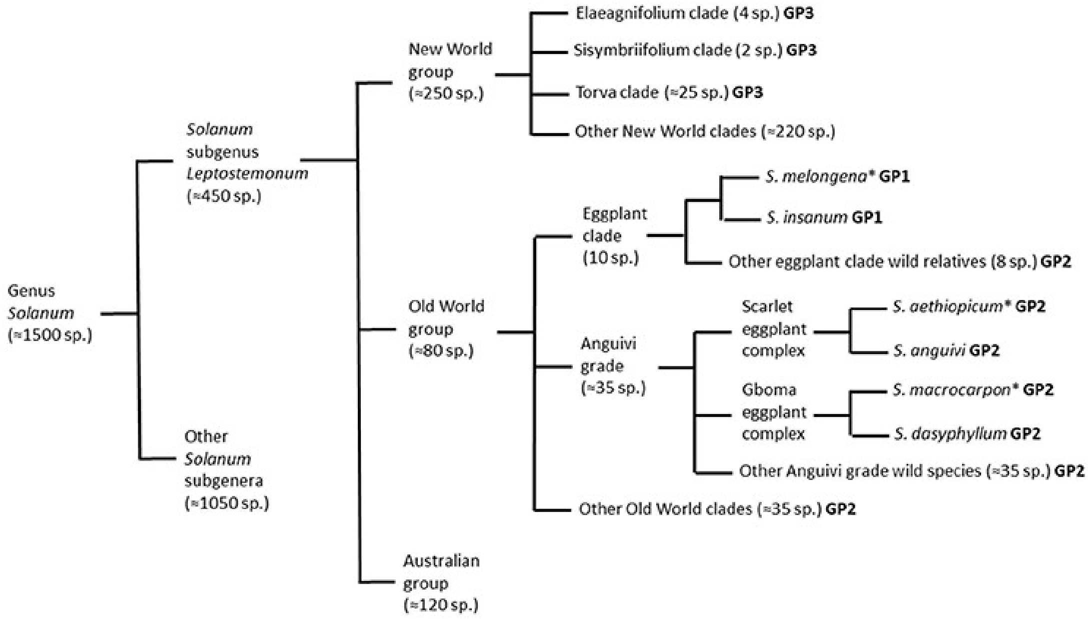


Figure 2. Schematic representation of taxonomic relationships between the cultivated eggplant (*Solanum melongena L.*) and other cultivated (*Solanum aethiopicum* L.*;* and gboma eggplant, *Solanum macrocarpon* L.) and wild relatives from the genus *Solanum* (Taher et al. 2017).

The *Solanum* genus is mega-diverse and may be divided into 13 clades. Eggplant is a member of the broad and taxonomically challenging *Leptostemonum* clade (subgenus *Leptostemonum* Bitter); (Knapp et al. 2013), sometimes known as the "spiny *Solanum*" group because to sharp epidermal prickles on stems and leaves (Vorontsova et al. 2013). The subgenus *Leptostemonum* has 450 species, many of which are New World species (Vorontsova and Knapp 2012). All three cultivated eggplants are Old World species (Figure 2). Over 300 *Solanum* species live in Africa, Eurasia, and Australia (Levin et al. 2006, Vorontsova and Knapp 2012). *Solanum melongena* and *Solanum macrocarpon* are in section Melongena Dunal (Lester and Daunay 2003, Lester et al. 2011), but *Solanum aethiopicum* is in *Oliganthes* (Dunal) Bitter group (Lester, 1986).

Solanum melongena has a diverse morphology and is often considered the same species as *Solanum insanum* (Ranil et al. 2017). Lester and Hasan (1991) classified wild and weedy eggplant into four taxonomically informal groupings, E–H, based on their distribution (Table 2). These four groupings are regarded to be two distinct species: *Solanum melongena* and *Solanum insanum* (Knapp et al. 2013). *Solanum insanum* now includes groups E and F, which are exceedingly thorny and wild or weedy in India and Southeast Asia (Ranil et al. 2017). Group G plants are primitive, with little fruits, while group H plants are less thorny and have enormous fruits (Daunay et al. 2001b, Weese and Bohs 2010). Both groups, G and H, constitute *Solanum melongena* (Knapp et al. 2013). Some research (Hurtado et al. 2012, Cericola et al. 2013) has found genetic and morphological differences between Occidental (the Mediterranean, North African, and Middle Eastern) and Oriental eggplants (from the southeast and eastern Asia).

Table 2. Cultivated eggplants (*Solanum melongena* L.; *Solanum anguivi* L.; *Solanum macrocarpon* L.) and their wild relatives (Taher et al. 2017).

Species	Group	Form of occurrence	Fruit diameter (cm)	Prickliness	Bitterness
Brinjal eggplant complex					
Solanum melongena	G	Cultivated (fruits)	3-4	Moderate	None to moderate
	H	Cultivated (fruits)	5-12	None to slight	None to slight
Solanum insanum	E	Weedy (wild)	1.5-2.5	Very high	Slight to moderate
	F	Weedy	2-3	Moderate to high	Slight to moderate
Scarlet eggplant complex					
Solanum aethiopicum	Aculeatum	Cultivated (ornamental)	3-8	High	Moderate
	Gilo	Cultivated (fruits)	2-10	None to slight	None to moderate
	Kumba	Cultivated (fruit and leaves)	5-10	None	None to slight
	Shum	Cultivated (leaves)	1.5-2.5	None	Moderate to high
Solanum anguivi L.		Wild, weedy	1-2	None to slight	High to very bitter
Gboma Eggplant Complex					
Solanum macrocarpon	fruit	Cultivated (fruits)	5-12	None to slight	Slight to moderate
	leafy	Cultivated (leaves)	2-6	None to slight	Slight to moderate
Solanum dasyphyllum Schumach		Wild (weedy)	3-4	Moderate to high	Moderate to high

Solanum melongena and the two other cultivated eggplants are closely related to a large number of wild species (Vorontsova et al. 2013, Syfert et al. 2016) that may serve as sources of variation for breeding programs, particularly for traits associated with adaptation to climate change as well as pest and disease resistance (Rotino et al. 2014). Eggplant is a diploid species with a basic chromosome number of 12 and a genome size of approximately 1.0 Gb (Barchi et al. 2019).

Eggplant is cultivated for its immature edible fruits. It is perennial but is typically grown as a frost-susceptible, warm-season annual. Plants are 0.4–1.5 m tall and branched, with large, broad leaves, and with a spiny- woody stem. The plant grows many branches in a roughly dichotomous pattern. On vegetative parts, anthocyanins, prickles, and hairiness vary quantitatively. The inflorescences are constituted of one to five andromonoecious cymes, while most current cultivars have solitary hermaphrodite blooms. The flowers are self-pollinating, purple or white, with a spiny calyx, five-lobed corolla, and yellow stamens (Daunay et al. 2001a). However, the most common flower type is five-merous (5 sepals, five petals, and five stamens). Eggplant is generally considered an autogamous species (Morris and Taylor 2017). However, insects visit flowers in open fields and warm conditions, and the allogamy rate can reach 70% or more (Dauny 2008).

The fruits are berries that vary significantly in shape (spherical, oblong, ovoid, oval, long and many intermediate) and size (tens of grams to over a kilo) and colour (whitish to dark purple, even black or combinations of these colours in stripes). Fruits range from 4–45 cm in length and 2–25 cm in diameter (Nothmann 1986). Chlorophyll and anthocyanin pigments, which can be present or absent as well as vary in their distribution patterns, affect a wide range of fruit hues. The seeds are white or yellow and may keep their viability for 4–6 years (Sękara et al. 2007).

3.1.2 Eggplant environmental requirements

In subtropical and temperate areas, eggplant is cultivated both in the open field (during the summer) and in greenhouses (during the winter) for commercial purposes. Eggplants require warmer environments than other *Solanaceae* members (e.g., tomatoes or peppers). Eggplant is a warm-season crop requiring 60–85 days to complete its life cycle. The plant requires a 10–12 h photoperiod and performs optimally at relatively high temperatures (23–26 °C) (Sękara et al. 2007). Eggplants are extremely sensitive to cold and poorly perform at low temperatures. In cold seasons, flowering, fertility, and fruit set are significantly diminished (Nothmann and Koller 1975). Growth stops at 10–12 °C, and flowering and fruiting are significantly affected. Sunlight locations are required for the optimum growth of eggplants. During low light periods in greenhouses, there will be no fruit set, and the blossoms will fall off.

Eggplants grow in sandy loam, loam, or clay loam soils that are well-drained, rich in organic matter, and have a pH between 6.0 and 6.5. Depending on the cultivar and cultural practices, plant spacing can range from 45 to 60 cm between plants and 60 to 100 cm between rows. Because yields and fruit quality are diminished in the 2nd year, eggplants are typically grown as a single-season crop (Nothmann 1986).

3.1.3 Cultivation technologies

Typically, eggplant cropping is started by sowing seeds in trays in greenhouses the transplantation of seedlings into the field (Sękara 2010). The use of seedling tray allows for nursery mechanization as well as the preservation of root integrity during seedling transplantation to the field. The seedling stage is an important stage in the vegetable production chain. The seedling quality and vigour are considered essential for future plant performance in the field. Also, using grafted seedlings is common in some countries. In France and the Netherlands, grafted transplants currently represent 65% and 75% of total eggplant production, respectively (Lee et al. 2010).

Commercial eggplant seedlings should be genetically and morphologically uniform, visually appealing, and healthy, with high physiological potential and resistance to stressful storage, transport, and transplanting conditions (Costa et al. 2013). The growing season for field-grown eggplant is short, as it is in temperate climate zones; seedling production in greenhouse nurseries should begin by the end of February/beginning of March to extend the crop cycle. To reduce the risk of frost damage occurring below the -0.1 °C critical temperature, advanced-age seedling plugs (9-10 weeks after sowing) should be planted in the field after the last frost (Costa et al. 2013). Because plants entered the generative phase faster and the fruiting period was long enough to obtain early and high yields, such production timing was described as contributing to a significant yield increase (Sękara 2010).

In greenhouses, eggplant can be cultivated in two periods: from winter to summer and summer to winter. Low light intensity during the winter cycle results in reduced yield and quality. Heating systems allow an increase in both yield and quality. However, they have high fuel consumption and are not energy-efficient, and their adoption must be carefully considered in light of the local climate. Various culture systems can be applied to the cultivation of eggplants, including soil, substrate, and nutrient film technique (NFT) systems.

Plant density depends on hybrid vigour, structure type (greenhouse, tunnel), crop cycle length, and technology applied. In soilless culture systems, the density can be 1.6–2.5 plant per m^2 (Iapichino et al. 2007). Higher densities can cause problems, especially during intense fructification – inducing inadequate ventilation, poor lighting, and increased humidity, resulting in the development of diseases or attacks by pests.

The eggplant is distinguished by its vigorous vegetative development, which results in excessive plant density. Pruning is an essential practice that reduces the number of shoots, leaves, and fruit sets on a plant. The pruning process depends on the cultivar, plant spacing, growing conditions, and time of the year (Cebula 1996). According to Ambroszczyk et al. (2008), eggplant pruned to two shoots, with the second shoot emerging from the sixth node, produced the highest early and total yield and also with the highest levels of ascorbic acid content (Ambroszczyk et al. 2008). Irrigation management is another essential factor for enhancing the environment, combating diseases and insect pests, and bolstering greenhouse eggplant yield and quality.

The primary objective of eggplant breeding is the production of high-yielding, high-quality, and disease-resistant cultivars. The colour of the fruit, the ratio of seeds to the pulp, the cooking duration, and the olanine content are all crucial characteristics for evaluating eggplant quality (Daunay and Hazra, 2012).

3.2 Introduction to vegetable grafting

Grafting is a connection of two or more pieces of plant tissue that are forced to develop vascular connections and grow as a single plant (Savvas et al. 2010). Grafting is a special type of asexual plant propagation, in which a part of a plant (scion) is joined to another plant (rootstock) to grow together and form a new plant. Grafting have been practiced, especially on fruit trees, for thousands of years and recently in vegetables. Nowadays, in modern horticulture, grafting is used for many purposes: to have dwarf trees and shrubs, to strengthen plants' resistance to diseases, to retain varietal characteristics, to adapt varieties to unfavourable soil or climatic conditions, to ensure pollination, to propagate certain species that can be propagated in no other way (reviewed by Mozafarian and Kappel 2019). The first self-grafting was used to produce large gourd fruit size as reported in the 1920s in Chinese and Korean books. However, the cultivated area of grafted vegetable seedlings has increased to decline biotic and abiotic stress damage for both open fields and protected cultivation. This method is used to improve vegetables' production and resource efficiency (Gaion et al. 2018).

Table 3. Major advantages and disadvantages of using grafted vegetables (Bie et al. 2017)

Advantages	Disadvantages
Yield increase	Additional seeds for rootstocks
Shoot growth promotion	Experienced labour needed
Diseases tolerance	Wise selection of scion/rootstock combination
Nematode tolerance/resistance	High price of seedling
Low temperature tolerance	Increased infection of seed-borne diseases
High temperature tolerance	Excessive vegetive growth
Enhanced nutrient uptake	Fruit harvesting may be delayed
Enhanced water uptake	Inferior fruit quality
High salt tolerance	Symptoms of incompatibility at later stage
Wet soil tolerance	Different cultural practices should be applied
Heavy metal and organic pollutant tolerance	Different combination of cropping season
Quality changes	Different combination of cropping method
Extend harvest period	

Grafted vegetables have been used commercially in both *Solanaceae* (tomato, eggplant, and pepper) and *Cucurbitaceae* members (watermelon, melon, cucumber, pumpkin, and bitter gourd) and rarely in other vegetables such as artichoke and common bean onto vigorous and disease resistant rootstocks (Bie et al. 2017). Grafting involves four phases: (1) selection of rootstock and scion species, (2) creation of a graft union by physical manipulation, (3) healing of the union, and (4) acclimation of the grafted plant (Colla et al. 2017, Mozafarian and Kappel 2020).

Despite all mentioned advantages, problems associated with grafting still exist; for instance, professional labours with essential technique are for the grafting process (Kumar and Sanket 2017), the high and somewhat unaffordable price of grafted seedlings and automated grafting machines (Tsaballa et al. 2013).

The following factors should be also considered when dealing with grafted crops cultivation (Lee et al. 2010):

- the grafted plants have a stronger root system
- water and nutrient uptake of the grafted plant is more intense
- enhanced photosynthetic activity and improved water absorption in the grafted plants
- a stronger antioxidative defence system is formed due to the grafting
- increased hormonal signal transmission in the grafted plants.
- as an alternative and environmentally friendly way to fight against soil-borne diseases

Therefore, it is crucial to consider proper cultivating technology to be applied concerning the self-rooted and grafted plant cultivation.

3.3 Purpose of vegetable grafting

3.3.1 Yield increase

In terms of economics, the yield is the most important factor from a farmer perspective. Grafting increases yield directly by revitalizing scions, maximizing resource use efficiency (e.g., water, fertilizer), and extending the harvest period. Additionally, it reduces the costs associated with plant protection measures compared to self-rooted vegetables.

Grafting is associated with significant increases in fruit yield in various fruit and vegetable species, despite certain soil-borne disease resistance (Table 4). In addition to *Fusarium* resistance, this yield increase was closely correlated with prolonged maintenance of plant vigour in the growing season. Similar outcomes were achieved with tomatoes whereby using 'Kagemusia' rootstock, the marketable yield of tomato increased by up to 54%, and with 'Helper' rootstock, by up to 51%. (Chung and Lee 2007). Significantly fewer abnormal fruits were produced by tomato plants grafted onto the majority of rootstocks compared to tomato plants with their own roots.

Other researchers have reported similar yield increases for watermelon, cucumber (Lee and Oda 2003).

Table 4. Increased yield of grafted plants relative to non-grafted or self-grafted plants in various vegetable crops (Bie et al. 2017)

Vegetable	Yield increase (%)	References
Melon	3.4-92	Ruiz et al. (1997); Lee et al. (2010); Condurso et al. (2012); Verzera et al. (2014); Salar et al. (2015); Mohammadi et al. (2015); Esmaeili et al. (2015)
Watermelon	22.7-43	Mohamed et al. (2014); Soteriou et al. (2015), Rouphael et al. (2008a)
Cucumber	8.8- 57	Rouphael et al. (2008b); Colla et al. (2012, 2013); Farhadi and Malek (2015)
Pepper	9.2	Jang et al. (2012)
Eggplant	23.83- 95	Gisbert et al. (2011a), Sabatino et al. (2018), Bogoescu and Doltu (2015), Musa et al. 2020
Tomato	5.4-80.3	Chung and Lee (2007); Schwarz et al. (2013); Wahb-Allah (2014); Bhatt et al. (2015); Boncato and Ellamar (2015); Suchoff et al. (2015)

3.3.2 Quality of grafted vegetables and postharvest behaviour

Quality is a phrase that is frequently used but rarely defined, this means that various client groups, such as breeders, producers, market participants, food industry workers, and consumers, have varying perspectives on quality (Shewfelt, 1999). In recent years, the fundamental purpose of horticulture has been to improve yield and productivity in order to serve the expanding global demand for vegetables. Due to the beneficial significance of vegetables in the human diet, excellent quality is more essential than the total yield for achieving competitiveness in modern horticulture. Based on accurate genotype selection, optimization of environmental conditions (light, temperature, humidity, atmospheric CO_2, and air pollutants), and optimization of agricultural practices such as water management, fertilization strategies, growth and development regulators, pruning, growing systems, harvesting stage, and grafting, it may be possible to improve the fruit quality of vegetables.

The eggplant fruit should be glossy, free of surface scalds and blemishes, and have an intact, dark-green calyx (Molinar et al. 1996). Eggplants of superior quality must be firm, healthy, and free of defects and off-flavours. There should be no browning of the white or creamy flesh. The seed coats should not be completely mature. Eggplants are still physiologically immature, when they are harvested (Gajewski and Arasimowicz 2004). Typically, fruit is harvested manually and selected primarily based on size. Late harvests are undesirable because they result in seedy and bitter fruit.

The quality of eggplant deteriorates with storage due to surface dehydration, epidermal scalds, wilting of the calyx tips, browning of the peel, and rot. Eggplants have a three-day maximum shelf life when stored at room temperature (Singh et al. 2016). Various technologies such as cold storage, modified atmospheric storage, and gamma irradiation are frequently used to maintain eggplant quality and shelf life (Sahoo et al. 2015). Low-temperature storage is a common technique for extending the postharvest shelf life of fruits and vegetables, preserving quality and nutritional value. However, because eggplant is a tropical fruit, it is susceptible to chilling when stored at temperatures below 7–10 °C for an extended time (Gao et al. 2015, Concellón et al. 2012). The maximum maintenance of quality attributes occurs at a storage temperature of 10 °C (Concellón et al. 2004, 2007, Zaro et al. 2014). Pitting and scalding the skin, pulp browning, seed darkening, and off-flavour development are typical chilling injury signs in eggplant fruit (Gao et al. 2015). Besides the chilling sensitivity of eggplant to cold storage, other techniques like polyamines (Rodriguez et al. 2001), jasmonic acid (Shi et al. 2019), 1-methylcyclopropene (Massolo et al. 2011) have showing promising results not at a large scale due to economic and market constrains on implementation. Consequently, developing a low-cost, safe, and environmentally friendly technology for dealing with eggplant losses becomes essential.

Polyphenol oxidases (PPO) catalyze the oxidation of phenolic acids to quinones, which results in the browning of eggplants' internal tissues when exposed to air (Dranca and Oroian 2016, Mishra et al. 2013). According to Mishra et al. (2013), the browning of fresh eggplant depends on the phenolic content and PPO activity. PPO activity differs among eggplant cultivars (Mennella et al. 2010, Prohens et al. 2007, Todaro et al. 2011). Some wild relatives of eggplant can be used to improve the phenolics content of cultivated eggplant because they have a high content of phenolic acids in the fruit flesh without affecting fruit flesh colour and browning (Kaur et al. 2014, Ma et al. 2011, Mennella et al. 2012, Meyer et al. 2015).

As the primary drivers for the expansion of vegetable grafting have been the resistance to soilborne pathogens (Colla et al. 2017), tolerance to abiotic stresses (Schwarz et al. 2010, Kumar et al. 2015a, b, c, Rouphael et al. 2018), and increase in yields (Lee et al. 2010). Numerous contradictory findings about changes in fruit quality by grafting were presented showing positive or negative impacts (Flores et al. 2010, Table 5). This could be explained by differences in growing environments, rootstock-scion interaction, and fruit harvest maturity standards (Rouphael et al. 2010). For instance, the fruit weight and shape of eggplant grafted onto different rootstocks like

Solanum torvum, *Solanum incanum* × *Solanum melongena* and *Solanum melongena* × *Solanum aethiopicum* rootstocks were similar to non-grafted, self-grafted (Gisbert et al. 2011a, b, Sabatino et al. 2016, Khah 2011). In contrast, Cassaniti et al. (2011) observed an increase in fruit weight when eggplant 'Black Bell' was grafted onto *Solanum torvum.* Fruit skin or flesh colour can be affected by grafting and different rootstocks. Moncada et al. (2013) indicated that grafting eggplant onto *Solanum torvum* resulted in a darker and less vivid colour of fruits.

Fruit texture is described as firmness related to calcium concentration, water relations, wax layer, and fruit transpiration. Grafting and rootstock can influence fruit firmness. Cassaniti et al. (2011) found that grafting by eggplant caused a reduction of 13% in fruit firmness. Arvanitoyannis et al. (2005) reported a similar result, who grafted eggplant onto *Solanum torvum* and *Solanum sisymbriifolium.*

Important quality parameters (good taste and flavour) related to the sugar and acid content of the fruit can be influenced by grafting and different rootstocks. Some researchers explained that grafting caused lower plant growth and fruit water content and increased soluble solids content (SSC) (Ntatsi et al. 2014a, b). In contrast, other researchers have reported that grafting has no effect on the sugar content of peppers, tomatoes, and eggplant (Colla et al. 2008, Turhan et al. 2011, Nicoletto et al. 2013, Khah 2011).

Gisbert et al. (2011a) and Sabatino et al. (2016) observed a higher total phenolic compound in the fruit of eggplant grafted onto *Solanum macrocarpon* and *Solanum torvum*, respectively. In contrast, the opposite finding was observed by Moncada et al. (2013). Awad et al. (2001) highlighted that grafted plants should be pruned properly due to the higher vigour of grafted plants, which can have a negative effect on the concentration of anthocyanins in eggplant. Vitamin C content of eggplant fruits were negatively affected by grafting on *Solanum torvum* and *Solanum sisymbriifolium.* Sensory analysis showed that sweetness, acceptance, and the hardness of non-grafted fruit were higher than grafted ones (Arvanitoyannis et al. 2005).

The impact of grafting on the postharvest quality of vegetables is not fully understood. To date, there have been few reports concerning improving postharvest quality by grafting vegetables, especially eggplant. Previous studies showed that grafting tomatoes significantly affected fruit quality during storage (Ozturk and Ozer 2019). Nevertheless, there are few published reports on the effect of grafting eggplant on fruit postharvest performance. According to one of these, grafting during storage negatively affected eggplant vitamin C and flesh firmness (Arvanitoyannis et al. 2005). Grafting eggplant 'Monarca' onto Java modulated fruit growth and quality at harvest and increased fruit tolerance to chilling injury during storage and induced phenotypic traits able to improve vegetable postharvest performance (Darré et al. 2021).

Table 5. Effect of different rootstocks on eggplant yield and fruit quality

Rootstock	Scion	Fruit yield	Texture	TSS	Skin colour	Pulp colour	Seed number	Phenol content	Calyx pickle	Reference
Solanum aethiopicum (accession 1)	Scarlatti	-	0	0		0				Sabatino et al. (2019)
Solanum aethiopicum (accession 2)	Scarlatti	0	0	+		+				Sabatino et al. (2019)
Solanum melongena × *Solanum aethiopicum*	Scarlatti	0	0	0		0				Sabatino et al. (2019)
Solanum torvum	Scarlatti	0	0	-		0				Sabatino et al. (2019)
Solanum macrocarpon	Black Beauty	-					0	+	+	Gisbert et al. (2011a)
Solanum torvum	Black Beauty	0					0	0	0	Gisbert et al. (2011b)
Emperador (*Solanum Lycopersicum*)	AndraF1	+								Bogoescu and Doltu, 2015
Emperador (*Solanum Lycopersicum*)	Sharapova F1	+								Bogoescu and Doltu 2015
Hikyaku	Hikyaku	+								Bogoescu and Doltu 2015
Hikyaku	AndraF1	0								Bogoescu and Doltu 2015
Solanum torvum	Bianca	+						+		Sabatino et al. (2016)
Solanum torvum	Birgah	0			+	-		-		Moncada et al. (2013)
Solanum torvum	Black Bell	0			+	0				Moncada et al. (2013)
Solanum torvum	Black Moon	-			+	0				Moncada et al. (2013)
Solanum torvum	Longo	0			+	0				Moncada et al. (2013)
'Heman' (*Lycopersicon hirsutm*)	Rima	+		0			+			Khah 2011
'Primavera' (*Lycopersicon esculentum*)	Rima	+		0			+			Khah 2011
'Heman' (*Lycopersicon hirsutm*)	Rima	+					+			Khah 2011
'Primavera' (*Lycopersicon esculentum*)	Rima	0					+			Khah 2011
Solanum torvum	Tsakoniki		-					-		Arvanitoyannis et al. (2005)
Solanum sisymbriifolium	Tsakoniki		-					-		Arvanitoyannis et al. (2005)
Beaufort F1 (*S. lycopersicum* L. × *S. habrochaites*)	Blackbell F1					+		-	-	Kacjan Maršic et al. (2014)
Beaufort F1 (*S. lycopersicum* L. × *S. habrochaites)*	Epic F1					-		-	-	Kacjan Maršic et al. (2014)

''+'' increase; ''-'', decrease; ''0'' no change in fruit characteristics, empty cells: non-measurement parameters

3.3.3 Grafting as a tool for tolerance of abiotic and biotic stresses

Mainly, vegetable crops are grown in open fields, but they can also be grown intensively under the protected structures of greenhouses for extended periods or continuously throughout the year. Such plants will frequently be subjected to adverse environmental conditions if the conditions are not regulated as thoroughly as they are in highly sophisticated greenhouses. This will result in the plants being unable to thrive in their surroundings. As a direct consequence of this, farmers frequently face a wide variety of challenges, most notably abiotic stress, and are unable to realize the full yield potential of their crops. There is a gap between actual to potential yield due to biotic and abiotic stress conditions in farms and even modern greenhouses (Peleg et al. 2011). One-third of the yield gap is related to biotic stress, including nematodes and soil-borne pathogens. It is estimated that 60-70% of the difference between the actual to potential yield is due to abiotic stress including salinity, drought, flooding, heavy metal, temperature, and nutrient deficiencies or toxicities (Rouphael et al. 2018).

Developing tolerant cultivars to abiotic stresses (due to low genetic diversity, the complexity of multigenic traits, and complicated genetic control of traits response to stress) has not been fully successful (Rouphael et al. 2018). In addition, due to rapidly changing abiotic and biotic stresses, plant breeders need new germplasm (King et al. 2010). One environment-friendly technique for avoiding or reducing losses in production caused by stress would be to graft the commercial varieties onto tolerant rootstocks. Vegetable grafting is considered as a rapid alternative compared to slow breeding methods for increasing plant resistance against abiotic stress (Flores et al. 2010, Penella et al. 2017).

Several researchers have illustrated that grafting commercial-sensitive cultivars onto tolerant rootstocks can alleviate the deleterious effect of stresses (Rouphael et al. 2018, Schwarz et al. 2010). According to previous studies by Venema et al. (2008), Keatinge et al. (2014), and Okimura et al. (1986), cold tolerance rootstocks LA 1777 (*Solanum habrochaites*), 'KNVF' (the interspecific hybrid of *Solanum Lycopersicum* × *Solanum habrochaites*) and chill-tolerant lines from backcrossed progeny of *Solanum habrochaites* LA 1778 × *Solanum lycopersicum* 'T5' alleviate suboptimal temperature in tomato for different scions. Penella et al. (2014) demonstrated that improving net photosynthesis rate under water-stressed conditions caused increased marketable yield of pepper when grafted onto the rootstocks 'Atlante', 'PI-15225', and 'ECU-973'. Similar results were reported by López-Marín et al. (2013) in sweet pepper.

Penella et al. (2014) and Sánchez-Rodríguez et al. (2014) concluded that improving grafted plant growth (tomato and pepper, respectively) under water stress condition can be related to increasing nutrient accumulation in plants (through deep and vigorous root system), nitrate reductase activity and NO_3^- assimilation. Sánchez-Rodríguez et al. (2014) observed an increased potassium (K) concentration in tomato drought-tolerant rootstock resulted in better osmoregulation.

The production of vegetables is adversely affected by pests and diseases. Due to the special cultivation conditions, the primary reason for grafting vegetables has been to provide resistance to soil-borne diseases. Grafting onto *Solanum* spp. wild relatives *Solanum torvum* and *Solanum sisymbriifolium* controlled nematodes in eggplant (Rahman et al. 2002). Grafting eggplant scion ('Bonica') on tomato rootstock ('Brigeor') provided complete protection from root-knot nematodes, corky root rot, and some protection from *Verticillium* wilt (Ioannou, 2001). Other studies by Gisbert et al. (2011a) evaluated yield and quality of eggplant fruits under nematodes-infected soil. It was found that grafting eggplant 'Black Beauty' onto Solanum torvum, Solanum macrocarpon and crosses between *Solanum incanum* and *Solanum aethiopicum* resulted in minimal galling, good compatibility, and high yields.

Using tomato rootstock 'Hawaii' 7996 (VI043614) showed effective resistance in bacterial wilt-infected tomato fields (Cardoso et al. 2012). The results of Zhang et al (2010) showed that grafting tomato 'Zaoguan 30' onto wilt-resistant rootstocks (LA2701, LA3202 and LA3526) inhibited the damage caused by bacterial wilt pathogens. Eggplant rootstocks 'EG 203' (Palada and Wu, 2007); 'Cheong Gang', 'BHN 1054' and 'BHN 998' (McAvoy et al. 2012); interspecific hybrid tomato rootstocks (*Solanum lycopersicum* × *Solanum habrochaites*) (Rivard et al. 2010); tomato rootstocks 'Dai Honmei' and 'RST-04-105-T' (Rivard et al. 2012) controlled bacterial wilt in tomato grafted plants. McAvoy et al (2012) grafted tomato cv 'BHN 602' onto 'Cheong Gang', 'BHN 1054', 'BHN 998' rootstocks and itself in open field and in greenhouse conditions and indicated less bacterial wilt than control and self-grafted plants.

Asian Vegetable Research and Development Center (AVRDC) classified a wide range of eggplant rootstock resistant to bacterial wilt (i.e. TS3, TS60A, TS89, TS36, Terong Lalap, TS75, Hijau Besar, Terung Hijau Kecil and Terong Hijau). Dabirian et al. (2017) demonstrated that the Super Shintoza rootstock reduced the incidence of microsclerotia and increased tolerance to *Verticillium* wilt in watermelon.

3.3.4 Improving salinity tolerance by grafting

Global food security is highly dependent on agricultural crops and their products, which require large increases to maintain the production-to-consumption gap. The growing human population, which currently stands at 7.6 billion and is predicted to surpass 9.7 billion by 2050, has made the importance of increasing crop yields even more apparent in recent years (FAO, 2018). Population growth will undoubtedly pressure the production of additional crops and food supplies, which appears to be a difficult task for plant biologists. Climate change and other biotic and abiotic factors simultaneously threaten the growth and output of agricultural crops. Among abiotic stresses, salinity is regarded as one of the most significant limiting factors responsible for the development and production decline of agricultural crops worldwide, particularly in dry and semiarid locations (Kaashyap et al. 2018). About 20–33% of the world's agricultural and irrigated land is affected by salinity (Soda et al. 2016, Machado and Serralheiro 2017). It is estimated that by 2050, around 50% of the soil will be affected by salinity, without the use of any effective mitigation techniques to alleviate the problem (Blumwald and Grover 2006).

The challenge of salinity occurs when the ion concentration of various salts (mostly NaCl) in soils exceeds the threshold level necessary for appropriate germination, development, and physiological activities of plant root zones. Standard agricultural soils that foster plant development have a salt level of 4 $dS.m^{-1}$, which is comparable to 40 mM NaCl. This salinity level is typically assessed as the electrical conductivity of the saturated extract (Shrivastava and Kumar 2015). In the rhizosphere, ionic concentrations are over 4 dS. m^{-1} induces stress conditions that hinder plant development in several ways. The natural addition of salts from rocks and minerals during the weathering process (primary salinity) or intensive human activity like as irrigation, agricultural intensification, and deforestation (secondary salinity) may be the leading sources of salinity. Additionally, high evaporation rates in the tropics seem to enhance the salt content of agricultural soil. Salinity has severe effects on plant water availability in the soil, transpiration and photosynthesis rates, stomatal opening and closing, and root functional activities (Khataar et al. 2018). The disparities caused by salt stress result in decreased crop development, physiologic processes, and yield outputs. The annual costs associated with agricultural losses due to salinity have been estimated at 27 billion US dollars. Combined with drought, crop losses caused by salinity vary from 20 to 50 percent in recorded research (Shrivastava and Kumar 2015), although losses caused by salt stress in unstudied regions may be much greater. From a physiological standpoint, almost all plants are sensitive to salt stress, despite the fact that their reactions to the applied stress vary depending on their tolerance level.

Salinity has a variety of detrimental effects on plants, including reducing the photosynthetic rate and chlorophyll content, altered anatomy and physiology of the plant, increased ROS generation, and consequently decreased plant development and production (Pessarakli 2020). It may accumulate Na^+ and Cl^- in plants, causing osmotic stress and interacting with photosynthetic compounds (Tavakkoli et al. 2010).

Eggplant is a moderately sensitive with a salinity threshold of 1.5 $dS.m^{-1}$ (Akinci et al. 2004, Ünlükara et al. 2010). This difference can be attributed to plant variety and experimental conditions. Previous researchers have described morphological and biochemical responses of eggplant to salt stress (Ünlükara et al. 2010, Abbas et al. 2010, Akinci et al. 2004). Savvas and Lenz (2000) and Abbas et al. (2010) previously showed that NaCl had no effect on vegetative growth or flower quantity but drastically impaired fruit production and mean fruit weight. The photosynthetic system has been identified as the most salt-sensitive plant component (Saied et al. 2003). Photosynthetic capacity, which can be determined through gaseous exchange and chlorophyll fluorescence measurements, is a good way to assess the effects of salt stress on plants and gain insight into the behavior of the photosynthetic machinery under stress (Maxwell and Johnson 2000, Rohacek 2002, Willits and Peet 2001). According to reports, salinity limits photosynthesis and gas exchange (Moradi and Ismail 2007, Naeem et al. 2010, Sharma et al. 2019a).

Over decades, attempts have been made to address the adversities produced by salinity stress on crops in order to maintain a sustainable output of agricultural crops and to secure future food security. Inducing salinity tolerance in salt-sensitive crops is one of the fundamental techniques of preventing agricultural losses caused by salinization. Genomic and molecular techniques to understanding the possibilities of salt resistance induction in crops have been useful in further developing crops that are tolerant to saline conditions (Luo et al. 2017). In addition to molecular approaches, breeding for salt tolerance, adequate agronomic irrigation practices, and the quest for cost-effective and realistic methods to mitigate the dramatic impacts of salinity on major crops must be used (Mozafarian and Kappel 2020).

Previously, several studies have been conducted to determine the impact of rootstocks on plant growth, fruit yield, and qualities of eggplant (Moncada et al. 2013, Gisbert et al. 2011b, Sabatino et al. 2016, 2018, 2019, 2020, Mozafarian et al. 2020). Earlier studies on grafting eggplant indicated that salt stress could be mitigated by enhancing plant growth, proline content, enzymes activity, increasing photosynthesis, increasing N and P content, decreasing the Na^+/K^+ ratio, and achieving a balanced absorption of Ca, Mg, Cu, Fe, Zn, and Mn (Qian et al. 2013; Talhouni et al. 2019). Semiz and Suarez (2019) conclude that salt tolerance of grafted eggplant onto Maxifort rootstock is associated with a reduced Na^+ and increased Ca^{2+} and K^+ uptake. According to Liu et al. (2007) and Wei et al. (2007), grafting eggplant ‘Suqiqie' onto Torvum Vigour (*Solanum torvum*) resulted in resistance to saline stress. Wei et al. (2009) demonstrated that seedlings grafted onto salt-resistant rootstock (*Solanum torvum*) were more tolerant to stress than non-grafted seedlings through antioxidant enzymes and polyamines.

Several salt tolerance rootstocks were suggested for tomato: wild tomato species including *Solanum pimpinellifolium*, *Solanum peruvianum*, *Solanum cheesmaniae*, *Solanum habrochaites*, *Solanum chmielewskii* and *Solanum pennellii* (Rao et al. 2013); Pera (Santa-Cruz et al. 2002) and Radja, Volgogradskij, Pera, and Volgogradskij × Pera (Santa-Cruz et al. 2002). He et al. (2009) grafted commercial tomato hybrid onto Chinese commercial tomato rootstock under 0 to 150 mM

NaCl; they observed that photosynthesis characteristics improved in grafted plants compared to control and self-graft.

Liu et al. (2007) and Wei et al. (2007) found that the grafting eggplant 'Suqiqie' onto Torvum Vigour (*Solanum torvum* Swartz) resisted to salinity stress conditions. Grafting common eggplant onto wild eggplant rootstock Tuolubamu (*Solanum torvum*) alleviate salt stress symptoms through plant growth, proline content, enzymes activity, enhancing photosynthesis, increasing N and P, reduction off Na^{+}/K^{+} value and a balanced absorption of Ca, Mg, Cu, Fe, Zn and Mn (Qian et al. 2013).

Penella et al. (2017) grafted pepper onto different rootstocks from the COMAV Gene bank at the UPV university (Valencia, east Spain): one from *Capsicum chinense* Jacq., one from *Capsicum baccatum* L. var. pendulum, and one from *Capsicum annuum* L. and showed higher marketable yield in the grafted plant than non-grafted and grafted onto commercial rootstock (Antinema) due to high photosynthesis level under stress conditions.

The rootstock is the primary component that enables the plant to resist stressors, and hence by selecting proper rootstocks could enhance their tolerance by limiting Na^{+} and Cl^{-} uptake to shoot, maintenance of photosynthesis, absorbing more water and nutrients (Edelstein et al. 2011; Aloni et al. 2010; Penella et al. 2016).

3.3.4.1 Mechanisms of salt tolerance in grafted plants

Root system plays an important role in the tolerance of grafted vegetables against salinity stress (Colla et al. 2010). Root length and density and their length, and therefore their surface area, may play an important role in ion and water absorption (Koevoets et al. 2016). The increased salt tolerance of grafted plants has frequently been linked to their root systems. In reality, the root systems are the most important organs of the plants when confronted with soil-related stressors like salt. Therefore, root features are primarily responsible for mitigating the negative effects of salt stress on shoot development (Kumar et al. 2017). He et al. (2009) found that the root dry mass of tomato plants decreased at 100 and 150 mM NaCl, compared to non-saline conditions, however the drop was less pronounced in grafted plants. Similar to Zhu et al. 2008, and Huang et al. (2009a, b) showed that the drop in root dry weight of grafted cucumber plants under NaCl stress was much less than that of non-grafted plants. Moreover, the partitioning of biomass between shoot and root revealed that, compared to non-grafted cucumber plants, grafted plants tended to accumulate more biomass in root, resulting in a bigger root-to-shoot ratio (Huang et al. 2009a). Using squash and bottle gourd rootstocks under salt stress conditions, the drop in root dry weight was much less in grafted watermelon plants than in non-grafted watermelon plants (Colla et al. 2006a, Yetisir and

Uygur, 2010). Therefore, at least in part, the superior growth performance of grafted vs. non-grafted vegetable crops under salt stress may be attributable to differential root development under salinity stress.

One of the earliest responses of plants to salt stress is a reduction in leaf growth, which is caused by a reduction in stomatal conductance. Salt stress inhibits photosynthesis by inhibiting the electron transport chain, which results in photoinhibition. The inhibition of photosynthesis reduces the growth of plants. Previous research has demonstrated that grafting of salt-tolerant rootstocks can increase the photosynthetic rate by protecting chloroplast structure and reducing oxidative damage, thereby delaying the rate of photoinhibition (Zhen et al. 2011, Liu et al. 2013).

The rate of net photosynthesis under salt stress was higher in tomato plants ('Durinta') grafted onto 'Energy', 'He-man', and 'Resistar' rootstocks, but there was no discernible effect of grafting on epigeal dry matter (Martorana et al. 2007). Under severe salt stress, He et al. (2009) observed high photosynthetic rates and water use efficiency in tomato plants ('Hezuo901') grafted onto 'Zhezhen No.1' rootstock. Comparing the responses of four tomato cultivars (Jenin1, Hebron, Ramallah, and Maramand) to four salinity levels (0, 50, 100, and 150 mM NaCl), Sholi (2012) found that the higher salt tolerance (up to 100 mM NaCl) of cultivar Ramallah was due to its higher photosynthesis rate and K^+/Na^+ ratio.

Two commercial hybrid tomato cultivars, 'Belle' and 'Gardel' scions grafted on two interspecific hybrid rootstocks, 'Beaufort' and 'Maxifort', exhibited no significant difference in net photosynthesis and stomatal conductance when exposed to NaCl compared to non-grafted plants (Marsic et al. 2018). Feng et al. (2019) also discovered that salinity-treated tomato scion grafted onto wolfberry (*Lycium chinense*) rootstock exhibited greater net photosynthesis, transpiration, stomatal conductance, ratio of variable to maximum fluorescence (F_v/F_m) and electron transport rate than non-grafted tomato plants.

Plants exposed to high salt concentrations experience ion imbalance, ion toxicity, and hyperosmotic stress. Secondary stressors, such as oxidative damage, frequently result from these fundamental impacts (Zhu, 2001). Numerous physiological and biochemical responses are developed by grafted plants in response to salt stress. These include 1) salt exclusion in the shoot and retention of salt ions in the root, 2) improved maintenance of potassium homeostasis, 3) compartmentation of salt ions in the vacuole, accumulation of compatible solutes and osmolytes in the cytosol, 4) activation of an antioxidant defence, and 5) induction of hormone-mediated changes in plant growth (Pessarakli, 2020).

Grafted plants inhibited the transfer of Na^+ from the root to the shoot (Romero et al. 1997, Estan et al. 2005, Goreta et al. 2008, Zhu et al. 2008). The increased salt tolerance of grafted vegetables has frequently been linked to reduced Na^+ and/or Cl^- levels in the shoot. Self-rooted tomato plants have greater Na^+ and Cl^- concentrations in their xylem and leaves than grafted tomato plants (Santa-Cruz et al. 2002, Fernández-Garca et al. 2002, Fernández-Garca et al. 2004a, b, Martinez-Rodriguez et al. 2008). Grafting increases the salt tolerance of tomatoes, but various rootstocks have variable abilities to regulate the transport of Na^+ and Cl^- to the tomato shoot, highlighting the significance of rootstock selection (Estan et al. 2005). Under NaCl stress, eggplant grafted onto *Solanum torvum* showed lower leaf Na^+ and Cl^- levels than self-rooted plants (Bai et al. 2005, Wei et al. 2007). Due in part to effective Na^+ exclusion from the watermelon shoot, 'Strong Tosa' (*Cucurbita maxima* Duch. × *Cucurbita moschata* Duch.) is able to survive salt stress better than other studied rootstocks (Goreta et al. 2008). Grafted plants have a higher K^+ content than self-grafted plants, which appears to correlate with their greater salt tolerance (Zhu et al. 2008, Huang et al. 2009 a, b).

Under NaCl stress, tomato plants grafted onto *Solanum lycopersicum* contain more soluble sugar and proline than self-rooted plants (Chen et al. 2003). Similarly, grafted cucumber plants have a higher soluble sugar and proline content, but a lower Na^+ and Cl^- content in the leaves than self-rooted plants under NaCl stress, indicating that the increased salt tolerance of grafted plants is associated with the change in osmotic component (Yang et al. 2006, Chen and Wang 2008, Huang et al. 2009a). In macronutrient-induced saline conditions, cucumber plants grafted onto *Cucurbita ficifolia* contain more soluble sugar than self-rooted plants. Even though compatible solutes have a higher energy requirement, grafted plants can still benefit from their greater accumulation. The overabundance of Na^+ in the leaf tissue can cause premature leaf senescence or even death, whereas a higher soluble sugar and proline content can mitigate, to some extent, the negative effect induced by salinity (Tester 2003).

Reduced stomatal conductance, decreased photosynthetic electron transport, and increased production of harmful ROS are all effects of salt stress that ultimately result in plant damage and death. ROS (such as hydrogen peroxide and superoxide radicals) disrupt plant metabolism by causing oxidative damage to proteins, nucleic acid, and lipids. To reduce ROS-induced oxidative damage, plants activate both enzymatic and non-enzymatic antioxidant systems (i.e., APX, CAT, SOD), monodehydro ascorbate reductase, dehydro ascorbate reductase, and glutathione reductase (GR). As demonstrated by a significant increase in the antioxidant activity of salt-treated (grafted) tomatoes, salt-induced ROS production in grafted plants is generally much lower than in non-grafted plants. In grafted plants, SOD and CAT activities tended to increase as salinity increased, whereas the opposite was true for non-grafted and self-grafted plants (He et al. 2009). Compared to self-rooted plants, the SOD, POD, and CAT activities in the roots of grafted plants were significantly higher (Zhang et al. 2008). In tomatoes, the alleviation of oxidative damage in grafted tomato plants under NaCl stress was due to an increase in the activities of CAT and enzymes involved in the ascorbate-glutathione cycle, including APX and GR (He et al. 2009). As a result, an effective antioxidant system is crucial for the increased salt tolerance of grafted plants.

In addition to enzymatic antioxidants, it was discovered that non-enzymatic antioxidants also contribute to the salinity tolerance of grafted vegetables. Under NaCl stress, the AsA and GSH contents of the leaves of grafted eggplant seedlings were significantly higher than those of self-rooted seedlings (Liu et al. 2007). Grafted tomato plants have a lower root O_2 production rate and lower H_2O_2 and MDA levels when subjected to an excess of Ca $(NO_3)_2$.

The role of phytohormones in modulating the union between shoot (scion) and root (rootstock) components in grafted plants has been the focus of research over the past few decades: in addition to regulating key metabolic processes at the graft union, endogenous plant bio-regulators (e.g., auxins, gibberellins, cytokinin, and ethylene) are also involved in signal transduction across the graft union (Sharma et al. 2019b). Chen et al. (2003) reported that regardless of the rootstock genotype and the salinity of the growth medium, the scion genotype and its ABA level played the most significant role in the growth of grafted plants.

Since salinity stress decreased plant cytokinin content, increasing root-to-shoot cytokinin transport by using a rootstock overexpressing the cytokinin biosynthesis genes such as isopentenyl transferase enhanced tomato salt tolerance by increasing vegetative and fruit growth, delaying leaf senescence, and maintaining stomatal conductance and PSII efficiency, thereby preventing or delaying the accumulation of toxic ions (Ghanem et al. 2011).

3.4 Rootstocks for eggplant and their performances

The cultivation of grafted solanaceous crops started with eggplant in the 1950s, followed by tomato and pepper in the 1960s. Currently, tomato has the most production area on rootstocks of any solanaceous crop. Various rootstocks from existing cultivars have been screened for use in each crop. Grafting in solanaceous crops has been used to provide scion resistance or tolerance not only to fungal diseases (e.g., *Fusarium oxysporum*, *Verticillium dahliae* and *Verticillium alboatrum*, *Sclerotium rolfsii*, *Pyrenochaeta lycopersici*), bacterial diseases (*Rhizoctonia solanacearum*), and viruses such as pepino mosaic virus, but also to abiotic stresses (Davis et al. 2008, King et al. 2010, Lee et al. 2010, Schwarz et al. 2010, Miguel et al. 2011). However, seed companies and breeders have recently expressed an interest in developing superior rootstocks for vegetables grown in specific conditions and environments. Growers can therefore make a decision on choosing rootstocks that are best suited to their specific needs.

Table 6. describes the features and functions of numerous species and hybrids now utilized as eggplant rootstocks. Rootstocks derived from the genus *Solanum* are the most popular for tomato cultivation and are also widely used for eggplant cultivation (Ioannou 2001).

Solanum torvum also known as turkey berry, devil's fig, and pea eggplant, is a neotropical bush belonging to the "spiny *Solanum*" (subgenus *Leptostemonum*) group (Levin et al. 2006). This species has become naturalized and is occasionally invasive in tropical areas of Africa, Asia, and Australia; it is also occasionally cultivated for its edible fruits, primarily in Southeast Asia and Africa (Gousset et al. 2005). *Solanum torvum* is of great interest as a rootstock for eggplant (*Solanum melongena* L.), as the plant is highly vigorous, fully graft-compatible with eggplant scions, and resistant to a broad spectrum of soil pathogens, including *Verticillium dahliae*, *Ralstonia solanacearum*, *Fusarium oxysporum*, and root-knot-nematodes (Schwarz et al. 2010). For the practical use of *Solanum torvum* as a rootstock in the commercial production of grafted eggplant plants as well as in breeding programs, the poor, irregular, and erratic germination of seeds is the most significant limitation (Gousset et al. 2005, Hayati et al. 2005).

Solanum melongena is an alternative rootstock for cultivating susceptible tomatoes under certain conditions; it has been shown to provide better protection than tomato rootstocks against bacterial wilt (*Ralstonia solanacearum*) and flooding during the hot, wet season in South-east Asia (Black et al. 2003) and to have good graft compatibility with tomato.

The wild species *Solanum sisymbriifolium*, also known as sticky nightshade, produces small fruits that are edible. This species has been used as a rootstock for tomatoes (Bletsos and Olympios 2008) and eggplants (Bletsos et al. 2003, Arvanitoyannis et al. 2005) to provide vigour and resistance to the plants (Bletsos et al. 2003). When grafted onto *Solanum sisymbriifolium* rootstocks, there was a reduction in the firmness and sweetness of the eggplant fruit, which was one of the observed negative effects on the eggplant fruit quality (Arvanitoyannis et al. 2005).

Solanum habrochaites is endemic to the cloud forests of the western Andean slopes up to elevations of 3600 meter above sea level and is well-known for its cold resistance and ability to maintain its growth rate at lower temperatures. It confers cold resistance on the grafted scion (Venema et al. 1999, 2005, 2008); this feature is crucial for the viability of early-season harvests and for conserving energy in northern European greenhouse tomato production. The species is also very robust, having a vast spreading habit, growing up to six meter wide and up to one meter tall, and with a corolla measuring up to five centimeters (Peralta et al. 2008); this unusually high vigour may be a significant influence in its success in rootstock hybrids.

The *Solanum melongena* × *Solanum incanum* and *Solanum melongena* × *Solanum aethiopicum* hybrids are vigorous rootstocks that enhance yield, fruit number and earliness, and show resistance to several diseases without negative effects on apparent fruit quality or composition; both hybrids exhibited high germination (> 90%), in contrast to the erratic germination of *Solanum torvum*, and also gave excellent compatibility (100% graft success) with eggplant (Gisbert et al. 2011a).

Table 6. Examples of eggplant rootstock for diverse purposes

Rootstock species	Purpose	References
Solanum melongena × *Solanum melongena*	Compatibility and grafting success, nematode resistance, yield, fruit number and earliness	Gisbert et al. (2011a)
Solanum torvum	Fruit yield, apparent quality and proximate and mineral composition	Gisbert et al. (2011b)
Solanum torvum	Reduction in eggplant fruit cadmium content	Arao et al. (2008)
Solanum torvum	pH, mechanical firmness and vitamin C content, and sensory parameters	Arvanitoyannis et al. (2005)
Solanum torvum	Growth and yield and *Verticillium* wilt resistance of eggplant	Bletsos et al. (2003)
Solanum torvum	Growth performance under saline stress	Colla et al. (2010)
Solanum incanum	Graft success, nematode resistance, fruit yield and quality improvement	Gisbert et al. (2011a)
Solanum incanum × *Solanum melongena*	Graft success, nematode resistance, fruit yield and quality improvement	Gisbert et al. (2011a
Solanum melongena × *Solanum aethiopicum*	Graft success, nematode resistance, fruit yield and quality improvement	Gisbert et al. (2011b)
Solanum macrocarpon	Fruit yield and quality improvement	Gisbert et al. (2011b)
Solanum integrifolium	Improved *Fusarium* wilt resistance	Gisbert et al. (2011b)
Solanum sisymbriifolium	Improved growth, yield and resistance to *Verticillium* wilt	Bletsos et al. (2003)
Solanum torvum × *Solanum sanitwongsei*	Resistance to bacterial wilt	Lee et al. (2010)
Solanum lycopersicum	Improved resistance to *Verticillium* wilt	Liu et al. (2009)
Solanum habrochaites	Graft success, nematode resistance, fruit yield and quality improvement	Gisbert et al. (2011a)
Solanum lycopersicum × *Solanum habrochaites*	Na_2SO_4 salinity resistance	Giuffrida et al. (2014)
Solanum lycopersicum × *Solanum habrochaites*	Macronutrient uptake	Leonardi and Giuffrida (2006)
Solanum lycopersicum × *Solanum habrochaites*	Graft success, nematode resistance, yield, fruit number and earliness	Gisbert et al. (2011a)
Solanum melongena	Reduction aubergine fruit Cd concentrations	Arao et al. (2008)
Solanum melongena	Root-knot nematode and corky root resistance	Louws et al. (2010)
Solanum melongena	Grafting success, improved nematode resistance and fruit yield	Gisbert et al. (2011a)

4. MATERIAL AND METHODS

4.1 Experimental Site

The research was conducted at the Institute of Horticultural Sciences, Department of Vegetable and Mushroom growing, Hungarian University of Agriculture and Life Sciences, between 2019 and 2020. Seedling production and greenhouse cultivation were conducted at Soroksár Experimental and Research Farm (47°23′49″ N, 19°09′10″ E, 120 m a.s.l.) from March to September 2019.

Figure 3. Soroksár Experimental and Research Farm (Source: Google EarthPro).

4.2 Plant material and Seedling Production

Eggplant 'Madonna' (Monsanto, US) has a big vigour plant with a well-developed root system. It produces medium-sized, black-coloured fruit, white pulp with a few seeds. It is recommended for greenhouse cultivation. **'Madonna'** was used as a scion, and six rootstocks were tested in this research: Taibyou (SH), Akansau (A), Torvum (ST), Hikyaku (SI), Emperador (E), Optifort (O). Self-grafted (SG) 'Madonna' was also tested, and non-grafted 'Madonna' eggplant as a control.

Taibyou:

(*Solanum grandifolium* × *Solanum melongena*), Takii Seeds (Japan), resistant to *Verticillium* wilt and *Fusarium* wilt

Akanasu:

(*Solanum integrifolium*), Takii Seeds (Japan), resistant to *Fusarium* wilt and bacterial wilt

Torvum:

(*Solanum torvum* L.), Kaneko (Japan), high resistance to bacterial wilt, *Verticillium spp*., *Fusarium spp*., and nematodes

Hikyaku:

(*Solanum melongena* × *Solanum integrifolium*), Kaneko (Japan), intermediate resistance to *Verticillium* wilt and *Fusarium* wilt

Emperador:

(*Lycopersicum esculentum* × *Lycopersicum hirsutum*), Rijk Zwaan (Netherlands), resistance to low temperatures, high resistance to *Verticillium spp*, *Fusarium spp*, *Pyrenochaeta lycopersici*, *Dydimella lycopersici*, intermediate resistance nematodes

Optifort

(*Solanum lycopersicum* × *Solanum habrochaites*), De Ruiter (Netherlands), highly resistant to Tomato Mosaic Virus, *Fusarium spp*, *Pyrenochaeta lycopersici*, *Verticillium spp.,* and medium resistance to nematodes, Extra vigour in relatively cold circumstances

Table 7 shows rootstocks list used in the research which some or all of them used in different experiments. More detail about experiment design is provided in 4.3.

Table 7. Rootstock used in the different experiment with their labels

Rootstock	Latin name	Label	4.3.1	4.3.2	4.3.3
Self-Rooting	*Solanum melongena*	SR	×	×	×
Self-Grafting	*Solanum melongena*	SG	×		×
Taibyou	*Solanum grandifolium* × *Solanum melongena*	SH	×	×	×
Akanasu	*Solanum integrifolium* 'Akanasu'	A	×	×	
Torvum	*Solanum torvum*	ST	×	×	×
Hikyaku	*Solanum melongena* × *Solanum integrifolium*	SI	×	×	
Emperador	*Lycopersicum esculentum* × *Lycopersicum hirsutum*	E	×	×	
Optifort	*Solanum* lycopersicum × *Solanum* habrochaites	O	×	×	

†4.3.1: Effects of different rootstocks on eggplant, 4.3.2. Effect of different rootstocks on fruit postharvest at two different temperatures during storage time, 4.3.3: Effect of selected rootstocks on eggplant under salinity stress

Figure 4. Seedling preparation steps from seed sowing (A), seedling after two weeks (B) grafting (C) and grafted seedling after two weeks (D)

Four eggplant rootstock seeds (SH, A, ST, and SI) were sown on 19th March, while the 'Madonna' scion and tomato rootstocks seeds (E and O) were sown on 4th April 2019. Two seeds were placed per pots (7 cm × 7 cm × 6.2 cm) in groups of 32 in each tray to produce grafted and non-grafted seedlings (Figure 4). The sown seeds were covered by a 30% perlite and peat mixture. Seeds were placed in 18 hours light, 25-26 °C temperature, and 70 to 80 % of air humidity. Irrigation with regular water is required to keep the substrate moist until seed germination. The seedling was irrigated with 1.5 kg of Ferticare starter (15: 30: 15) in 1000 liters of water with EC 1.8-2 $dS.m^{-1}$ from germination until the cotyledon and first true leaves. Ferticare I (14:11:25+ micronutrient) was applied to seedlings from the first true leaves to planting out.

After germination, the seedlings were raised in the polyethylene plastic house with heating from downstairs during the night, until the dicotyledon and first true leaves appeared. Irrigation was applied with fertilizer solution.

When the seedlings had an adequate diameter, 'Madonna' eggplant scion was grafted onto SH, ST, A, SI, E, O and 'Madonna' (as self-grafting). Seedlings were grafted by hand using the splice grafting method (Figure 4, 5). The cutting was made using a regular cutting blade sterilized with 70% ethanol. The used grafting technique was completed by attaching a silicone clip at the graft union to ensure that correct fit and the correct amount of pressure was applied. For one week, the grafted plants were left for healing with low light and high humidity conditions and then adapted to normal conditions (Lee et al. 2010).

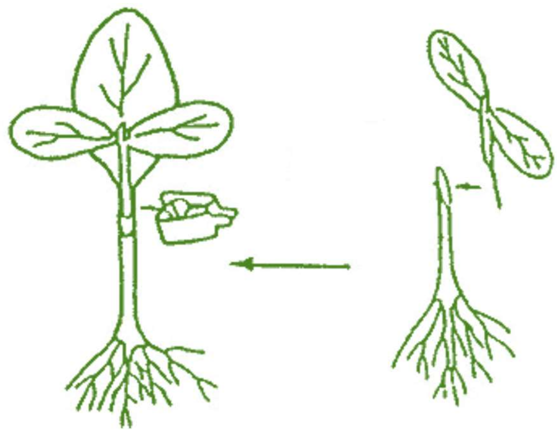


Figure 5. Splice grafting method used in this experiment (Lee et al. 2010)

4.2.1 Greenhouse conditions

A greenhouse experiment was conducted in 2019 to determine plant physiology at different growth stages, fruit yield, and quality of grafted plants as compared to self-rooted plants under stress and non-stress conditions.

Three weeks after grafting (14th May), all seedlings were transplanted into 10-liter pots containing peat substrate (Kekkila, Finland) with 0-25 mm particle size in an unheated polyethylene greenhouse (Figure 6).

Figure 6. Plastic house structure and pot layout inside the plastichouse at Soroksár Experimental and Research Farm

4.2.2 Cultivation methods, irrigation, and nutrient management

The experiment was conducted with four replications and five plants in each replication. The distance between the plants was 50 to 55 cm, and the distance between the rows was 120 cm (Figure 6). Drip irrigation system was used. Irrigation was applied twice a week with a fertilizer solution (Ferticare I, Yara Company) containing 14 N: 14 P: 25K plus microelements. The used amount of fertilizer was 2.5 kilograms in 1000 liters of water. One liter of the solution was applied to each plant per one-time irrigation.

The condition inside the plastic house, including temperature and relative humidity, was recorded by the Flower Power Sensor data logger (Parrot Company, France), as shown in Figure 7.

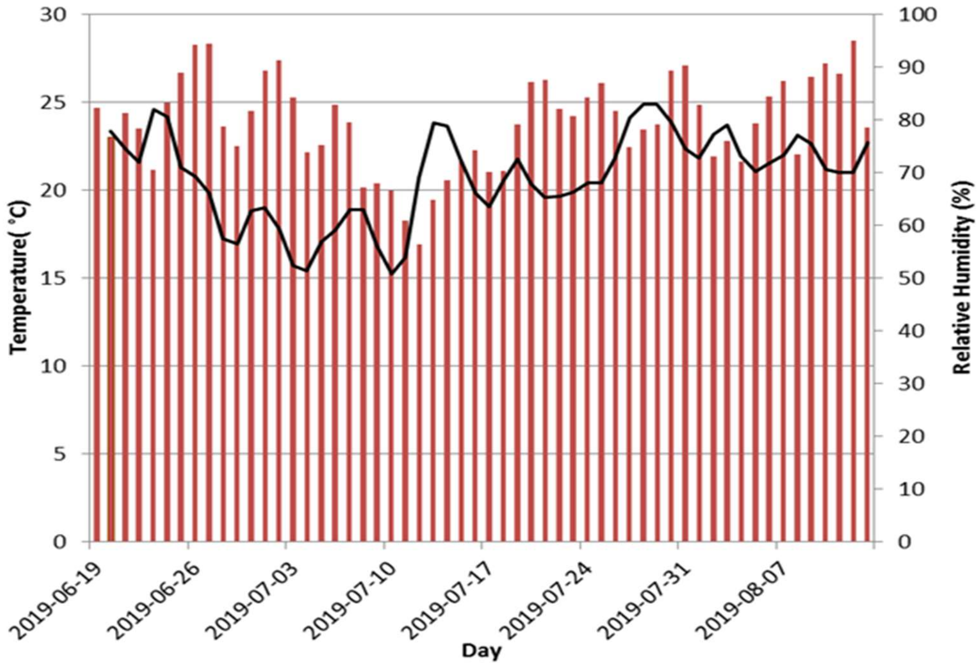


Figure 7. Temperature and relative humidity inside the plastic house during the cultivation

4.2.3 The training system, support, leaf, and flower removing

Supporting eggplant is important after transplanting the plant to the final growing system to make sure that they will grow upright (Figure 8). The applied training was a V cordon system with two stems per plant. Side shoots and suckers were removed frequently. Mature fruits were picked once a week (the 26th June - 3rd Sep 2019) according to fruit dimension, colour, and glossiness.

Figure 8. Plants inside the plastic house during the productive stage

4.3 Establishment of treatments and the measured parameters

To obtain a greater understanding of the plant's physiological and productive characteristics under various conditions, we used all or selective rootstock in combination with other treatments (Table 7 on page 34). The preparation of seedlings for each experiment was identical to that previously described.

4.3.1 Effects of different rootstocks on eggplant

All six rootstocks were evaluated in normal conditions compared to self-rooted and self-grafted plants for plant growth and production.

Seedlings with similar development stage from each combination and non-grafted counterparts were selected and then transferred to the laboratory for evaluation. SPAD value, chlorophyll fluorescence, water potential (Ψw), RWC of leaf and stem, root length, diameter, volume, and fresh and dry weight were measured from each seedling. At the greenhouse, SPAD value, stem length, and root diameter were measured.

Mature fruits were hand-picked weekly from June to October (15 times), and fruit weight, length, diameter was measured. Same size fruits from each combination were selected and then transferred to the laboratory to measure TSS, pH, skin, and pulp colour.

Fruits harvested from rootstocks SR, SH, ST, SI, E, and O were selected to evaluate sensory measurements based on questionnaire results for different attributes. The questionnaire results were converted into a grade scale from 0 to 100.

4.3.2 Effect of different rootstocks on fruit postharvest at two different temperatures during storage time

To understand the fruit shelf-life and effect of different temperatures on fruit quality, an experiment was designed as a factorial based on CRD with three factors, including different rootstocks, temperature storage, and storage days. Undamaged fruits from six rootstocks (SH, ST, SI, A, E, and O) and self-rooted plants were selected, delivered to the lab, and separated into two groups. After that, fruits are packed in the low-density polyethylene bag and placed at 0 and 10 °C in temperature-controlled stores. Measuring was done at the start of storage and after 3, 6 and 9 days. On each sampling day, 12 fruits from each storage group and each rootstock were observed for pulp colour, firmness, pH, and TSS values. On each sampling day, 12 fruits from each storage were observed for pulp colour, firmness, pH, and TSS values.

4.3.3 Effect of selected rootstocks on eggplant under salinity stress

This research was carried out as a factorial experiment using a completely randomized design (CRD) to determine the influence of different rootstocks on salt damage mitigation. Rootstocks were used in this experiment, including SH (*Solanum grandifolium* × *Solanum melongena*), ST (*Solanum torvum*), self-grafted, and self-rooted treated with no (control) and 80 mM NaCl (Hannachi and Labeke (2018) and Wu et al. (2012)) with four replications and five plants in each replication.

A total of 2 types of nutrient solutions were used: Ferticare I (14:11:25 + microelements) with an EC value of 3.80 $dS.m^{-1}$ for control plants, Ferticare I + 80 mM NaCl with an EC value of 11.40 $dS.m^{-1}$ for salt stress condition, all treatments received two doses of calcium nitrate during cultivation. The EC of water and each fertilizer solution was measured with a manual electrical conductivity meter (HI 98311 DiST® 5 EC/TDS-Tester, Hanna, Italy). Each plant was irrigated with the same type and amount of nutrient solution. The pH and the EC were controlled during each irrigation according to the values measured in the drainage water.

Several parameters like chlorophyll pigments and carotenoids, SPAD value, chlorophyll fluorescence, RWC, water potential, and Na^+ and Cl^- concentration were measured. Fruit picked weekly from June to October and fruit yield and quality such as TSS, firmness, skin, and pulp colour were measured from each scion-rootstock and salinity treatment.

4.4 Measurement and evaluation methods

The following methods were used to evaluate each parameter for each experimental design.

4.4.1 Physiological measurement

- The seedling was taken from its growing container. The root-clinging substrate was washed away by running water. The root section was then separated from the aerial part. Tissue was utilized to remove surplus water from the root surface. A digital calliper was used to measure root diameters, and a ruler was used to measure root lengths.
- The root was subsequently placed on a digital scale, and its weight was recorded. After that, the samples were placed in an oven at 60°C for 12 hours. The dried root was removed from the oven and allowed to cool. A digital scale was used to measure the weight of the root.
- A glass beaker filled with water was used to measure root volume. In order to calculate the root volume, the water volume after completely submerging the root in water was subtracted from the water volume without the root.
- The relative chlorophyll content was measured using the Soil Plant Analysis Development, SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ltd., Japan).
- The chlorophyll fluorescence of the leaf was determined by a portable chlorophyll fluorometer (Model, OS5P Optisciences, Inc., Winn Avenue, Hudson, USA).
- The weight (g) of each fruit was measured using a digital weighing scale as soon as it was picked, and marketable and unmarketable fruit were distinguished based on their respective weights.
- A ruler was used to measure the width (mm) and length (mm) of the fruits.
- The fruit index was determined by dividing the width of the fruit by its length.
- To measure chlorophyll and carotenoids pigments, leaf discs from the fully opened sixth leaf from the top of three plants per treatment/combination were used to determine photosynthetic pigments. The chlorophyll was extracted from the tissue by grinding it with a mortar and pestle in ammoniacal acetone (10 mL). Centrifuge the resultant extracts at 3000 g for 3 minutes. The total chlorophyll concentrations were determined by spectrophotometry (CT 200 spectrophotometer). The absorbance of the solution was measured at 470, 647, and 664 nm. Formulae and extinction coefficients used for the determination of chlorophyll were described by Wellburn and Lichtenthaler (1984).
- In order to measure relative water content (RWC), individual leaves were separated from the stem and weighed to ascertain their fresh weight (F.W). Leaves were floated in distilled water inside a closed petri dish to calculate the turgid weight (T.W). After

12 hours, leaf samples were weighed. After the imbibition phase, leaf samples were dried in a preheated oven at 80°C for 48 hours and measure dry weight (D.W) of samples with balance. RWC was calculated using the following formula (Pieczynski et al. 2013): RWC (%) = [(F.W–D.W)/(T.W–D.W)] × 100

- The leaf water potential (Ψw) was measured twice at the start of the vegetative and productive periods with a potentiometer (WP4, Decagon Devices, Pullman, WA, USA).
- The Na^+ and Cl^- concentration of leaves, roots, and fruits was evaluated using an ICP-OES spectrometer (IRIS Thermo Jarrel ASH, Corp., Franklin, MA, USA) on homogenous samples (Bőhm et al. 2017).

4.4.2 Fruit quality evaluation

- A pH meter measured the acidity from two sides of each fruit flesh in all combinations.
- The mixtures of three fruit pulps from each replication were blended using a standard kitchen blender.
- The total sugar content (TSS) was measured using the Refractometer (PAL-1 Brix 0-53% Digital Hand) with the fruit juices.
- The firmness of fruits was determined using a hand-held penetrometer. The pressure value was expressed in kg/cm^3.
- The skin colour on two sides of three fruits from each replication was determined using a colourimeter Minolta Chroma meter CR-400 (Minolta Corporation, Ltd., Osaka, Japan). The chromaticity of fruits was quantified using L^*, a^*, and b^* colour space coordinates. Chroma (C*) and Hue angles (H°) were calculated as the following formula: $C^* = (a^{*2} + b^{*2})^{1/2}$, $H° = \tan^{-1}(b^*/a^*)$.
- The whitening index (DW), oxidation potential (OP), and colour differences (CD) of fruit pulp were all determined using the colourimeter. Two fruits from each replication were cut longitudinally with a sharp plastic knife with a straight edge. In the center and lateral zones, the colour pulp was measured immediately after cutting ($L0$) and 30 minutes later (L^*30). Colour space has been separated into three dimensions (L^*, a^*, and b^*), with L^* representing brightness (0 being black and 100 being white), a representing red to green, and b representing blue (blue to yellow). The DW_0 was calculated using the formula as the Euclidean distance between the colour coordinates and the pure white coordinates ($L^* = 100$ $a^* = 0$ $b^* = 0$) (Prohens et al. 2007):

$DW_0 = ((100\text{-}L)^2 + a^{*2} + b^{*2})^{0.5}$

- The CD was calculated as the distance between the colour coordinates at 0 and 30 minutes in Euclidean space:
  $CD = [(L^*_{30} - L^*_0) + (a^*_{30} - a^*_0) + (b^*_{30} - b^*_0)$
  Additionally, the OP of fruits was estimated by $L^*a^*b^*$ values using the following formula (Larrigaudiere et al. 1998): $OP = L^*_{30} - L^*_0$
- Ten independent slices from the equatorial region of fruits were cut and incubated at 20 °C to induce seed browning and facilitate seed boundaries identification. Images were used to determine the number of seeds by using the software ImageJ (Version 1.8.0_172; Research Services Branch, National Institute of Mental Health, Bethesda, MD, USA).

4.4.3 Sensory evaluation

Sensory measurements were made on fruit harvested from six different rootstocks based on questionnaire results. Twelve trained tasting panellists evaluated 10 quality attributes according to ISO 13,299 standard (Table 8).

First, the sensory attributes and their corresponding reference values were determined to reduce the variation in the resulting dataset. For the sensory test, small pieces of the fruit were boiled for 20 min, placed in numbered plates, and were immediately assessed. The questionnaire results were converted into a grade scale from 0 to 100.

Table 8. Definitions of sensory attributes used in the quantitative descriptive analysis

Attributes	Characteristic
Flesh colour	Dark- light
Odour	None- very intensive
Flesh firmness	Soft- firm
Flesh juiciness	not very juicy- very juicy
Flavour intensity	not perceptible- intense
Tart, bitter taste	None- very intensive
Pungent flavour	None- very intensive
Sweet taste	not very intensive- very intensive
After taste	None- very intensive
Off-flavour	None- very intensive

4.5 Statistical analysis

The data was analysed using Statistix 8 software (Tallahassee, FL, USA). The first experiment was arranged in a completely randomized design (CRD) with four replications and five plants in each replication. Data were subjected to the one-way analysis of variance (ANOVA), and means were separated using the Tukey's multiple comparison test at $p<0.05$.

The combined results of the sensory evaluation were plotted on profile diagrams, which ProfiSens, a sensory analysis software, prepared. Tests were performed according to ISO 8589. Differences between data were evaluated with univariate ANOVA and Fisher's least significant difference (LSD) significance level evaluation procedures.

The postharvest experiment was conducted in a factorial design with three factors, including six rootstocks, two storage temperatures, and five storage days. The three-way analysis of variance (ANOVA) was used to analyses the data by Statistix 8. The means were separated using the Tukey's multiple comparison test at $p<0.05$. The salinity research was carried out as a factorial experiment using a completely randomized design (CRD) with two factors including two different rootstocks and salinity level. Data were subjected to the two-way analysis of variance (ANOVA), and means were separated using the Tukey's multiple comparison test at $p<0.05$.

5. RESULTS AND DISCUSSION

5.1 Differences in growth and physiological traits of grafted and non-grafted seedlings

The root morphological trait of the grafted seedling is shown in Table 9. Root length was significantly increased in grafted eggplant onto O compared to SR. However, root diameter increased in all grafted seedlings except rootstock O. The highest fresh and dry root weight was observed in seedlings grafted onto SI. Seedlings grafted onto SH, A, SI, and ST had the highest root volumes (Table 9, Figure 9).

Table 9. Effect of different rootstocks on root characters of eggplant after four weeks of grafting

Rootstock	Root length (cm)	Root diameter (cm)	Root fresh weight (g)	Root dry weight (g)	Root volume (ml)
SR	14.00 ± 1.41 bc	4.55 ± 0.27 c	1.20 ± 0.30 bc	0.08 ± 0.03 d	1.00 ± 0.41 d
SG	11.00 ± 1.73 c	3.43 ± 0.38 d	0.73± 0.50 c	0.06 ± 0.05 d	1.00 ± 0.58 d
SH	13.75 ± 1.22 bc	5.61 ± 0.38 ab	3.12 ± 0.40 ab	0.21±0.03 bc	4.00 ± 0.47 ab
ST	12.67 ± 1.41 c	5.66 ±0.27 ab	2.54 ±0.30 bc	0.22 ± 0.03 bc	3.50 ± 0.41 a-c
SI	14.00 ± 1.22 bc	5.88 ± 0.27 a	4.44 ± 0.40 a	0.39 ± 0.03 a	4.25 ± 0.41 a
A	11.50 ± 1.22 c	6.11 ± 0.31 a	3.28 ± 0.50 ab	0.29 ± 0.05 ab	4.50 ± 0.58 a
E	19.50 ± 1.22 ab	5.94 ± 0.27 a	1.94 ± 0.30bc	0.13 ± 0.03 cd	2.25 ± 0.41 b-d
O	20.50 ± 1.22 a	5.03 ± 0.27bc	1.43 ± 0.30 bc	0.09 ± 0.03 d	2.00 ± 0.41 cd

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador, O = Optifort

The performance of grafted plants under stressful conditions is often determined by the characteristics of the rootstock's root system. In grafted plants, root length and density, root hairs, and root surface area all play a crucial role in determining salt tolerance (Colla et al. 2010, He et al. 2009). Plant growth and crop yield were positively influenced by a vigorous root system, which produced more cytokinins and transported water to the shoot system through xylem sap (Oztekin and Tuzel 2011). Among the rootstocks examined in this study, seedling grafting on Tayibou displayed the highest fresh and dry weight and root volume which was used in the salinity experiment (Chapter 5.5). He et al. (2009) observed that root dry mass was reduced in tomatoes grown under saline stress, but the decrease was smaller in plants grown on rootstocks compared with non-saline conditions. In addition, the most typical consequence of soil salinity is the restriction of growth caused by Na^+ and Cl^- toxicity. It has been reported that grafted plants restrict the movement of Na^+ from the root to the shoot when grown on appropriate rootstocks (Goreta et al. 2008, Zhu et al. 2008).

Figure 9. Root structure in grafted eggplant seedling on different rootstocks

Table 10. Effect of different rootstocks on SPAD and RWC of eggplant seedlings after four weeks of grafting

Rootstock	SPAD	Stem RWC (%)	Leaf RWC (%)
SR	34.38 ± 1.50 a-c	89.02 ± 2.61 a	61.48 ± 3.16 b
SG	32.85 ± 2.12 a-c	87.11 ± 3.19 a	62.60 ± 4.47 ab
SH	35.03 ± 1.51 a-c	90.13 ± 2.26 a	65.15 ± 3.64 ab
ST	36.63 ± 1.50 ab	91.81 ± 2.26 a	66.65 ± 3.16 ab
SI	39.05 ± 1.50 a	91.65 ± 2.26 a	67.56 ± 3.64 ab
A	35.20 ± 2.16 a-c	88.91 ± 3.19 a	80.35 ± 4.47 a
E	32.63 ± 1.50 bc	93.60 ± 2.26 a	59.14 ± 3.16 b
O	30.30 ± 1.50 c	91.65 ± 2.26 a	66.16 ± 3.16 ab

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador, O = Optifort. †††RWC: relative water content.

The results of SPAD value of leaves showed no significant differences between grafted and non-grafted seedlings (Table 10). Stem RWC was not influenced by grafting while leaf RWC significantly increased in seedling grafted onto A rootstock (Table 10).

5.2 Effect of different rootstocks on growth and some physiological traits of plants during greenhouse cultivation

Grafting eggplant onto SH, ST, SI and A significantly increased the SPAD value of the leaves. Plants grafted onto E and O rootstocks had the highest diameter in scion and rootstocks 112 days after grafting (Table 11). The cause of this phenomenon can be related to the fact that vigorous rootstocks allow plants to absorb more water and nutrients, which can result in a higher SPAD value and plant growth.

Table 11. Effect of different rootstocks on plant growth 112 days after grafting

Rootstock	SPAD	Plant height (cm)	Rootstock diameter (mm)	Scion diameter (mm)
SR	47.07 ± 3.65 cd	173.00 ±22.84 b	-	14.17 ± 1.45 b
SG	43.69 ± 1.99 e	166.25 ± 29.75 b	15.75 ± 2.90 b	16.65 ± 2.07 ab
SH	56.11 ± 2.71 b	201.25 ± 15.17 ab	20.23 ± 3.71 b	19.75 ± 2.76 a
ST	60.08 ± 2.62 a	191.50 ± 17.02 ab	16.38 ± 3.36 b	15.99 ± 0.44 ab
SI	57.63 ± 3.83 ab	206.75 ± 21.19 ab	18.91 ± 2.04 b	18.05 ± 1.95 ab
A	57.38 ± 2.08 ab	196.67 ± 17.39 ab	19.92 ± 3.26 b	16.82 ± 0.15 ab
E	51.14 ± 3.80 c	235.38 ±16.77 a	29.69 ± 4.72 a	19.50 ± 1.22 a
O	47.07 ± 3.29 cd	231.75 ± 26.16 b	31.51 ± 2.15 a	19.78 ± 2.45 a

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at P<0.05. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador*,* O = Optifort

5.3 Effect of different rootstocks on fruit yield, quality, and consumer evaluations

As shown in Table 12, Figure 10, grafting 'Madonna' onto O and E rootstocks caused the lowest fruit length in comparison with the SR and SG rootstocks. Moreover, it has been observed that self-grafted 'Madonna' significantly increased the width of fruit relative to the fruit harvested from control and other combinations (except ST). Statistical analysis showed that fruit shape index was not significantly (p<0.05) influenced by rootstocks.

Our results showed that the total marketable fruit number significantly increased by grafting in comparison with SR and SG. Average fruit weight decreased by grafting onto O rootstock in comparison with other combination (except SG). Grafting 'Madonna' on eggplant rootstocks (SH, ST, SI, and A) significantly increased total marketable fruit yield while tomato rootstocks (E and O) had no significant effect. Total marketable yield of *Solanum torvum* (ST) rootstock was two times higher than control, self-grafted plants (Table 12).

Table 12. Effect of different rootstock combinations on eggplant fruit shape, fruit number, and yield during 15 times harvesting

Rootstock	Fruit length (cm)	Fruit width (cm)	Total fruit number (per plant)	Average fruit weight (g)	Total marketable yield (kg/ plant)
SR	16.97 ± 2.57 a	8.06 ± 1.11 b-d	7.40 ± 0.85 b	0.28 ± 0.07 a-c	1.65 ± 0.53 c
SG	18.10 ± 1.70 a	9.38 ± 0.87 a	7.12 ± 2.89 b	0.26 ± 0.07 bc	1.89 ± 0.45 c
SH	16.34 ± 2.03 ab	1.94 ± 0.83 cd	13.63 ± 0.64 a	0.29 ± 0.07 ab	3.36 ± 0.68 ab
ST	16.58 ± 0.83 a	8.36 ± 0.78 ab	15.26 ± 0.83a	0.28 ± 0.09 a-c	3.94 ± 0.80 a
SI	16.93 ± 1.17 a	8.18 ± 0.97 bc	12.05 ± 1.17 a	0.31 ± 0.07 a	3.23 ± 0.47 ab
A	16.91 ± 2.01 a	8.19 ± 1.11bc	12.80 ± 1.79 a	0.29 ± 0.07 ab	3.34 ± 0.21 ab
E	15.66 ± 1.89 bc	8.11 ± 0.80b-d	12.34 ± 1.70 a	0.28 ± 0.07 a-c	2.80 ± 0.27 a-c
O	14.94 ± 1.45 c	7.68 ± 0.80 d	11.76 ± 3.57 ab	0.24 ± 0.08 c	2.39 ± 0.34 bc

† The values represent the mean of four replications (5 plants in each replication) ± *SD*. Different letters within the same column are significantly different between means according to Tukey's multiple range test at P<0.05. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador*,* O = Optifort

Our results showed that the lowest fruit length was observed at E and O rootstocks and highest fruit width was at SG rootstocks. Fruit shape is controlled genetically; however, Sabatino et al. (2018, 2019) and Gisbert et al. (2011a) demonstrated that eggplant fruit shape (length and width) is affected by the rootstock. In line with our findings, Passam et al. (2005) stated that grafting can increase eggplant fruit size. Moreover, Cassaniti et al. (2011) harvested longer fruits from 'Black Bell' × *Solanum torvum* combination than from self-grafted plants. In cucumber, shape index in grafted plants was higher than non-grafted ones (Colla et al. 2013), while in watermelon grafting it had no influence on fruit size and shape, according to some studies (Colla et al. 2006, Soteriou et al. 2014). Therefore, these results are different due to genotype, vigorous rootstocks, and grafting combinations (Kyriacou et al. 2017). For instance, grafting tomato onto vigorous rootstocks (i.e., Maxifort; Beaufort) increased the fruit size, while grafting onto less vigorous rootstocks (i.e., Brigeor, Energy, Firefly, Linea 9243, and Nico) reduced tomato fruit size (Schwarz et al. 2013, Turhan et al. 2011, Romano et al. 2020).

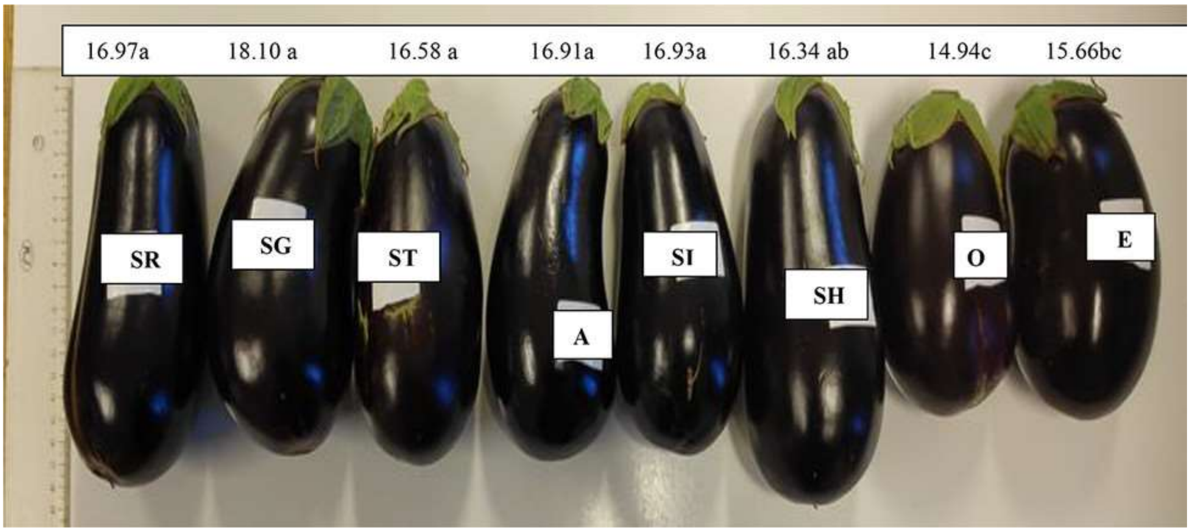


Figure 10. Effect of grafting eggplant 'Madonna' on different rootstocks on fruit shape

†SR= self-root; SG= self-grafting, ST= *Solanum torvum,* A = *Solanum integrifolium,* SI = *Solanum melongena* × *Solanum integrifolium,* SH= *Solanum grandifolium* × *Solanum melongena***,** O = Optifort, E = Emperador

All SH, ST, A, and SI rootstocks improved the total fruit yield. Fruit number, and earliness of eggplant 'Cristal F1' grafted onto eggplant rootstocks was reported to be higher than that of grafted onto E and O rootstocks (Gisbert et al. 2011b). In line with our results, Sabatino et al. (2016) reported that eggplant 'Scarlatti F1' grafted onto *Solanum melongena* × *Solanum aethiopicum* rootstock had higher total and marketable yield than plants grafted onto *Solanum aethiopicum*. They also found that higher marketable yield of grafted eggplant onto *Solanum torvum* and *Solanum macrocarpon* can be the result of higher fruit numbers, which associate with increasing water and nutrient absorption (Sabatino et al. 2016). Gisbert et al. (2011a) confirmed that grafted plants with higher yield had earlier fruit harvest. In the current experiment, the higher marketable yield is due to a higher harvested fruit number in grafted plants.

According to ANOVA, *L** value and CIRG index (Colour index of red) of fruit skin from all combinations was not significantly ($p<0.05$) different with the self-rooted (SR) plants. Grafting 'Madonna' onto O, E, A, and SH significantly increased the *a** value of skin fruit relative to SR and SG (Table 13). Fruit harvested from O rootstock had the highest *b** value compared with the control SR. Our results showed that the highest Hue value was observed at E and O rootstocks in comparison with SR and SG. Chroma value of skin fruit increased when O, E, and A was used as rootstock compared with either non-grafted or self-grafted plants (Table 13).

Table 13. Effect of different rootstock combinations on chromatic characteristics of eggplant fruit skin

Rootstock	*L**	*a**	*b**	Hue	CIRG
SR	25.22 ± 3.05 a	3.09 ± 1.33 d	-0.72 ± 0.17 bc	3.18 ± 4.19 cd	6.62 ± 5.21 a-c
SG	25.07 ± 1.39 a	2.95 ± 2.00 d	-0.73 ± 0.16 bc	3.05 ± 5.22 d	6.69 ± 4.49 a
SH	25.36 ± 1.80 a	3.62 ± 0.62 a-c	-0.71± 0.17 bc	3.70 4.44 a-c	6.53 ± 2.14 a-c
ST	25.58 ± 1.59 a	3.32 ± 0.88 b-d	-0.75 ± 0.11 bc	3.40 ± 3.53 b-d	6.51 ± 3.45 a-c
SI	25.08 ± 1.69 a	3.27 ± 1.06 cd	-0.79 ± 0.11 c	3.72 ± 3.29 cd	6.65 ± 4.21 ab
A	25.61 ± 2.43 a	3.65 ± 0.67 a-c	-0.69 ± 0.13ab	3.71 ± 3.31 a-c	6.47 ±5.67 bc
E	25.53 ± 2.20 a	3.89 ± 0.94 ab	-0.67 ± 0.14 ab	3.95± 4.48 ab	6.46 ± 3.67 c
O	25.45 ± 2.23 a	4.08 ± 0.86 a	-0.611 ± 0.24 a	4.14 ± 5.72a	6.46 ± 3.54 c

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador*,* O = Optifort; †††*L**: lightness, *a**: red/green coordinate, *b**: yellow/blue coordinate, CIRG: colour index of red

The darkest skin colour is connected to a high concentration of anthocyanin. Results of Moncada et al. (2013) showed that grafting eggplant 'Biragh' onto *Solanum torvum* caused a darker and less vivid fruit skin colour (lower value of *L** and chroma), while other cultivars (Black Moon and Black Bell) were not influenced by rootstock. Moreover, the highest Hue value was observed when eggplant 'Scarlatti' was grafted onto *Solanum torvum* and *Solanum aethiopicum* rootstocks in an experiment by Sabatino et al. (2019). In present study, the most noticeable finding was that grafting 'Madonna' onto O rootstock resulted in low-quality fruit skin, with the Hue value of 4.14, and chroma of 349.51. In tomato, variable results were found in fruit skin colour by grafted plants compared to non-grafted ones (Schwarz et al. 2013, Ulukapi et al. 2007).

A CIRG index of 5 indicates red dark violet skin, and higher than 6 indicates blue–black skin. In the current experiment, eggplant 'Madonna' normally had dark black skin and grafting did not have any significant influence on CIRG index. Kacjan Maršic et al. (2014) reported that grafting eggplant 'Blackbell' onto tomato rootstock 'Beaufort' increased CIRG index, while in another cultivar ('Epic') decreased. It can be explained that scion variety has different responses to grafting according to Kacjan Maršic et al. (2014). Moreover, they concluded that higher vigour of grafted plants negatively influenced the anthocyanins, and the pruning of plants should be carried out during the cultivation to improve the fruit colour (Kacjan Maršic et al. 2014).

The results of pulp colour measurements are presented in Table 14. No significant differences were observed in *L*0*, *a**, CD and DW_0 between grafted and SR plants. Moreover, the results of present study showed that grafting onto tomato rootstocks (E and O) significantly decreased the OP value of pulp fruit relative to SR and SG.

Table 14. Effect of different rootstock combinations on chromatic characteristics, colour difference, whiteness degree and oxidation potential of eggplant pulp

Rootstock	L_0*	*b**	CD	DW	OP
SR	84.89 ± 0.93 ab	29.08 ± 0.13 a-c	12.16 ± 2.98 a-c	33.10 ± 3.96 a-c	9.97 ± 2.89 a
SG	85.43 ± 1.46 ab	26.84 ± 0.17 c	12.62 ± 5.62 ab	30.85 ± 1.36 c	10.66 ± 4.53 a
SH	84.62 ± 1.03 ab	29.15 ± 0.17 a-c	13.61 ± 3.94 a	33.24 ± 2.45 a-c	8.67 ± 3.69 ab
ST	84.03 ± 0.91 b	30.14 ± 0.16 ab	11.46 ± 3.07 a-c	34.25 ± 2.39 ab	9.67 ± 2.71 ab
SI	85.26 ± 1.39 ab	29.05 ± 0.11 a-c	12.48 ± 3.70 ab	32.93 ± 3.63 a-c	9.38 ± 4.47 ab
A	84.65 ± 0.82 ab	30.32 ± 0.11 a	13.21 ± 5.56 a	34.30 ± 4.19 ab	11.03 ± 6.41 a
E	86.36 ± 0.98 a	27.70 ± 0.13 bc	7.37 ± 2.79 c	31.30 ± 1.55 bc	5.81 ± 2.72 b
O	83.91 ± 1.05 b	31.39 ± 024 a	8.29 ± 2.41bc	35.51± 1.94 a	5.81 ± 2.64 b

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador*,* O = Optifort ††† *L**: lightness, *b**: yellow/blue coordinate, CD: colour difference; DW: whiteness degree; OP: oxidation potential

It seems that Emperador and Optifort rootstocks had lower browning degree and colour difference value than self-rooted and self-grafted plants, and fruit harvested from these combinations oxidized less than others (Table 13). High oxidation potential is expected due to the high phenolic compound content of the eggplant. Moreover, it may be influenced by many factors, e.g., scion genotype, rootstocks, and environmental conditions. Moncada et al. (2013) and Sabatino et al. (2018) reported that grafting eggplant onto *Solanum torvum* had little or no effect on pulp browning. However, other rootstocks had different reactions; for instance, *Solanum paniculatum* and *Solanum macrocarpon* showed lowest (Sabatino et al. 2018), while *Solanum aethiopicum* gave the highest oxidation potential in eggplant (Kyriacou et al. 2017). Seed number and fruit size may lead to different colour and oxidization in fruit pulp after cutting. A negative correlation between the browning index and fruit size, and positive relation with seed number, has been reported by Radicetti et al. (2016).

Table 15. Effect of different rootstock combinations on pH, total soluble solids (TSS), firmness, and seed number of eggplant fruits

Rootstock	pH	TSS (Brix°)	Firmness (kg/cm^3)	Seed number
SR	5.55 ± 0.07 a	5.28 ± 0.64 b	4.93 ± 0.32 a	21.81 ± 3.05 c
SG	5.57 ± 0.05 a	5.80 ± 0.71 a	4.18 ± 0.21 b	29.50 ± 1.45 bc
SH	5.46 ± 0.04 ab	5.26 ± 0.66 b	4.56 ± 0.14 ab	47.30 ± 2.23 a
ST	5.53 ± 0.05a	5.34 ± 0.59 b	3.51 ± 0.34 c	38.70 ± 1.59 a-c
SI	5.44 ± 0.11 ab	4.78 ± 0.20c	3.56 ± 20 c	44.36 ± 1.69 ab
A	5.38 ± 0.07 b	5.62 ± 0.73 ab	4.04 ± 0.34 bc	25.46 ± 1.80 c
E	5.56 ± 0.05 a	4.62 ± 0.17 c	2.77 ± 0.61d	27.09 ± 2.23 bc
O	5.53 ± 0.10 a	4.72 ± 0.34 c	2.43 ± 0.15 d	28.15 ± 1.39 bc

† The values represent the mean of four replications (5 plants in each replication) ± SD. Different letters within the same column are significantly different between means according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador, O = Optifort

As shown in Table 15, TSS value of fruit flesh was negatively influenced by grafting onto SI, E, and O rootstocks, while SG resulted in the highest TSS value in the pulp. Fruit firmness significantly decreased by grafting (except grafting onto SH rootstock). The pH value of the flesh was not influenced by different rootstocks.

Several studies confirmed that fruit quality seldom varied significantly between grafted and non-grafted plants. For instance, previous results by Arvanitoyannis et al. (2005) and Cassaniti et al. (2011) confirmed a reduction in eggplant flesh firmness by grafting. Similarly, tomato fruits harvested from grafted plants were not firmer than control and self-grafted plants (Schwarz et al. 2013). Lower water uptake in non-grafted plants caused lower water content in eggplant fruit and harder texture (Arvanitoyannis et al. 2005). The current experiment showed that grafting significantly reduced TSS of eggplant 'Madonna'. In line with our results, lower TSS was observed in eggplant fruits ('Faselis') obtained from grafted on *Solanum torvum*, while no significant difference was found in fruits ('Rima') obtained from tomato hybrid rootstocks compared to the rest of combinations (Khah et al. 2011). Lee et al. (2010) reported that grafting eggplant onto *Solanum torvum* had no influence on TSS. Previous studies showed that firmness and SSC of non-grafted and self-grafted melon was higher than grafted fruit in the Guan et al. (2015) study, and they explained that it is due to the improved water status of grafted melon by enhancing leaf water potential, leaf stomatal conductance, transpiration rate, and amount of xylem sap, which then can reduce TSS of the fruit (Guan et al. 2015, Rouphael et al. 2010). Fruits obtained from SH and SI × 'Madonna' combination had the highest seed number, and it can be explained that higher nitrogen absorption in the grafted plant may cause a higher seed number in the fruit (Akanbi et al. 2007).

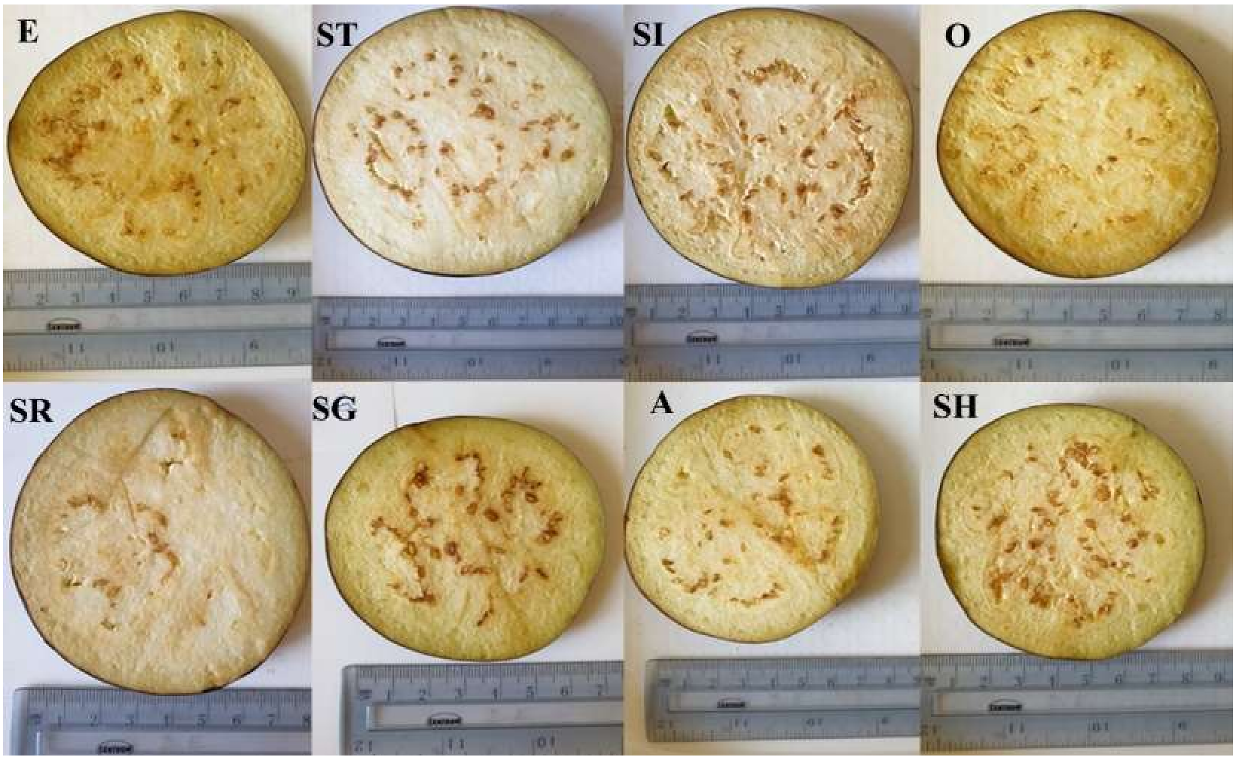


Figure 11. Effect of different rootstock combinations on fruit seed number

††SR= self-root; SG= self-grafting, SH= *Solanum grandifolium* × *Solanum melongena,* ST= *Solanum torvum,* SI = *Solanum melongena* × *Solanum integrifolium,* A = *Solanum integrifolium*; E = Emperador**,** O = Optifort

In the current experiment, grafting eggplant onto SH and SI rootstocks sharply increased the seed number of fruits in comparison with SR (Table 15; Figure 11).

Sensory analysis data showed a significant difference in four parameters (flesh colour, firmness, sweet taste, and intensive odour) between selected rootstocks. Fruits harvested from SR, ST, and O had lighter flesh colour than other rootstock combinations. Respectively, SR and E had the lowest and highest flesh firmness between grafting combinations according to panellist's evaluation. Grafting onto ST showed significantly stronger sweet taste as compared to SR fruits.

Fruits harvested from SI showed significantly intensive odour among all combinations (Figure 12). Bitter taste, pungent flavour, off-flavour, aftertaste, flesh juiciness, and flavour intensity were not significantly influenced by grafting.

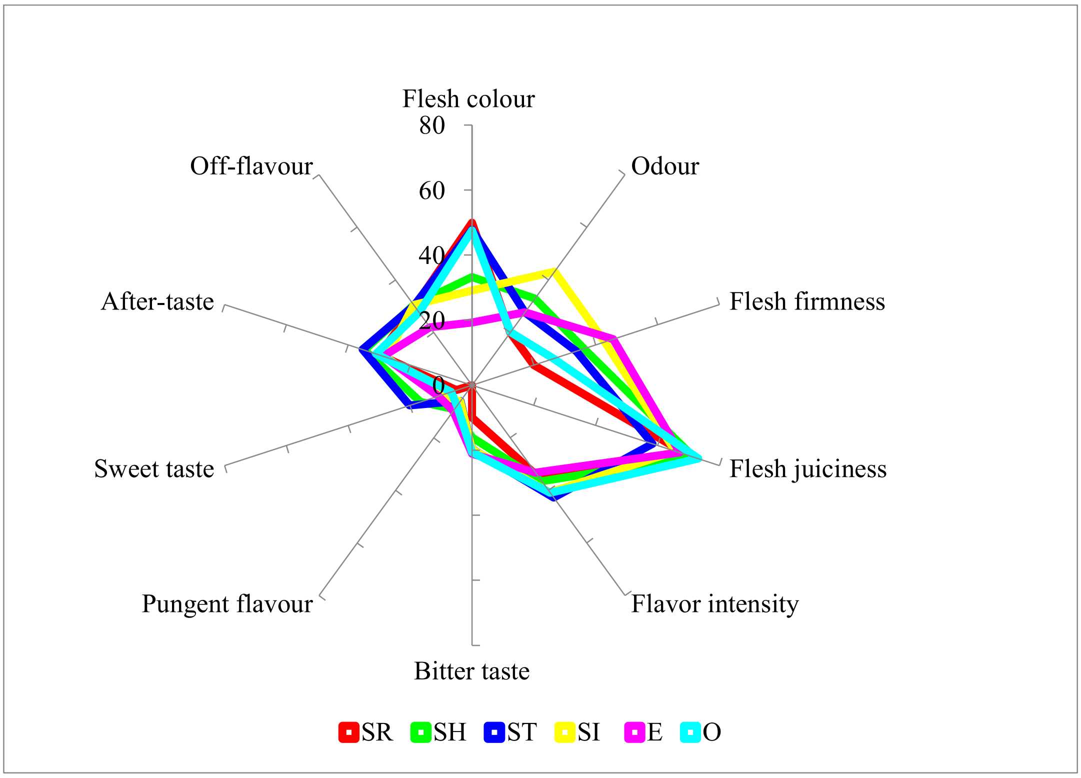


Figure 12. Effect of different rootstock combinations on sensory evaluation of fruit by trained panelists

†SR= self-root; SG= self-grafting, ST= *Solanum torvum*, SH= *Solanum grandifolium* × *Solanum melongena*, SI = *Solanum melongena* × *Solanum integrifolium*, O = Optifort; E = Emperador; A = *Solanum integrifolium*

Combining sensory and instrumental measurements provided a thorough evaluation of the effects of grafting and rootstock combination (Guan et al. 2015). Grafting eggplant 'Tsakoniki' onto *Solanum torvum* resulted in fewer empty spaces and harder fruits more than in case of other combinations (Arvanitoyannis et al. 2005). Moreover, they reported that fruits grafted on *Solanum sisymbriifolium* had fewer seeds and less intensive tart flavour than the rest of the treatments. Another interesting finding was that all grafted plants resulted in less sweet fruits and lower acceptability ratings in the panellist test (Arvanitoyannis et al. 2005). In our experiment, fruit harvested from ST had a sweeter taste and lighter colour, and fruit harvested from SI showed intensive odour, according to consumer evaluation. In tomato, according to the experiment of Gioia et al. (2010), grafting onto 'Beaufort' and 'Maxifort' rootstocks did not influence sweetness, sourness, and the tomato-like taste of the fruits. Barrett et al. (2012) and Casals et al. (2018) reported that grafting had negative effects on acceptability and the tomato flavour descriptors assessed by a consumer test.

5.4 Effect of different rootstocks on fruit postharvest at two different temperatures during storage time

Table 16. Main effect of storage temperature, storage days and rootstocks on eggplant fruit

Treatments		*L**	*a**	*b**	OP	pH	Firmness (kg/cm^3)	TSS (Brix°)
Storage day	0	84.70a	-3.98a	29.59a	7.72a	5.50a	4.17a	5.10a
	3	83.80b	-3.56a	28.55ab	7.61ab	5.29c	3.75b	4.90b
	6	83.45b	-3.96a	27.75b	5.86c	5.37b	3.53bc	-
	9	85.15a	-3.70a	25.39c	6.83bc	5.42b	3.58c	-
Storage temperature	10°C	84.30a	-3.70a	27.27b	7.14a	5.34b	3.78a	5.08a
	0°C	84.07a	-3.94a	28.09a	7.08a	5.44a	3.68a	4.92a
Rootstock	SR	85.22a	-4.13a	26.33b	7.57a	5.39ab	3.99a	4.74ab
	ST	84.71a	-3.65a	27.68ab	7.63a	5.37b	3.88a	5.06ab
	SI	84.65a	-3.62a	28.19a	7.20ab	5.38b	3.77a	4.85b
	SH	84.61a	-3.75a	27.61ab	7.97a	5.36b	4.04a	5.38a
	O	83.37ab	-3.97a	27.87ab	6.16b	5.41ab	3.42b	4.59b
	E	83.01b	-3.86a	28.00ab	6.8ab	5.43ab	3.41b	4.89ab
	A	84.45ab	-3.65a	27.88ab	7.37ab	5.36b	3.88a	5.32a
F value								
Storage day		**	**ns**	**	**	**	**	**
Temperature		**ns**	*	**	**ns**	**	**ns**	**ns**
Rootstocks		**	**ns**	**ns**	**	*	**	**
Storage day × Temperature		**ns**	**ns**	**	**ns**	**	**ns**	**ns**
Storage day × Rootstock		**	**	**	**	**	**	**
Temperature × Rootstock		**	**ns**	**ns**	**	**ns**	**ns**	**ns**
Storage day × Temperature × Rootstock		**ns**	*	**ns**	*	**	**	**ns**
Coefficient of variation (%)		2.74	17.96	8.43	19.12	1.62	14.95	9.46

† ns= not significant, * = significant at P<0.05, ** = significant at P<0.001, ***= significant at P<0.0001. ††Different letters within the same column are significantly different according to Tukey's multiple range test at P<0.05. †††SR= self-root; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena,* SI = *Solanum melongena* × *Solanum integrifolium,* O = Optifort; E = Emperador; A = *Solanum integrifolium* ††††*L**: lightness, *a**: red/green coordinate, *b**: yellow/blue coordinate, OP: oxidation potential, TSS: total soluble solids

Pulp lightness (*L**) was significantly affected by storage day, rootstock, the interaction of storage day × rootstock, and temperature × rootstock (p< 0.01). The results indicated that *L** significantly decreased on days 3 and 6 and then increased after 9 days of storage. The lowest *L** value was obtained on fruit from E rootstock (Table 16).

As shown in Table 17, fruit from grafted plants showed an almost similar *L** value to fruit from self-rooted plants during storage days except the *L** value of fruit decreased from the O rootstock on day 6 as compared to SR on the same day and also, E rootstock on days 3 and 6 as compared to the same rootstock on day 0.

*L** of fruit from different rootstocks reacted differently to the temperature (Figure 13A). The *a** colour value of fruit pulp ranged from -4.56 to -2.60 in SI × day 0 and A × day 3, respectively. The results showed that the *b** value significantly decreased from 29.59 to 25.39 at the end of the storage day. Lower temperatures showed a higher *b** value of the fruit. Furthermore, according to the *b** value data, fruit from O rootstock on harvesting day (day 0) had more yellowish pulp colour. The *b** value of fruit harvested from O rootstock significantly decreased by storage day as relative to day 0 as well as fruit from SR on days 6 and 9 as compared to day 0 and 3. All fruit harvested from grafted plants had higher *b** value than fruit from SR on storge day 6.

Table 17. Interaction effects of storage day and rootstocks on eggplant fruit

Storage day	Rootstock	*L**	*a**	*b**	OP	pH	Firmness (kg/cm^3)
0	SR	84.89a-d	-4.1a-d	29.08a-c	9.97a	5.55ab	4.93a
	ST	84.03a-d	-2.86a-c	30.14ab	9.67a	5.53a-c	3.51c-f
	SI	85.26a-c	-4.56cd	29.05a-c	7.13a-c	5.44a-f	3.56c-f
	SH	84.62a-d	-4.01a-d	29.15a-c	8.82ab	5.46a-e	4.56ab
	O	83.91a-d	-3.69a-d	31.39a	5.81a-c	5.53a	2.43g
	E	86.36ab	-4.71d	27.69a-e	5.81a-c	5.56a	2.77fg
	A	84.65a-d	-4.24a-d	28.82a-c	7.90a-c	5.38c-h	4.04a-d
3	SR	82.76b-e	-3.42a-d	28.76a-c	6.43a-c	5.27gh	4.04a-d
	ST	83.84a-d	-3.80a-d	28.22a-e	7.25a-c	5.26h	4.18a-d
	SI	85.40a-c	-3.72a-d	29.06a-c	5.68a-c	5.29f-h	4.28a-d
	SH	84.19a-d	-3.62a-d	27.45b-e	8.26a-c	5.30f-h	4.14a-d
	O	85.33a-c	-4.42b-d	27.66b-e	4.68bc	5.31f-h	4.21a-c
	E	79.30e	-2.70ab	30.05ab	3.80c	5.33e-h	4.16a-d
	A	84.15a-d	-2.60a	29.33ab	6.08a-c	5.29f-h	4.15a-d
6	SR	85.56a-c	-4.24a-d	24.97de	7.25a-c	5.41b-f	3.52d-f
	ST	84.31a-d	-4.21a-d	28.20bc	8.05a-c	5.35e-h	3.87b-d
	SI	83.88a-d	-3.57a-d	28.96ab	7.05a-c	5.37c-h	3.93b-d
	SH	84.13 a-d	-3.54a-d	27.80a-d	8.43a-c	5.35d-h	3.58c-f
	O	81.86de	-4.19a-d	27.83bc	7.16a-c	5.36e-h	3.52d-f
	E	82.56c-e	-3.72a-d	28.16bc	8.73a	5.38d-h	3.11e-g
	A	83.70a-d	-3.85a-d	28.59a-c	8.07a-c	5.36d-h	3.60c-f
9	SR	86.91a	-4.54cd	24.36de	7.06a-c	5.32e-h	3.97b-d
	ST	86.05ab	-3.37a-d	25.38c-e	6.20a-c	5.37d-h	3.94b-d
	SI	84.65a-d	-3.07a-d	26.44b-e	8.25a	5.41b-g	3.45c-f
	SH	85.74a-c	-3.95a-d	25.93b-e	6.14a-c	5.34d-h	4.13a-d
	O	83.88a-d	-3.35a-d	24.64e	6.01a-c	5.50a-f	3.43c-f
	E	84.04a-d	-4.33a-d	26.35b-e	6.90a-c	5.51a-d	3.78b-e
	A	85.55a-c	-3.98a-d	24.77de	7.32a-c	5.43a-h	3.85b-e

†Different letters within the same column are significantly different according to Tukey's multiple range test at P<0.05. ††SR= self-root; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena,* SI = *Solanum melongena* × *Solanum integrifolium,* O = Optifort; E = Emperador; A = *Solanum integrifolium* ††††*L**: lightness, *a**: red/green coordinate, *b**: yellow/blue coordinate, OP: oxidation potential

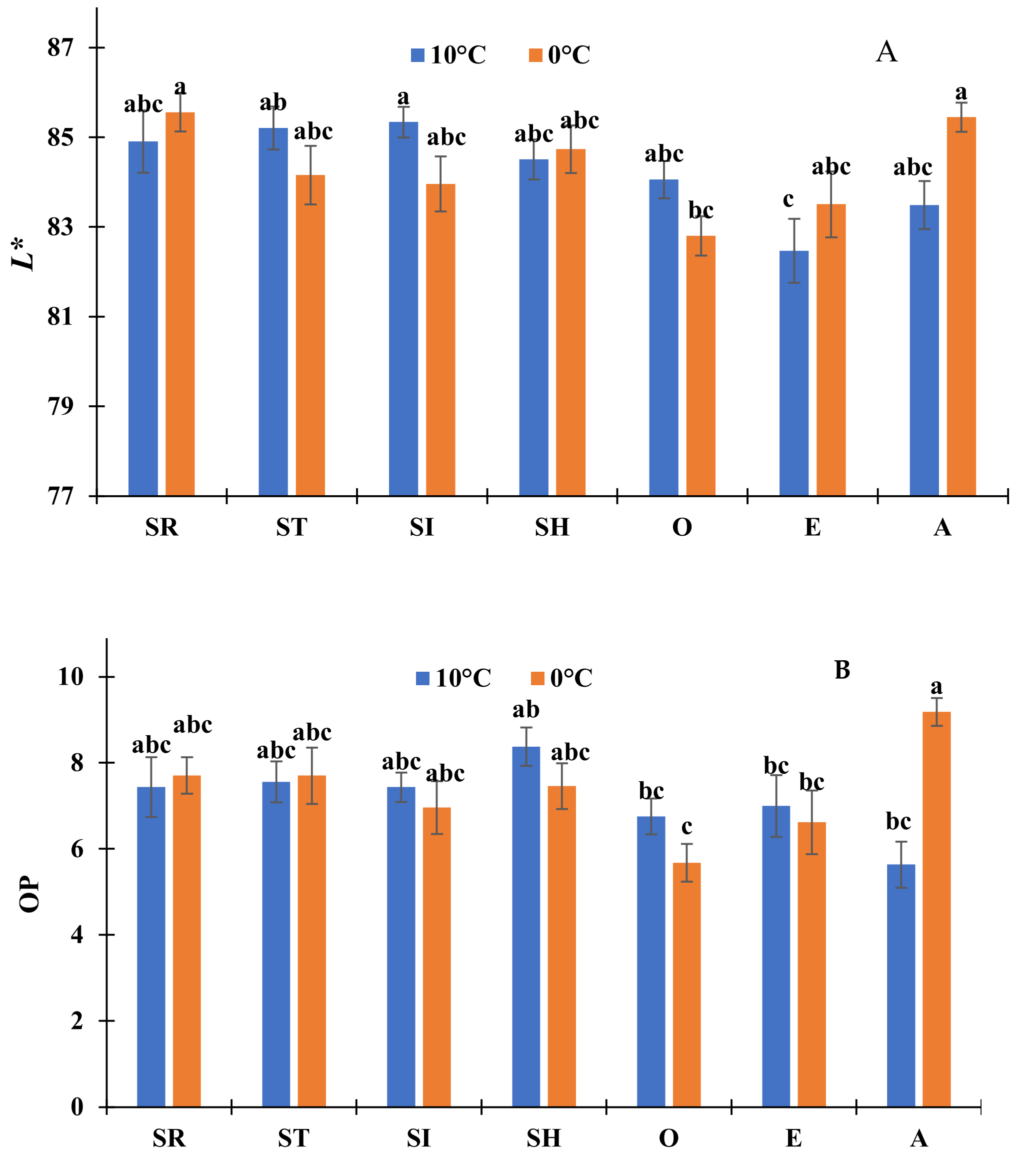


Figure 13. Interaction effects of storage temperature and rootstock on *L value (A) and oxidation potential (OP) (B) of eggplant**

†Different letters within the same column are significantly different according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; ST= *Solanum torvum*, SH= *Solanum grandifolium* × *Solanum melongena*, SI = *Solanum melongena* × *Solanum integrifolium*, O = Optifort; E = Emperador; A = *Solanum integrifolium*

††††L: lightness, OP: oxidation potential,*

On day 6 of storage, the fruit had the lowest OP. The lowest OP values were observed in fruit obtained from O rootstock (Figure 14; Table 16). The data analysis revealed that storage day × rootstock, temperature × rootstock, and storage day × temperature × rootstock had a significant effect on fruit OP values (Table 16). On day 3, the fruit of O rootstock had the lowest OP values compared to SR on day 0 (Table 17). The interaction effect of rootstock and temperature showed that OP significantly increased in the fruit harvested from A rootstock at 0 °C relative to 10 °C (Figure 13B). The highest OP value was observed on SR, ST, and A rootstock's fruits at 0 °C on day 0 (Figure 14C).

On day 3, the pH value of fruit declined dramatically ($p< 0.01$), then increased and remained steady on day 9. Fruit stored at 0 °C had a higher pH value than fruit stored at 10 °C (Table 16). The interaction effect of storage day and temperature was significant ($p< 0.01$). The pH value of fruit harvested from E was higher than SR on days 9 (Table 17). Interaction results of temperature, storage day, and different rootstocks indicated that the pH value of fruit from SR, ST, SH, O and A significantly declined on days 9 at 10 °C compared to fruit stored at 0 °C (Figure 14 B). Similar results were obtained on day 6 for fruit harvested from SR, ST, SI, E and A rootstocks. No differences were observed in fruit juice pH between grafted and non-grafted tomatoes and peppers (Colla et al. 2008; Khah et al. 2011). These findings are similar to Gioia et al. (2010) and Nicoletto et al. (2013). In our experiment, a slight reduction was observed in the fruit juice pH of grafted plants.

As shown in Table 16, fruit firmness significantly decreased with storage day ($p< 0.01$). Lower fruit firmness values were obtained from O and E than fruit harvested from SR and the rest of the rootstocks (Table 16). The effect of rootstock × storage day interaction on firmness was also significant ($p< 0.01$). By the end of the storage day, fruit firmness decreased significantly and the reduction in grafted plants onto SH was slightly less than in non-grafted plants on day 9 (Table 17). As shown in Figure 17 C on day 0, the highest firmness value was observed in the fruit of non-grafted plants. The firmness change was almost similar at both temperatures between the examined rootstocks on days 0, 3, and 6 (except for ST on day 5, SI on day 3 and O on day 9).

During storage, the firmness of fruits and vegetables reduces owing to the activation of cell wall destroying enzymes. The firmness of eggplant fruits was reduced from the harvesting day to 9 storage days. In agreement with our findings, Jha et al. (2002) and Abano et al. (2019) reported a decrease in the firmness of eggplant after storage, which was related to the eggplant shrinking and the epidermis layer. Moreover, the restriction in metabolic activities is connected with decreased activity of cell wall destroying enzymes, resulting in firmness retention for a longer period (Chauhan et al. 2015). Our results showed that temperature had no significant effect on fruit firmness. In addition to the effect of scion genotype on firmness, the type of rootstock can also influence fruit firmness. A reduction in fruit firmness was reported in the eggplant 'BlackBell' grafted onto *Solanum torvum* (Cassaniti et al. 2011) and 'Tsakoniki' grafted on *Solaum torvum* and *Solanum sisymbriifolium* (Arvanitoyannis et al. 2005). These results are similar to our findings, so grafting onto Emperador and Optifort rootstocks decreased the fruit firmness. On the other hand, the rest of the rootstocks had the same effects on fruit firmness as fruit harvested from the self-rooted plants. Changes in hormone status and water and nutrient intake in grafted vegetables caused by certain rootstocks may cause changes in fruit firmness (Rouphael et al. 2010). The difference could be related to a diverse root system in different rootstock-scion combinations (Arvanitoyannis et al. 2005). The effect of time × rootstock revealed that fruit firmness from different rootstocks was remarkably similar on a given day and decreased with storage. In line with our findings, Ozturk and Ozer (2019) found that the fruit firmness was different between grafted and non-grafted plants on the first day and during storage.

The analysis of variance revealed that storage day, rootstock, and their interaction all affected the TSS value of fruit (Table 16). The TSS value significantly decreased from the harvesting day to the third day of storage. TSS value did not differ between grafted and self-rooted plants, but fruit harvested from A and SH rootstocks had higher TSS value than fruit harvested from SI (Table 16).

The improvement of tomato fruit sweetness due to grafting is rarely reported (Kyriacou et al. 2017). Similarly, to tomatoes, information on the taste components of eggplant fruits in connection to grafting is inconsistent. In line with our results, Lee et al. (2010) and Khah (2011) discovered that *Solanum torvum*, *Solanum habrochaites* and *Solanum lycopersicum* rootstock did not affect eggplant fruit sugar. The lower TSS concentration in the fruits of grafted plants to non-grafted ones was probably due to the higher water content in the grafted plants (Turhan et al. 2011, Krumbein and Schwarz 2013). TSS value of fruits harvested from grafted and non-grafted plants slightly decreased on the 3rd day of storage.

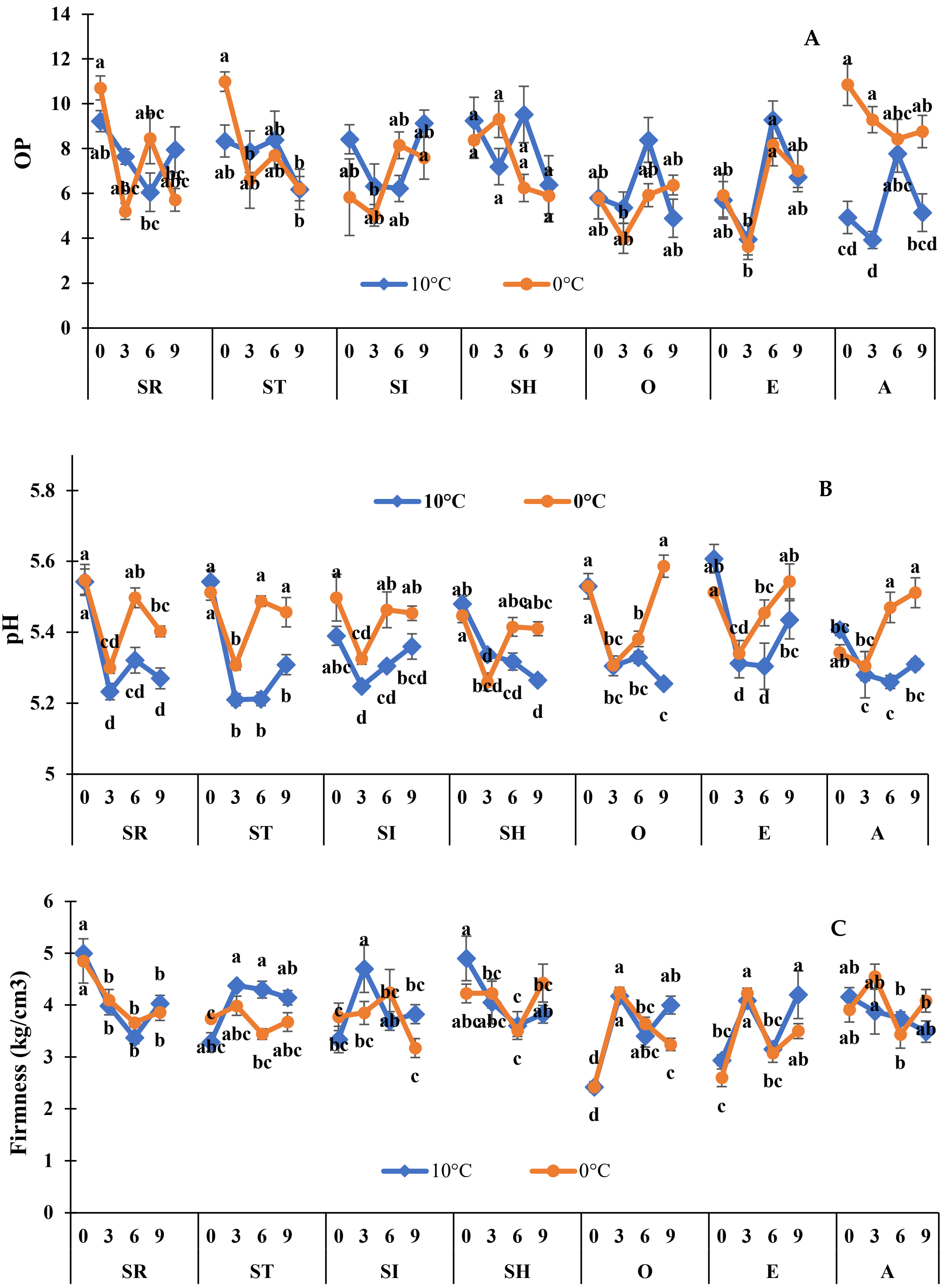
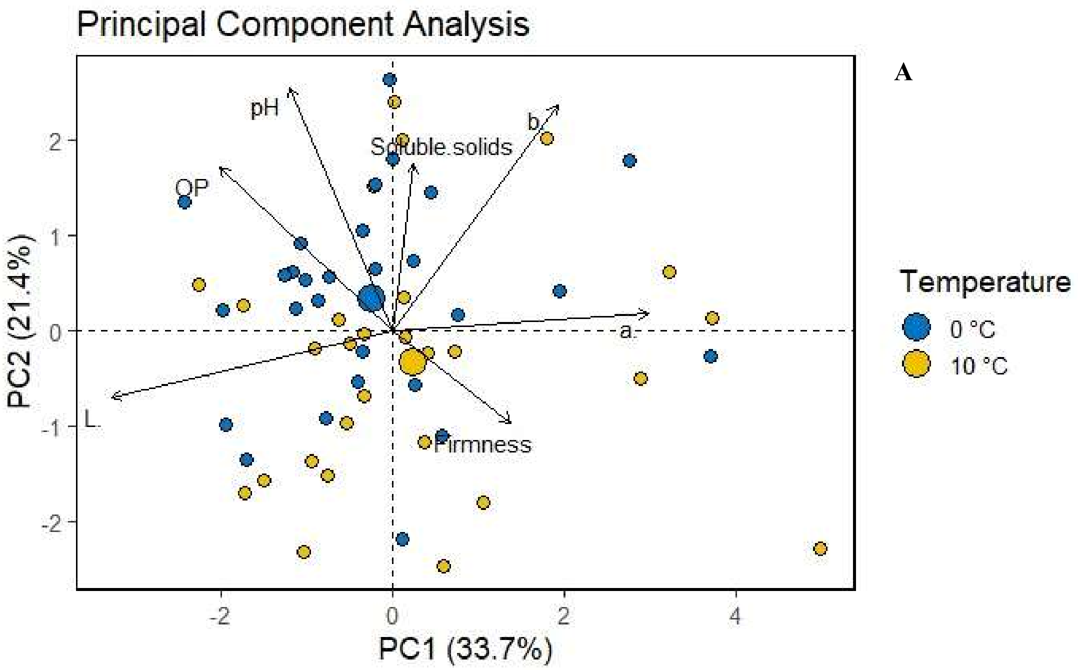


Figure 14. Interaction effects of temperature, storage day and rootstock on OP (A), pH (B) and firmness (C) eggplant. †Different letters within the same column are significantly different according to Tukey's multiple range test at P<0.05. ††SR= self-root; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena,* SI = *Solanum melongena* × *Solanum integrifolium,* O = Optifort; E = Emperador; A = *Solanum integrifolium* †††† OP: oxidation potential,



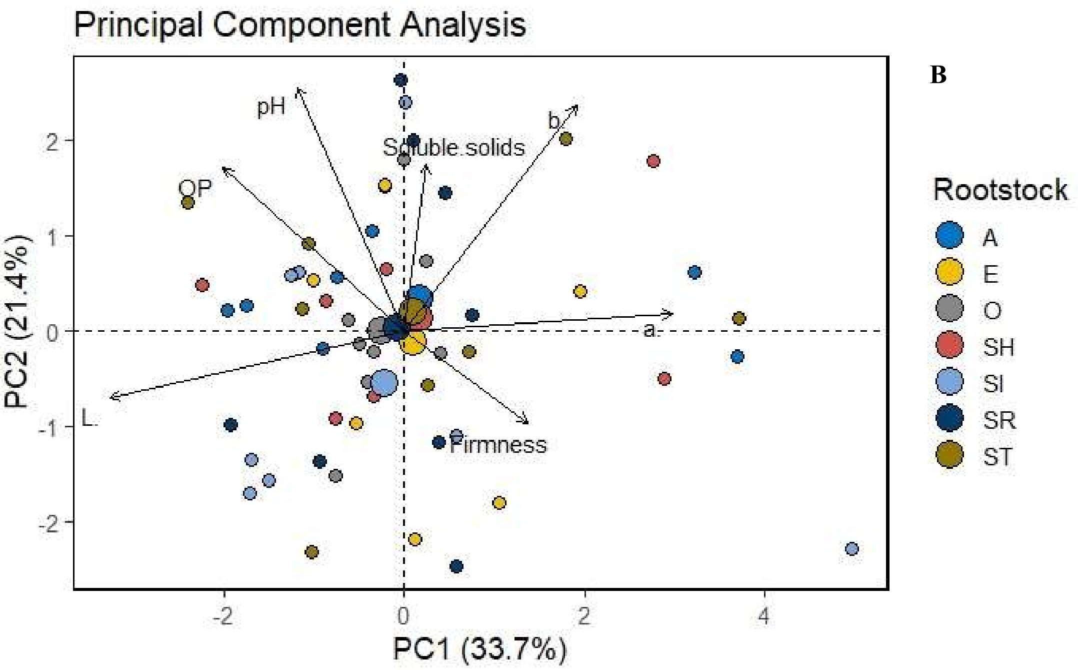


Figure 15. Principal component analysis for all parameters responses of eggplant to storage temperature (A) and rootstocks (B)

††SR= self-root; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena,* SI = *Solanum melongena* × *Solanum integrifolium,* O = Optifort; E = Emperador; A = *Solanum integrifolium*

According to the principal component analysis (PCA) test in Figure 15, the first two components constituted 55.1% of the total variation. The first component accounted for 33.7% of the changes, while the second component accounted for 21.4%. It was revealed that the levels of pH and OP were placed in the II coordinate zone and shared the highest resemblance, but *b** was positioned in the first zone and TSS was located on the boundary of these two zones, acting as a mediator between pH changes and b changes. Additionally, *L*0 pulp was in the third region and firmness was in the fourth region, which was the opposite of the changes in pH and OP. It was also discovered that *a** was situated between the changes in *b** and firmness. The findings of the distribution associated with the storage temperature treatment also indicated that the distribution of the 0 °C temperature treatment was greater in the second zone, whereas the distribution of the 10 °C treatment was greater in the third and fourth zones. It is evident that the third and fourth zones are for storage circumstances at a temperature of 10 °C, and that the characteristics included in these sections are more closely associated with this temperature (Figure 15A). The rootstock distribution results also revealed that most of these values were placed in the middle of the coordinates and did not differ much from one another, with the exception of SI (Figure 15B).

Colour and firmness greatly influence consumer desire and increased fruit firmness extends the fruit's shelf life. Browning occurs due to reactions between phenolic compounds and oxidative enzymes during storage. It is correlated with long-term storage or chilling damage and significantly affects eggplant fruit quality (Cantwell and Suslow 2000). The *L** value and fruit OP significantly decreased on days 3. Also, our findings indicated that the *L**, *a** value, and OP index were unaffected by temperature and the interaction of storage day × temperature. This result is contrary to that of Concellón et al. (2004, 2007), who showed that the *L** value of eggplants remained constant throughout 15 days of storage at 10 °C but gradually decreased while stored at 0 °C. Fruit harvested from various rootstock-scion combinations reacted differently depending on temperature and storage day.

5.5 Effect of selected rootstocks on plant physiology and fruit yield and quality under salinity stress

SPAD value decreased significantly (11% compared to control) in response to salt stress, whereas grafting onto SH dramatically enhanced SPAD value in both saline and normal conditions (Table 18). The interaction between salinity and rootstock considerably affected the leaf pigment variable. Significant reductions in chlorophyll a and b were observed in the leaf of a plant exposed to 80 mM NaCl. Despite this, the rootstocks SH, ST, and SG were suffered less than SR plants. The maximum total chlorophyll concentrations were shown in control grafted plants on SH. In saline conditions, grafted plants onto SH followed by ST, and SG plants exhibited less total chlorophyll loss than SR plants. The interaction effect of grafting and salinity revealed that salinity significantly decreased carotenoid concentrations in SR plants compared to non-saline environments. Under salt stress conditions, the carotenoid values dramatically rose in grafted plants compared to SR plants (Table 18). The carotenoid values dramatically rose in grafted plants compared to SR plants (Table 18, 19).

Table 18. Effect of grafting on SPAD value and photosynthetic pigments under salt stress conditions during vegetative stage

Salinity	Grafting	SPAD	Chlorophyll *a* (mg g^{-1} FW)	Chlorophyll *b* (mg g^{-1} FW)	Total Chlorophyll (mg g^{-1} FW)	Carotenoids (mg g^{-1} FW)
Interaction effect of salinity and grafting						
Control	SR	54.30bc	18.03bc	3.07 bc	21.10bc	1.43ab
	SG	52.55b-d	16.90bc	3.12bc	20.03c	1.51ab
	ST	55.27ab	18.49b	3.44ab	22.36b	1.80 a
	SH	58.22a	23.46a	3.87a	26.90a	1.58ab
Salinity	SR	48.45e	9.76e	1.68e	11.44 e	0.41c
	SG	50.60de	14.55d	2.44d	17.07d	1.31b
	ST	51.35c-e	14.79d	2.61cd	17.23d	1.34b
	SH	52.30b-d	16.35cd	2.74cd	19.10c	1.33b
Main effect of salinity and grafting						
Control		53.86a	19.08a	3.28a	22.36a	1.56a
Salinity		51.90 b	14.00b	2.46b	16.47b	1.12b
	SR	51.82bc	16.41b	2.21c	19.17b	1.10b
	SG	49.52c	13.05c	2.75b	15.27c	1.33ab
	ST	53.91ab	16.52b	3.24a	19.76b	1.51a
	SH	56.26a	20.18a	3.28a	23.46a	1.41a
Salinity		*	***	***	***	***
Rootstock		***	**	***	***	*
Salinity Rootstock		*	**	*	*	***
CV		4.56	8.26	13.98	7.85	20.25

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at P<0.05. ††ns= not significant, *= significant at P<0.05, ** =significant at P<0.001, ***= significant at P<0.0001. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

The use of grafted vegetables can help the plants to mitigate the negative effects of abiotic stresses, and both scion and rootstock can affect the tolerance of grafted plants (Colla et al. 2010). We observed that salinity had a detrimental effect on eggplant's physiological traits, yield, and fruit quality, as well as that grafting onto SH and ST can be a useful tool for minimizing this effect.

In line with our results, Colla et al. (2012; 2013) reported that grafted plants exposed to salt had a higher SPAD index than non-grafted plants. Hegazi et al. (2015) reported that salt stress significantly decreased the chlorophyll content of eggplant leaves. The exposure of grafted eggplant to salt conditions resulted in higher chlorophyll pigment values than non-grafted or self-grafted plants. Previous result by Fernández-Garcia et al. (2002) explained that grafting could improve the adverse impact of salinity by protecting chlorophyll.

Table 19. Effect of grafting on photosynthetic pigments under salt stress conditions during flowering period

Salinity	Grafting	Chlorophyll *a* (mg g^{-1} FW)	Chlorophyll *b* (mg g^{-1} FW)	Total Chlorophyll (mg g^{-1} FW)	Carotenoids (mg g^{-1} FW)
Interaction effect of salinity and grafting					
Control	SR	25.68 b-d	5.15a-c	30.65cd	1.73 c
	SG	26.95bc	5.56ab	32.10bc	2.08 bc
	ST	31.48a	6.15a	37.64a	2.49 ab
	SH	28.88ab	5.68ab	34.56ab	2.67 a
Salinity	SR	17.20 f	3.73d	20.94f	1.16d
	SG	21.47 e	4.30cd	26.19e	1.54 cd
	ST	25.09 cd	4.71b-d	29.39c-e	1.55 cd
	SH	22.66 de	4.91bc	28.23de	1.68 cd
Main effect of salinity and grafting					
Control		28.25 a	5.47a	33.77a	2.24a
Salinity		21.60 b	4.58b	26.18b	1.48b
	SR	21.44 b	4.32c	25.77b	1.62 b
	SG	26.02 a	4.72bc	30.37a	1.64 b
	ST	27.07a	5.86a	32.93a	2.02 ab
	SH	25.07 a	5.19ab	30.74a	2.17a
Salinity		***	**	***	***
Rootstock		***	**	***	**
Salinity × Rootstock		*	*	*	*
CV		9.12	14.56	8.36	21.08

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at P<0.05. ††ns= not significant, *= significant at P<0.05, ** =significant at P<0.001, ***= significant at P<0.0001. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

The interaction results of grafting and salinity on chlorophyll fluorescence in Table 19 showed that salinity significantly decreased F_v/F_m in eggplant leaves. In contrast, the decrease in grafted plants (SG, ST, and SH) was slighter than in SR. Similarly, Quantum yield of photosystem

II (Φ_{PSII}) value had a more significant reduction in SR in plants grown with NaCl treatment, and the highest Φ_{PSII} was observed at SH × Control and SH × Salinity.

One evaluation method of plant response to stress conditions is chlorophyll fluorescence monitoring. Our results showed that the inhibitory effect of NaCl on F_v/F_m in grafted plants was much milder than those non-grafted and self-grafted plants (Table 20). Moreover, Φ_{PSII} was more sensitive to salt stress than F_v/F_m. In line with the present experiment results, the value of F_v/F_m in self-rooted and self-grafted plants was lower than grafted ones in tomato and cucumber under NaCl stress conditions (He et al. 2009, Liu et al. 2012, Nabil et al. 2020). These findings show that grafting may be able to prolong photoinhibition in the presence of salt stress (He et al. 2009). He et al. (2009) found that the greater Φ_{PSII} in grafted plants was positively linked to better photosynthesis under salt stress and Φ_{PSII} was significantly lower with a minor or no decline in F_v/F_m, which might be attributed more energy was wasted thermally in Φ_{PSII}.

Salinity slightly decreased the leaf RWC and grafting onto SH and ST improved it (Table 20). Also, salt supplementation reduces water potential in eggplant leaves and is mainly productive. Interaction results of rootstocks and NaCl treatment showed that grafting stimulated the adverse effect of salinity on water potential at both times.

Salinity significantly decreased the leaf water potential and grafting onto different rootstocks improved. Under saline conditions, the water uptake of plants decreases (Fernández-García et al. 2004a, b). Orsini et al. (2013) found that the leaf water potential was decreased by salinity stress (40 and 80 mM NaCl), higher in non-grafted plants than self-grafted melon plants. In agreement with our findings, Santa-Cruz et al. (2002) observed an increase in leaf water content in grafted tomato plants under saline conditions, which could be attributed to the root characteristics.

Table 20. Effect of grafting on chlorophyll fluorescence and leaf water potential under salt stress conditions

Salinity	Grafting	F_v/F_m	Φ_{PSII}	Leaf water potential (Ψw 1 MPa)	Leaf water potential (Ψw 2 MPa)	RWC (%)
		Interaction effect of salinity and grafting				
Control	SR	0.86a	0.80a	- 2.37 a	- 2.58 a	76.89bc
	SG	0.86a	0.80a	- 4.37 ab	- 1.81 a	78.55bc
	ST	0.86a	0.81a	- 4.23 ab	- 1.91 a	91.42a
	SH	0.87a	0.81a	- 3.80 a	- 1.76 a	87.57ab
Salinity	SR	0.80d	0.65d	- 7.53 b	- 6.00 b	69.25c
	SG	0.82cd	0.69c	- 4.38 ab	- 4.02 ab	72.16c
	ST	0.83bc	0.72bc	- 3.44 a	- 3.32 ab	75.18bc
	SH	0.85ab	0.73b	- 3.99 a	- 2.82 ab	75.92bc
		Main effect of salinity and grafting				
Control		0.86 a	0.80a	- 3.84	- 2.01 a	83.61a
Salinity		0.82 b	0.70b	- 4.69	- 4.04 b	73.13b
	SR	0.83 b	0.72b	- 5.95 a	- 2.95	76.03
	SG	0.84 ab	0.75a	- 4.11 ab	- 2.31	77.23
	ST	0.84 ab	0.77a	- 3.91 b	- 3.96	78.41
	SH	0.86b	0.76a	- 3.08 b	- 2.89	81.79
Salinity		***	***	***	***	***
Rootstock		*	***	***	***	ns
Salinity × Rootstock		*	**	***	***	***
CV		2.78	3.73	15.36	10.81	6.72

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at $P<0.05$. ††ns= not significant, *= significant at $P<0.05$, ** =significant at $P<0.001$, ***= significant at $P<0.0001$. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena.* †††† F_v/F_m: ratio of variable to maximum fluorescence, Φ_{PSII}: Quantum yield of photosystem II, RWC: Relative water content

As shown in Figure 16, the highest total marketable yield was observed in Control × SH as well as Control × ST (4.24 and 3.96 kg/plant, respectively) compared to SR in non-stress conditions. A slight decrease in total yield per plant was observed at SR in response to salinity treatment and grafting onto SH significantly increased total yield by 20% compared to 80 mM NaCl stressed in SR plants.

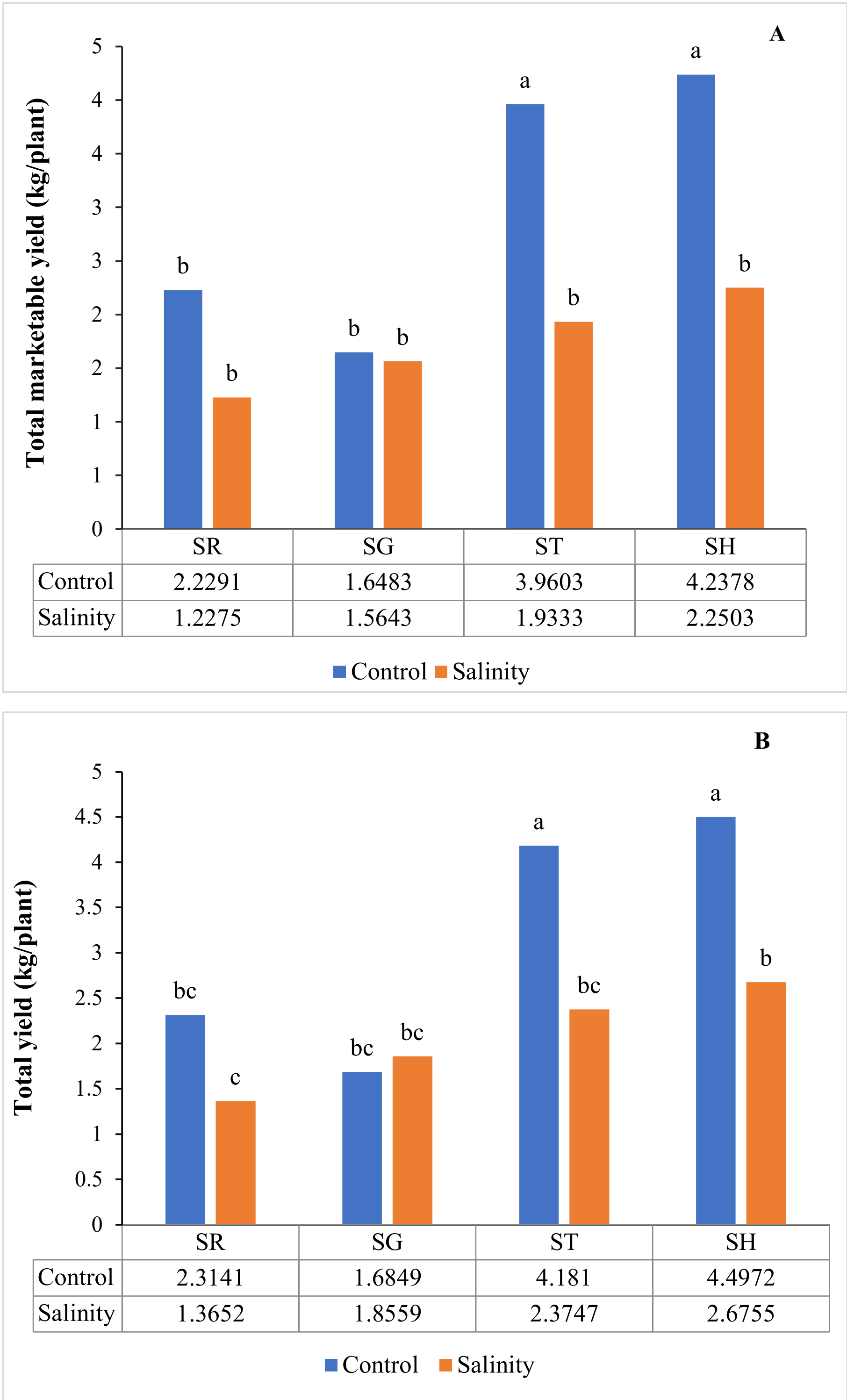


Figure 16. Interaction effect of salinity and grafting on total marketable yield (A), total yield (B)

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

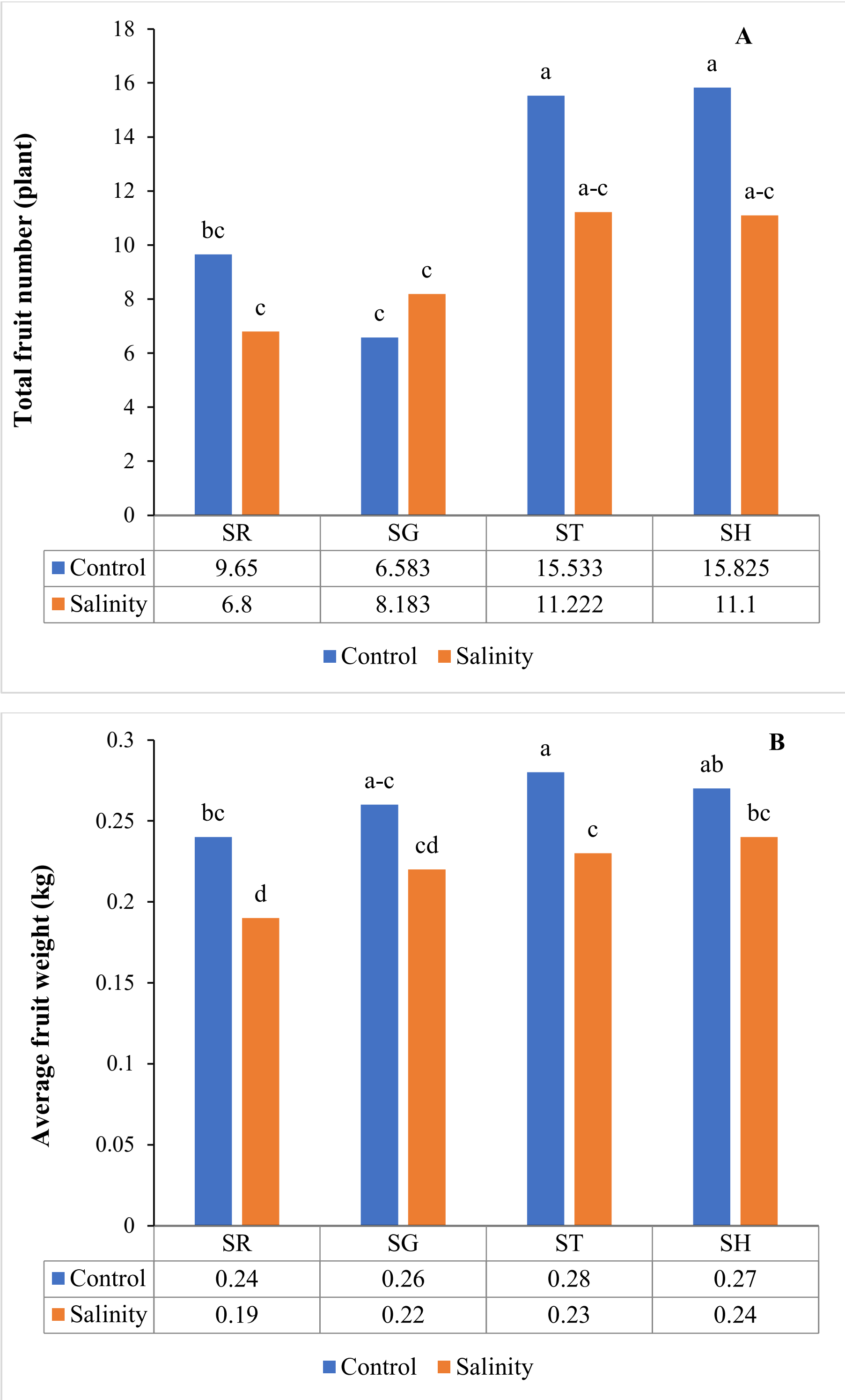


Figure 17. Interaction effect of salinity and grafting on fruit number (A), fruit average weight (B)

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at $P<0.05$. ††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

In non-stress conditions, increasing the total fruit yield of eggplant by grafting has been reported by several researchers, depending on the scion cultivars and rootstock and their compatibility (Moncada et al. 2013, Mozafarian et al. 2020, Sabatino et al. 2016, Gisbert et al. 2011a). In the present study, increasing fruit yield in the grafted plant under saline conditions is related to average fruit weight. Similarly, the higher fruit yield of grafted plants relative to self-rooted plants was reported in eggplant; tomato; pepper under saline conditions (Santa-Cruz et al. 2002, Semiz and Suarez 2019, Fernández-García et al. 2004, Estañ et al. 2005, Penella et al. 2016, Wei et al. 2007). The higher yield of grafted plants in stress conditions is related to a lower accumulation of Na^+ and Cl^-. Also, it can be attributed to increasing nutrient uptake, enhancing the production of hormones and scion vigour (Colla et al. 2010, Bai et al. 2005).

In non-stress conditions, the total fruit number per plant increased by grafting onto SH and ST. Salinity significantly decreased average fruit weight compared to non-stress conditions (by 12%). However, grafting onto ST and SH significantly enhanced the average fruit weight reduction in saline conditions (Figure 17).

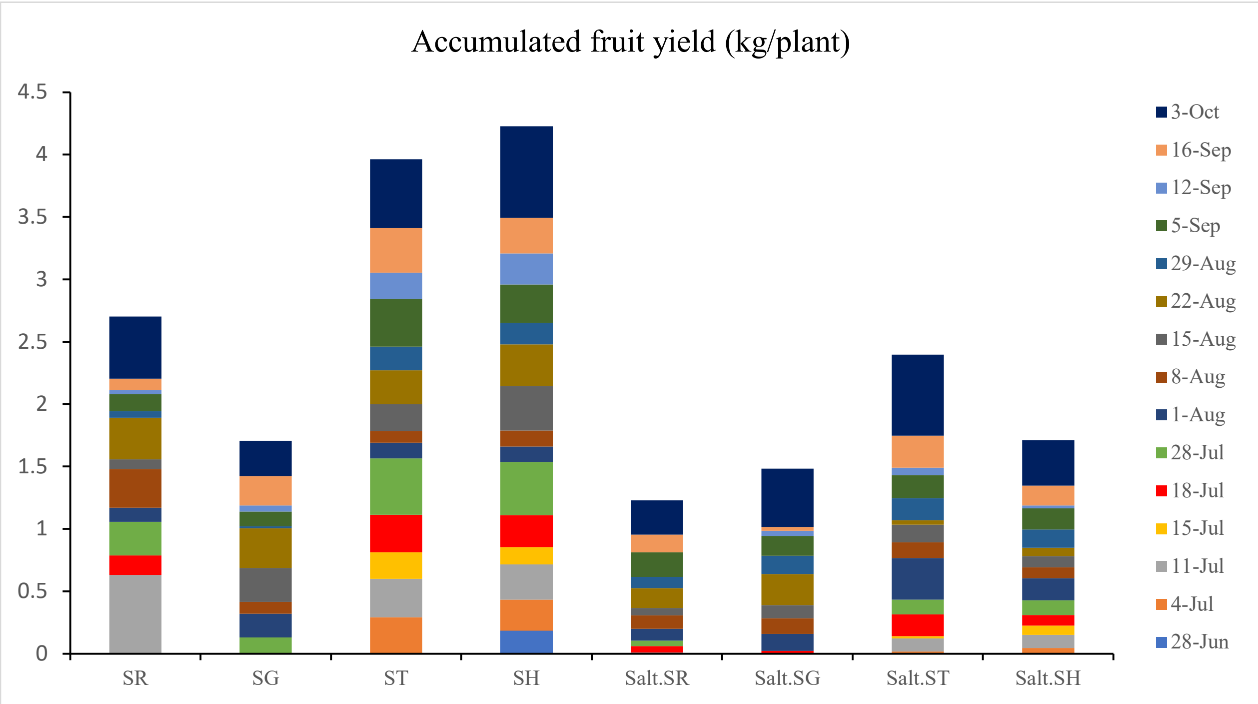


Figure 18. Interaction effect of salinity and grafting on accumulated fruit yield per plant during the 15-harvesting time.

†SR= self-root; SG= self-grafting; ST= *Solanum torvum*, SH= *Solanum grandifolium* × *Solanum melongena*

The first and second fruit was obtained from grafted plants onto SH grown under non saline conditions on 28th of June and then from grafted plants onto SH and ST under both saline and non-saline conditions on 4th of July. Under saline conditions, fruit from grafted plants was ready to pick earlier than the SR and SG (Figure 18). Under normal conditions, the number of harvesting and yield per harvest were greater in grafted plants into SH and ST than in SR and SG.

Salt supplementation considerably decreased fruit length. However, the reduction was less in fruit harvested from grafted plants onto SH and ST. Also, salinity significantly decreased eggplant fruit width. Fruit picked from plants grafted onto SH had the lowest firmness. Grafting, salt condition, and their interaction had no effect on the pH of the fruit. TSS value increased significantly by salinity and grafting onto ST (Table 21).

Table 21. Effect of grafting on fruit size, firmness, pH and total soluble solids (TSS) under salt stress conditions

Salinity	Grafting	Fruit length (cm)	Fruit width (cm)	Firmness (kg/cm^3)	pH	TSS (Brix°)
Interaction effect of salinity and grafting						
Control	SR	16.78 ab	8.27	7.75	5.47	2.96 d
	SG	18.23 a	9.21	9.50	5.36	3.69 b-d
	ST	16.58 b	8.36	8.98	5.46	4.08 b-d
	SH	16.67b	8.51	5.67	5.51	4.53 b
Salinity	SR	12.45 d	7.41	9.44	5.40	4.14 bc
	SG	13.83 cd	8.16	7.15	5.40	3.56 cd
	ST	14.30 c	8.10	7.51	5.38	5.61 a
	SH	14.46 c	8.43	8.45	5.35	4.36 bc
Main effect of salinity and grafting						
Control		17.06 a	8.59 a	7.99	5.45	3.96
Salinity		13.76 b	8.02 b	8.14	5.38	4.27
	SR	14.60 b	4.84 b	8.59 a	5.44	3.85 b
	SG	16.03 a	8.69 a	8.33 ab	5.38	3.33 b
	ST	15.41 a	8.23 a	8.25 ab	5.42	4.84 a
	SH	15.57 a	8.47 a	7.06 b	5.43	4.44 a
Salinity		***	*	ns	ns	ns
Rootstock		*	*	*	ns	***
Salinity × Rootstock		*	ns	ns	ns	***
CV		11.67	13.92	21.10	2.85	24.38

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at P<0.05. ††ns= not significant, *= significant at P<0.05, ** =significant at P<0.001, ***= significant at P<0.0001. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

Our results showed that the CIRG index increased with salinity and grafting. Kacjan Maršić et al. (2014) reported the darkness of eggplant fruit from 'Epic' decreased from self-grafted plants in comparison with grafting onto 'Beaufort' rootstock. They concluded that the CIRG and browning index was highly dependent on the combination of the grafting and scion. Anthocyanin is the essential compound for eggplant peel colours. Kacjan Maršić et al. (2014) and Sabantino et al. (2018) found that anthocyanin concentration depends on grafting. The reason could be that the nitrogen level required for developing red colour in eggplant skin may decrease under salt stress conditions. At the same time, grafting can enhance N accumulation (Uygur and Yetisir 2009).

Table 22. Effect of grafting on skin colour CIELAB colour parameters under salt stress conditions

Salinity	Grafting	*L**	*a**	Hue	Chroma	CIRG
Interaction effect of salinity and grafting						
Control	SR	25.41	3.56 cd	3.64 cd	347.61	6.53 a-c
	SG	25.32	3.69 b-d	3.75 b-d	349.66	6.52 bc
	ST	25.59	4.08 b-d	4.13 b-d	350.81	6.42 bc
	SH	25.87	4.53 b	4.57 b	337.68	6.30 c
Salinity	SR	24.86	4.14 bc	4.20 bc	350.85	6.60 ab
	SG	24.38	2.96 d	3.05 d	346.53	6.85 a
	ST	25.55	5.61 a	5.63 a	325.90	6.27 c
	SH	25.14	4.36 bc	4.40 bc	331.01	6.49 bc
Main effect of salinity and grafting						
Control		25.55a	3.96	4.02	346.44	6.44 b
Salinity		24.98b	4.27	4.32	338.57	6.55 a
	SR	25.13ab	3.85 b	3.92 b	349.23	6.57 ab
	SG	24.85b	3.33 b	3.40 b	348.09	6.68 a
	ST	25.57a	4.84 a	4.88 a	338.36	6.35 c
	SH	25.50ab	4.44 a	4.49 a	334.34	6.40 bc
Salinity		**	ns	ns	ns	***
Rootstock		*	***	***	ns	*
Salinity× Rootstock		ns	***	***	ns	*
CV		4.52	24.38	24.32	15.98	5.18

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at $P<0.05$. ††ns= not significant, *= significant at $P<0.05$, ** =significant at $P<0.001$, ***= significant at $P<0.0001$. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum*, SH= *Solanum grandifolium* × *Solanum melongena*

The DW_0 ranged from 27.99 (Control × SR) to 35.63 (Salinity × SH) (Table 23). The oxidation activity of fruit pulp was higher in harvested fruits of plants grown in saline conditions. As shown in table 23, salinity significantly decreased L^*_0 (2.84%) of fruit pulp. Grafting eggplant onto ST and SH decreased L^*_0 in comparison with self-rooted plants. The interaction results showed that the lowest L^*_0 was obtained in SH and SG in stress conditions (82.20, 82.84). Our results showed that the brighter fruits (SR × Control; SG × Control) had a lower value of Hue angle, degree of whiteness, and oxidation potential than other combinations in stress and non-stress conditions. The interaction of grafting and salinity showed a high browning pulp in the fruit of SR under stress conditions (about two times more than the SR plant in normal conditions).

Table 23. Effect of grafting on flesh colour CIELAB colour parameters L^*_0, degree of whiteness (DW_0), colour difference (CD) and oxidation potential (OP) under salt stress conditions

Salinity	Grafting	L^*_0	Hue	Chroma	DW_0	CD	OP
Interaction effect of salinity and grafting							
Control	SR	87.58	25.28 d	101.26	28.18 c	8.06	5.46b
	SG	87.50	24.90 d	100.03	27.99 c	8.15	4.87b
	ST	85.60	25.94 cd	99.69	29.70 bc	9.24	5.98b
	SH	84.04	28.33 a-c	98.44	32.54 ab	8.31	6.05b
Salinity	SR	85.90	27.61 bc	100.98	31.03 a-c	13.92	10.18a
	SG	82.84	29.69 ab	97.51	31.38 a-c	9.81	9.24ab
	ST	84.04	26.95 b-d	99.25	34.35 a	11.89	6.84ab
	SH	82.20	30.80 a	97.37	35.63 a	10.43	6.24ab
Main effect of salinity and grafting							
Control		86.20 a	26.12 b	99.85	29.60 b	8.44 b	5.59b
Salinity		83.75 b	28.76 a	98.77	33.10 a	11.52 a	8.12a
	SR	86.74 a	26.45 b	101.12 a	29.61 b	10.99	7.82
	SG	85.21 ab	27.30 b	98.77 ab	31.17 b	8.98	7.05
	ST	84.82 bc	26.45 b	99.47 ab	30.54 b	10.57	6.41
	SH	83.12 c	29.56 a	97.91 b	34.08 a	9.37	6.14
Salinity		***	***	ns	***	*	***
Rootstock		***	***	*	***	ns	ns
Salinity × Rootstock		ns	*	ns	*	ns	*
CV		2.93	8.21	4.10	9.02	3.10	21.99

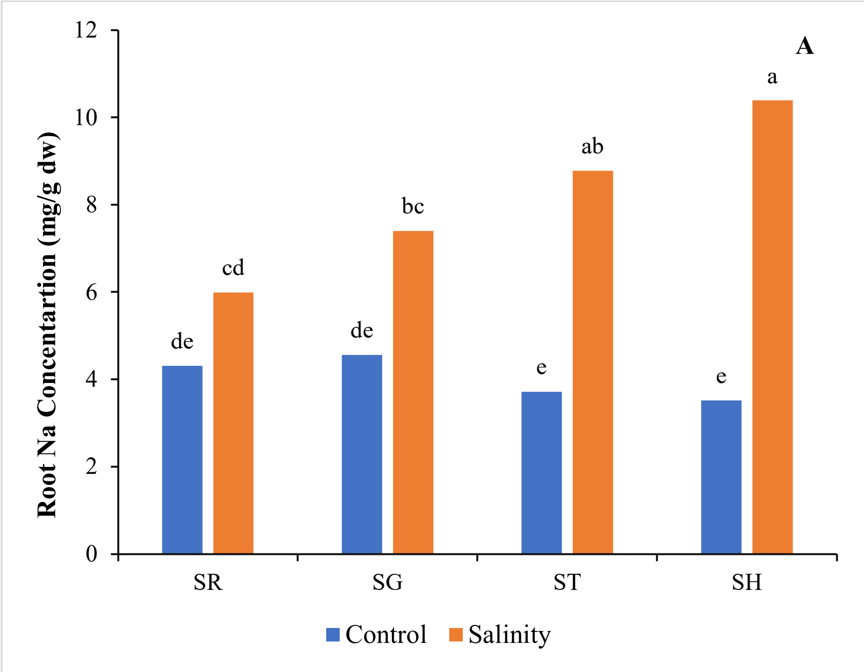
†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at P<0.05. ††ns= not significant, *= significant at P<0.05, ** =significant at P<0.001, ***= significant at P<0.0001. †††SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

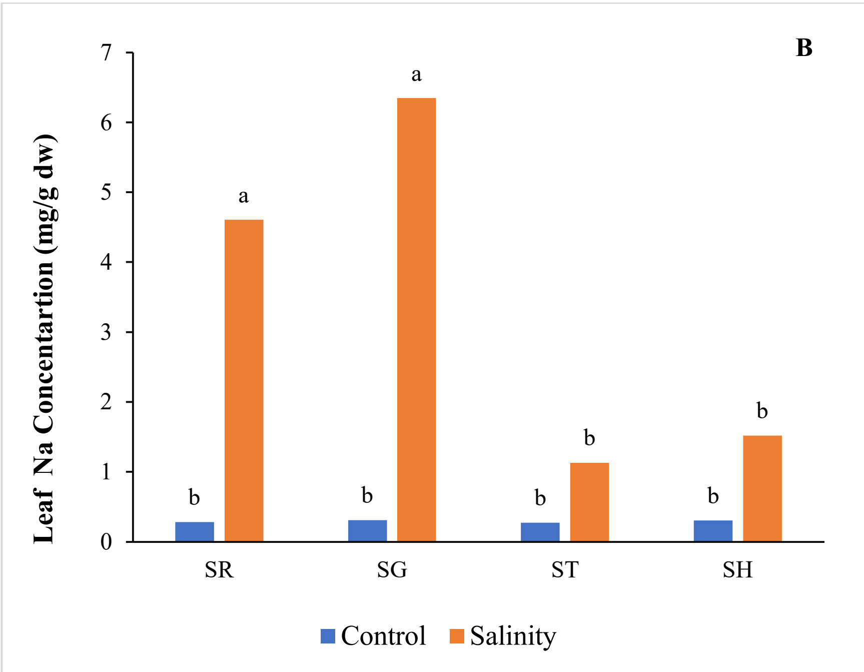
Consumers and industry prefer white-fleshed and late browning eggplant varieties. Grafting onto *Solanum torvum* showed no discernible effect on pulp lightness, whereas fruits grafted onto *Solanum paniculatum* and *Solanum macrocarpon* had the least amount of lightness (Sabatino et al. 2018). Moncada et al. (2013) grafted four eggplant cultivars onto *Solanum torvum*. They reported that grafting did not affect the fruit's lightness or browning potential. The flesh and skin colour appear to be determined mainly by cultivar and rootstock combinations. Browning pulp was less prevalent in grafted fruit than self-rooted fruit (Moncada et al. 2013). Our results indicated that fruits harvested from SH rootstock plants had the highest DW_0 and the lowest L_0* and chroma.

Comparing landraces, commercial, and hybrid eggplant varieties revealed that landrace varieties produced fruit closer to pure white (DW_0) than commercial varieties. In contrast, hybrid and commercial varieties produced fruit with a lower mean degree of browning after exposure to air (OP and CD) than landrace varieties. This phenomenon is probably due to the selection of breeding programs (Prohens et al. 2007). The oxidation of phenolics in fruit flesh causes it to brown when exposed to air, decreasing apparent quality. Polyphenol oxidases display a wide range of activity among eggplant varieties (Dogan et al. 2002), which can be a reason for less browning (OP) in self-rooted plants than grafted onto SH and ST rootstocks. On the other hand, browning is correlated to phenol compounds and salinity increased total phenols in eggplant fruits (Hegazi et al. 2015). Therefore, it can be concluded that salinity can increase the browning index of fruits.

Plants grafted onto ST and SH rootstocks had a higher Na^+ concentration in the root and less in leaf and fruit (Figure 19). No significant differences were found between SH and ST in Na^+ accumulation. Plants grafted onto ST and SH accumulated (14% and 17%) more Na^+ in their root than SR in saline conditions. The highest sodium concentration in the leaf and fruit was determined in SR and SG plants.

In agreement with our findings, numerous reports indicate that tolerant rootstock increased salt tolerance by reducing Na^+ and Cl^- transfer to the shoot (Panella et al. 2017, Martínez-Rodríguez et al. 2008, Colla et al. 2010). The salt tolerance of grafted pepper resulted from the lower accumulation of Na^+ and Cl^- in the shoot (Penella et al. 2015). Fernández-García et al. (2004) consider that graft union could limit the passage of Na^+ and Cl^- to the scion. Moreover, Estañ et al. (2005) indicated that the varied marketable yield responses were attributed to the diverse abilities of the rootstock to regulate the transport of toxic saline ions.


A
Root Na Concentartion (mg/g dw)
12
10
8
6
4
2
0
de
cd
de
bc
e
ab
e
a
SR
SG
ST
SH
Control
Salinity


B
Leaf Na Concentartion (mg/g dw)
7
6
5
4
3
2
1
0
b
a
b
a
b
b
b
b
SR
SG
ST
SH
Control
Salinity

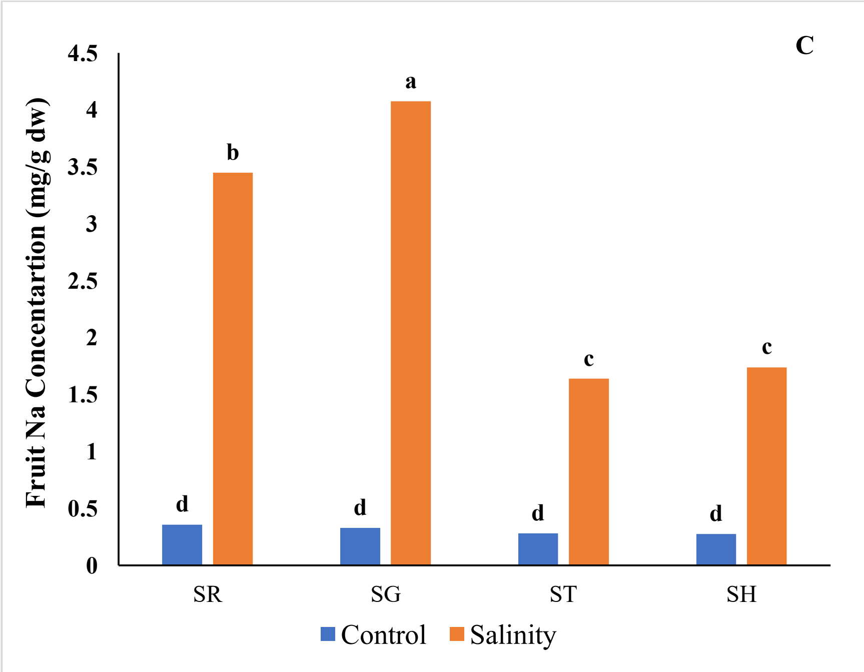
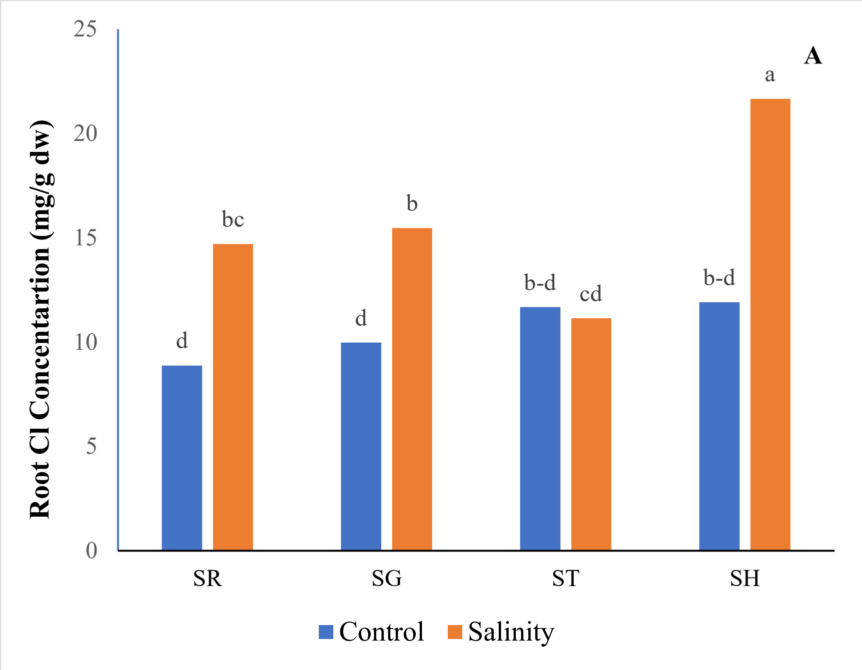


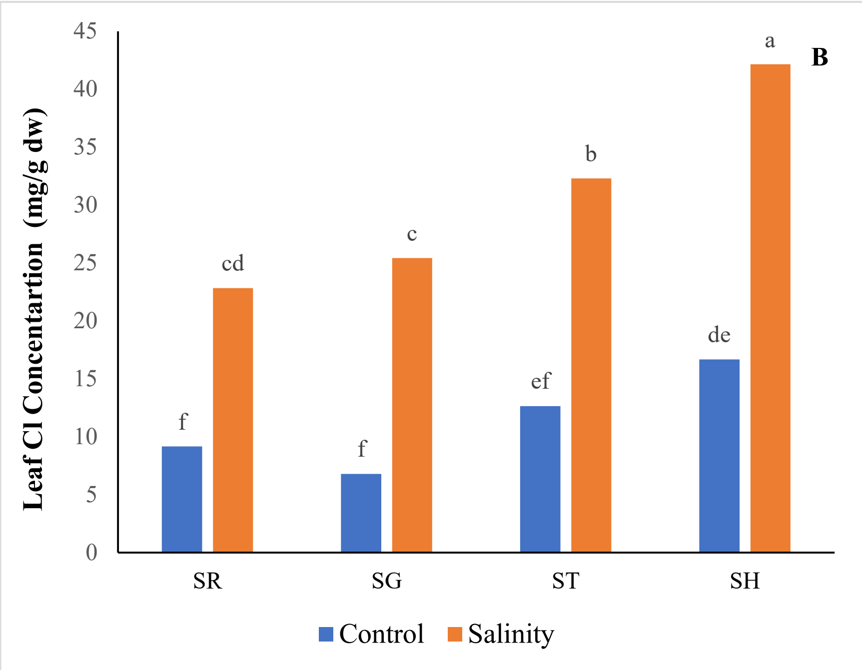
Figure 19. Interaction effect of salinity and grafting on Na^{+} concentration in root (A), leaf (B) and fruit (C)

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at $P<0.05$. †SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

There was a significant increase in chloride concentrations in the leaves, roots, and fruits of all grafted combinations compared to non-grafted plants when subjected to saline conditions (Figure 20). While there was no significant difference in chloride concentration between SH and ST in fruit, the concentration in leaf and root was significantly higher in SH. Under saline conditions, plants grafted on SH accumulated (18.5%) more Cl- in their fruit than SR.

Contrary to the results of the present study, the response of tomato 'Faridah' grafted onto 'Unifort' rootstock under saline circumstances, the accumulation of Na+ and Cl- was significantly lower in grafted plants than in non-grafted (Al-Harbi et al. 2017). In another study, Santa-Cruz et al. (2002) discovered that the accumulation of Na+ and Cl- ions in leaves differed depending on the graft combination. In comparison to self-grafted 'Moneymaker' plants, the combination of 'Moneymaker' and 'Kyndia' had a lower Na+ and comparable Cl- content. However, this response was different for the combination of 'UC-82B' and 'Kyndia,' which induced a decreased accumulation of both Na+ and Cl- ions. Like our finding, grafting decreases the concentrations of Na+, but not Cl− in the leaves of melon and watermelon (Colla et al. 2006 a, b).


A
Root Cl Concentartion (mg/g dw)
25
20
15
10
5
0
bc
b
b-d
cd
b-d
a
d
d
SR
SG
ST
SH
Control
Salinity


B
Leaf Cl Concentartion (mg/g dw)
45
40
35
30
25
20
15
10
5
0
cd
c
b
a
f
f
ef
de
SR
SG
ST
SH
Control
Salinity

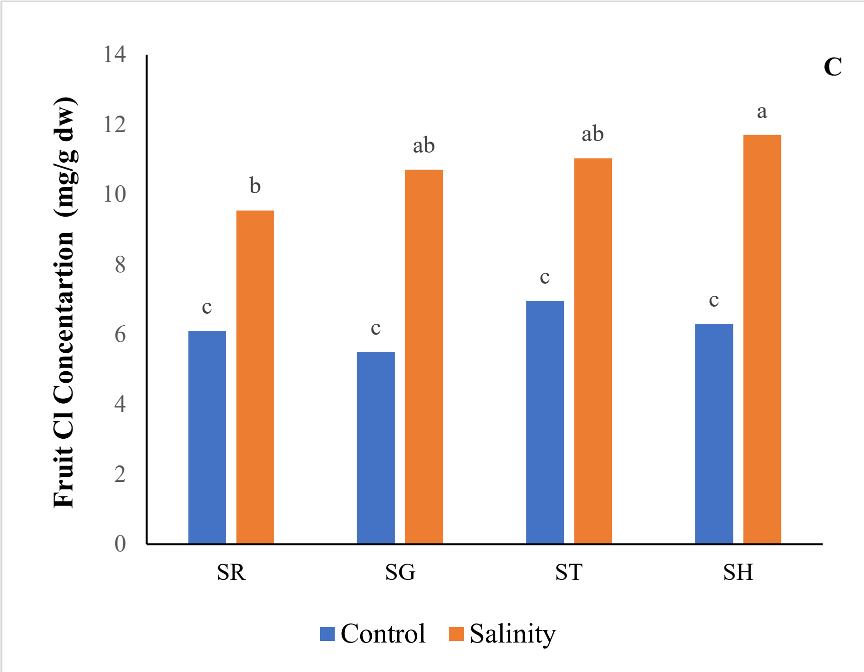


Figure 20. Interaction effect of salinity and grafting on Cl^- concentration in root (A), leaf (B) and fruit (C)

†Different letters within the same column are significantly different between means of four replication (5 plants in each replication) according to Tukey's multiple range test at P<0.05. †SR= self-root; SG= self-grafting; ST= *Solanum torvum,* SH= *Solanum grandifolium* × *Solanum melongena*

6. CONCLUSION AND SUGGESTION

According to our first experiment, in which six different rootstocks were compared with non-grafted and self-grafted plants, grafting onto SH, ST, SI, and A rootstocks led to an increase in fruit production. Likewise with our findings, Sabatino et al. (2016) and Gisbert et al. (2011a, b) revealed that grafted plants produced greater yields than non-grafted plants. We have noticed that the fruits harvested from grafted plants on E and O rootstocks are inferior to other fruits in terms of quality variables such as fruit color and browning. The browning of eggplant fruit tissue is caused by a high concentration of phenolic compounds, which is influenced by numerous circumstances. There are numerous reports of the influence of various rootstocks on the browning of fruit tissue. Macadona et al. (2013), for instance, reported that Torvum was ineffective against the browning of eggplant. There is no evidence to suggest that tomato rootstock has a beneficial influence on the browning of eggplant flesh at this point in time.

In accordance with the findings of Khah et al. (2005), the grafting of 'Madonna' variety eggplant onto various rootstocks decreased the TSS of the fruit in the present research. There are contradicting findings regarding fruit firmness, with certain rootstocks increasing and others decreasing the fruit firmness of grafted plants. The firmness of the fruit was reduced by the use of all of the rootstocks tested in this experiment with the exception of SH. Sensory analysis data showed a significant difference in four parameters (flesh colour, firmness, sweet taste, and intensive odour) between selected rootstocks.

In a second study examining; the impact of different rootstocks on eggplant postharvest at two different temperatures, it was observed that fruit stored at 0 °C had a greater pH value than fruit stored at 10 °C. Interaction results between temperature, storage day, and several rootstocks revealed that the pH value of fruit from SR, ST, SH, O, and A decreased significantly on day 9 at 10 °C compared to fruit stored at 0 °C.

Fruits and vegetables lose firmness during storage due to the activation of cell wall-degrading enzymes. After nine days of storage, the firmness of eggplant fruits is significantly lower than it was on the day of harvest. Both Jha et al. (2002) and Abano et al. (2019) found a decrease in the firmness of eggplant following storage, which was associated to the eggplant shrinking and the epidermal layer. These findings are in agreement with our observations. The interaction effect of day and rootstock demonstrated that the firmness of fruit from different rootstocks on the day of harvest was very similar but declined with storage. In accordance with our findings, Ozturk and Ozer (2019) discovered that the fruit firmness on the first day and throughout storage differed between grafted and non-grafted plants. Overall, we discovered that the storage temperature had a greater impact on the analyzed characteristics of eggplant fruits than the examined rootstock.

A plant subjected to 80 mM NaCl displayed significant reductions in photosynthetic pigmentation. Despite this, SH, ST, and SG rootstocks were less damaged than SR. Previous findings by Kiran et al. (2019), Fernández-Garcia et al. (2002), and Nabil et al. (2020) were similar to the results of the present study. In grafted plants, the inhibitory effect of NaCl on F_v/F_m was drastically lower than in non-grafted and self-grafted plants. These results indicate that grafting may extend photoinhibition in the presence of salt stress (He et al. 2009).

As Santa-Cruz et al. (2002) found in tomatoes, salinity significantly reduced the leaf water potential of eggplant, and grafting onto different rootstocks benefited the plant, which might be linked to the root characteristics.

In the present study, the average fruit weight is associated to an increase in fruit yield in grafted plants grown in salty environments. In eggplant, tomato and pepper grown in saline circumstances, grafted plants produced more fruit than self-rooted plants in previous studies by Santa-Cruz et al. 2002, Semiz and Suarez 2019, Fernández-Garca et al. 2004, Estan et al. 2005, Penella et al. 2016, Wei et al. 2007.

Numerous studies have found that tolerant rootstock improves salt tolerance by lowering Na^+ and Cl^- transfer to the shoot (Panella et al. 2017, Martnez-Rodrguez et al. 2008, Colla et al. 2010). In the current experiment, both ST and SH rootstocks had higher Na^+ concentrations in the root and lower concentrations in the leaf and fruit, resulting in a higher marketable yield.

Solanum torvum is highly vigorous, and resistant to a broad of soil pathogens and root-knot-nematodes and abiotic stress (Schwarz et al. 2010). However, seed germination is weak, irregular, and inconsistent (Gousset et al. 2005, Hayati et al. 2005). According to the findings of present study, *Solanum grandiflorum* × *Solanum melongena* has the potential to be an alternate rootstock that reduces the effects of salinity stress.

7. NEW SCIENTIFIC FINDINGS

1. It was found that grafting eggplant 'Madonna' onto Optifort rootstock significantly reduced fruit width (by 5%) and length (by 17%) compared with fruit harvested from non-grafted plants. Also, as a result of grafting 'Madonna' onto Torvum, Taibyou, Akanasu, and Hikyaku, the total fruit yield was increased, with Torvum showing the highest value (60%) compared to non-grafted 'Madonna' plants.
2. The research has also shown that the oxidation potential and its consequent browning of 'Madonna' fruit pulp was significantly decreased by 70% when grafted onto Emperador and Optifort as compared to fruit harvested from non-grafted 'Madonna' plants.
3. As a result of this study, the ΦPSII significantly decreased in non-grafted 'Madonna' plants (23%) grown under 80 mM NaCl compared to non-stress conditions, whereas the reduction was less in grafted 'Madonna' onto Taibyou (9%). Under salt stress conditions, the total chlorophyll content of eggplant 'Madonna' grafted onto Torvum was 40% higher than non-grafted 'Madonna' plants.
4. The result of this research indicated that the average fruit weight of non-grafted 'Madonna' plants significantly decreased under salinity stress (20%) as compared to non-stress conditions. Under the stress conditions, grafting of 'Madonna' eggplant onto Torvum and Taibyou, significantly increased the average fruit weight by 21% and 26%, respectively, in comparison with non-grafted 'Madonna' plants.
5. In this research, eggplant 'Madonna' grafted onto Torvum and Taibyou accumulated (14% and 17%) more Na^+ in their roots than non-grafted in saline conditions. The highest sodium concentration in the leaf and fruit was determined in non-grafted and self-grafted plants. It was found that plants grafted onto Taibyou under saline conditions exhibited a higher concentration of Cl^- in their leaves and fruits as compared to non-grafted 'Madonna' plants (about 84% and 18.15%).

8. SUMMARY

Vegetable grafting is considered a rapid alternative method compared to the relatively slow breeding process aiming to overcome the adverse effect of salinity. In addition to reducing biotic and abiotic stress, grafting may also affect the quality of the fruit and postharvest quality of eggplant. Different experiments were designed to understand 1) the effect of different rootstocks on the yield and quality 2) fruit postharvest quality over 9 days at two different temperatures 3) to determine the salinity tolerance of grafted plants relative to non-grafted.

To prepare the seedling, the eggplant was grafted onto several rootstocks, including tomato rootstocks Optifort (O) and Emperador (E), and four *Solanum* rootstocks; *Solanum grandiflorum* × *Solanum melongena* (SH), *Solanum torvum* (ST), *Solanum melongena* × *Solanum integrifolium* (SI), and *Solanum integrifolium* (A) compared with self-grafted (SG) and self-rooted (SR) as control.

All grafted and non-grafted seedling were transplanted into plastic house in 10L pots filled with peatmoss. Fruits were picked weekly for 15 times and immediately weighted by balance. The results showed that the total marketable yield significantly increased by grafting onto ST (3.94 kg/plant), SH (3.36 kg/plant), and A (3.34 kg/plant) relative to SR (1.65 kg/plant). The chromatics characters of skin and pulp were slightly influenced by rootstocks. Our findings confirmed that grafting decreased the eggplant firmness (except SH) of the flesh. Fruit harvested from the Optifort/'Madonna' combination had the rounded shape, lowest firmness, and TSS value, while the lowest oxidation potential was observed in this combination. The highest seed number was observed in SH/'Madonna' and SI/'Madonna' combinations. During the sensory evaluation, the lightest color of fruit flesh was found in SR, ST, and O, and the sweetest taste was observed in fruits harvested from ST rootstock.

Fruit harvested from grafted onto ST, SH, SI, A, E and O, and non-grafted plants stored at 0 and 10 °C storage for nine days to check their postharvest behaviour. The TSS, L* and b* values of pulp declined throughout storage. The pH of the fruit pulp decreased during storage at 10 °C. The lowest firmness was observed in fruit grafted on E and O. The OP value decreased for fruit harvested from O rootstock. At 0 °C, the OP value increased in fruit harvested from A rootstock. Fruit firmness reduction at the end of storage in fruit grafted onto SH was less than in the other rootstocks and control plants.

Also, another experiment was arranged to understand the response of grafted and non-grafted eggplant under saline conditions. Two rootstocks were used, including *Solanum* *grandifolium* × *Solanum melongena* (SH) and *Solanum torvum* (ST), along with self-grafted (SG), self-rooted (SR) plants, and two NaCl concentration were used 80 mM and 0 as control.

Results showed a significant decrease in SPAD value, chlorophyll a, b, carotenoids, and total chlorophyll in response to NaCl. Grafted plants had higher photosynthesis pigments than non-grafted plants grown under saline conditions. The F_v/F_m and ΦPSII reductions in NaCl treatment were significantly lower in grafted plants than in self-rooted plants. The results showed that grafting eggplant onto SH significantly enhanced the reduction of total fruit yield as compared to self-rooted plants exposed to saline conditions by increasing average fruit weight. The interaction of salinity and grafting indicated that the CIRG index on fruit skin decreased on fruit harvested from ST under saline conditions. Salinity significantly increased the whitening index and oxidation potential of fruits. Plants grafted onto SH and ST accumulated more Na^+ in their roots than in their fruit and leaves. SH and ST rootstocks protect the 'Madonna' scion against salinity stress and show better photosynthetic pigment and chlorophyll fluorescence and lower Na^+ concentration in the scion under stress conditions, with higher fruit yield and quality.

9. APPENDICES

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9.2 List of figures

9.3 List of Tables

Table 22. Effect of grafting eggplant for skin colour CIELAB colour parameters under salt stress conditions

Table 23. Effect of grafting eggplant for flesh colour CIELAB colour parameters L_0*, degree of whiteness (DW_0), colour difference (CD) and oxidation potential (OP) under salt stress conditions

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