Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)

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(2017-12-027)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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Certified that the thesis entitled **"Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)"** is a record of research work done independently by **Mr. Sadanand Kumbar** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Affectionately Dedicated

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INTRODUCTION

1. INTRODUCTION

Brinjal (*Solanum melongena* L.), also known as aubergine or eggplant, is a popular, widely cultivated warm season vegetable crop grown in subtropical and tropical regions of the world. It is indigenous to India belonging to the night shade family (Solanaceae). Brinjal is a popular vegetable grown on commercial scale in almost all the states of India. Apart from India, this crop is of great importance in the warmer regions of Central, Southern, far east and southeast Asia and is grown more extensively in China, Japan, Turkey, Egypt, Italy, Indonesia, Spain and Philippines.

Eggplant is a bushy shrub which grows to a height of 60-120 cm. The plant is erect, compact and well branched. Leaves are large simple, lobed, alternate with solitary large, violet or white coloured flowers. The stem, leaves and calyx areeither spined or glabrous. The fruit is a pendant, fleshy berry, ovoid, obovoid or long cylindrical, while the seeds are borne on the fleshy placenta filling the locular cavity completely (Kumar, 2008).

India is second largest producer of vegetables in the world with an annual production of 181 MT in 2017-18. Brinjal covers 6.69 lakh ha (8.14%) of the total area under vegetable crops and contributes 12.40 lakh ha (9%) of the total vegetable production in India. Top three brinjal producing states in India are West Bengal (24.34%), Odisha (16.21%) and Gujarat (11.86%). In Kerala it is grown in an area of 1.57 (000ha) with the production of 20.30 (000 MT) (NHB 2017-18). India (23.3%) and China (68.7%) together accounts for 92% of world production of brinjal. Egypt, Turkey and Iran are the other important producer of this crop.

The unripe tender, soft fruits are primarily used as a cooked vegetable for the preparation of various dishes through out India and the world. Round fruits are baked or boiled for the preparation of a smashed product called Bhartha. Small round fruits are used in curry preparation especially in Southern India. The long ones are used as fried, stuffed or stewed. It has much potential as a raw material for pickle preparation and dehydration industries (Goiterogenic principle). Saponin content in fruits plays an important role in the development of the richness of the flavor. Eggplant is also widely used for medicinal purposes. Various plant parts are used in decoction, as powder or ash

for curing ailments such as dysentery, toothache, skin infections, asthenia, otitis, cholera, bronchitis, dysuria, and haemorrhoids. Eggplant is also ascribed narcotic, anti-asthmatic and anti-rheumatic, antidiabetics (white brinjal), appetizer, aphrodisiac, cardio tonic and is beneficial in vata and kapha (Daunay and Chadha 2003).

The nutritive value per 100g of raw eggplant is carbohydrates (5.7g), fat (0.19g), protein (1.01mg), thiamine (0.039 mg), riboflavin (0.037 mg), niacin (0.649 mg), pantothenic acid 0.281 mg), Vit. B_1-thiamin (0.08 mg), Vit. B_2- riboflavin (0.02 mg), Vit. B_3- niacin (0.59 mg), Vit. B_6-pyridoxin (0.08 mg), folate (22 µg), Vit. C-ascorbic acid (2.2 mg), Calcium (9 mg), iron (0.24 mg), magnesium (14mg), phosphorus (25 mg), potassium (230mg), zinc (0.16mg) and manganese (0.25 mg) (USDA, 2018).

Brinjal is subjected to the attack of many diseases which cause damages in all growth stages thereby limiting production. Some of the most common fungal diseases of eggplant are *Phomopsis* blight or fruit rot caused by *Phomopsis vexans*, leaf spot caused by *Alternaria* sp. and *Cercospora* sp. and *Verticillium* wilt caused by *Verticillium dahlia.* Other diseases are little leaf disease of eggplant caused by MLOs (mycoplasma like organisms), bacterial wilt caused by *Ralstonia solanacearum*; and several mosaic diseases caused by viruses. Incidence of insect pest is one of the most limiting factors for increasing yield potential of brinjal. Brinjal fruit and shoot borer *(Leucinodes orbonalis)* and jassids or cotton leafhopper *(Amrasca biguttela biguttela)* are destructive pests of eggplant, the former causing upto 70% yield loss. It is also susceptible to the two spotted red spider mite *(Tetranychus urticae),* aphids *(Aphisgossypii),* Epilachna beetle and root knot nematodes.

Brinjal cultivation in coastal regions is severely affected by the incidence of bacterial wilt disease caused by *Ralstonia solanacearum*. It accounts for 15-23% of crop loss before fruiting and the average yield loss is 54.6-62.5% due to further death of the bearing plants before reaching full maturity (Das and Chattopadhyay, 1955). Bacterial wilt is primarily a soil borne bacteria which enters the plants through root injuries. Inside the plant, the bacteria multiply and blocks the vascular bundles, the chief conducting tissue of water and nutrients, thereby causing sudden wilting of plants. Bacterial wilt is very common in Kerala, especially in Solanaceous vegetables like tomato, brinjal and chilli. It is very difficult to manage bacterial wilt in the field due to persistent and pervasive nature of the pathogen. Integrated management practices focus

on crop rotation, cultural practices, avoidance, sanitation, host plant resistance, fumigation and grafting on disease resistant rootstocks. The management practices recommended are either to choose wilt resistant cultivars/varieties/hybrids for cultivation or to adopt grafting on bacterial wilt resistant rootstocks as all other management practices are of limited practical feasibility. Grafting is widely practiced in Solanaceous vegetables (Tomato, Brinjal, Chilli, and Capsicum) all over the world and the vegetable growing farmers in Kerala who are growing hybrids especially under precision farming system of cultivation are commercially utilising grafted plants. Grafting in vegetables has emerged as a promising and surgical alternative tool to the relatively long and slow conventional breeding methods aimed at increasing tolerance to biotic and abiotic stresses. Grafted plants on resistant rootstocks of Solanaceous vegetables were highly resistant to bacterial wilt and high yielding (Narayanankutty *et al.*, 2015)

Brinjal can be successfully cultivated throughout the year in Kerala. However successful cultivation is severely affected by the incidence of bacterial wilt caused by *Ralstonia solanacearum.* The pathogen is highly diverse and its management is a challenging task. Choice of a variety for cultivation is very important as it determines the production, demand and marketability of the produce.

Observation trials conducted at Agricultural Research Station, Mannuthy involving 12 genotypes comprising of seven *Solanum* species *viz. S. viarum, S. indicum, S. incanum, S. insanum, S. macrocarpon, S. acculatissimum* and *S. sysimbrifolium*, three *Solanum melongena* collections viz. Brinjal Purple Long, Brinjal Purple Round and Brinjal Green Round, brinjal variety "Haritha", and chilli cultivar 'Ujjwala'. Only Brinjal Purple Long, Brinjal Purple Round, Brinjal Green Round, Haritha and Ujjwala showed resistance to bacterial wilt in both the seasons (Narayanankutty *et al.*, 2018). There are many high yielding varieties and hybrids, both from public and private sector, released for commercial cultivation but all of them are highly prone to the bacterial wilt disease caused by *Ralstonia solanacearum*. Hence it is necessary to identify more number of rootstocks and scion cultivars for getting maximum yield and bacterial wilt resistance. Keeping this background in view, present research topic deals with objectives for evaluation of rootstocks reportedly resistant to bacterial wilt and to study the field performance of grafted brinjal plants on resistant rootstocks.

REVIEW OF LITERATURE

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2. REVIEW OF LITERATURE

Brinjal (*Solanum melongena* L.) is an important, widely cultivated warm season vegetable grown in India. The tender fruits are used for cooking as a vegetable for the preparation of various dishes throughout India and the world. Diverse agro-climatic conditions in our country provides opportunity for year round cultivation of brinjal. Wide range of varieties and hybrids are grown in different parts of the country.

Brinjal can be successfully cultivated throughout the year in Kerala. However, eggplant cultivation in Kerala is limited due to the high incidence of bacterial wilt caused by *Ralstonia solanacearum.* Management of this disease is a challenging task because the pathogen is highly diverse in pathogenicity. There are many high yielding varieties and hybrids, both from public and private sector, released for commercial cultivation but in Kerala, all of them are highly prone to the bacterial wilt disease. Choice of a variety for cultivation is very important as it determines the production, demand and marketability of the produce.

Under field condition management of this pathogen is very difficult. Crop rotation, cultural practices, soil amendments, field equipment disinfection, sanitation, avoidance, fumigation, weed removal, host plant resistance and grafting on disease resistant rootstocks are the some of the measures used to reduce the bacterial wilt disease. Crop rotation with non-host crops decreases the incidence of *Ralstonia solanacearum* population in the soil and subsequently reduce the bacterial wilt incidence. Grafting on disease resistant rootstocks has been successful and is currently practiced for bacterial wilt management in and around the globe (McAvoy *et al.,* 2012). Some of the reviews on which this study is based are given in this following chapter.

2.1. *Ralstonia solanacearum* as the causal organism for bacterial wilt of brinjal

The earliest description of the bacterial wilt disease was proposed by Burill (1890), in connection with an unidentified bacterial pathogen affecting southern potato tubers in the United States. Later, in 1896 Smith started detailed research, which resulted in the first ever description of the disease and the causal agent. In India, bacterial wilt disease was first recorded from Pune district of Maharashtra by Cappel (1892) and the nature of

the bacterial disease was described by Butler (1903). Coleman (1909) reported the pathogen as *Pseudomonas solanacearum* but later, renamed as *Ralstonia solanacearum* (Yabuchi *et al.*, 1995).

2.1.1. Biology and epidemiology

Ralstonia solanacearum is a wide spread phyto-phathogenic bacterium that causes devastating wilt disease in many economically important crops. It is a gram negative rod shaped flagellated bacterium that inhabits in the soil. It grows well under aerobic conditions at an optimum temperature of 28-32^{0}C (Hayward, 1991; Schaad *et al.,* 2001). It is considered as a species complex and it belongs to β-protobacteria (Alvarez *et al.,* 2010). *Ralstonia solanacearum* is a highly diverse species complex comprised of four genetically distinct phylotypes that belongs to different geographic origins (Meng, 2013a).

Under wet conditions, swimming motility of the bacterium helps in movement in soil spreading the disease from one plant to another plant. It disseminates in many ways *viz.,* water flow in soil, infected plant material and contaminated soil or field supplies and equipment (Louwas *et al.,* 2010). Major sites of *Ralstonia solanacearum* entry into the plants are wounds and natural openings that occur on the roots of the plants, then multiplies rapidly within the xylem tissue after invading into the cortical tissue, and effectively clogs the water conducting vascular bundle, causing wilting symptom (Meng, 2013b).

Ralstonia solanacearum is attracted towards host plant root exudates, hence swimming motility is most important and here chemotaxis *i.e.,* the presence of diverse amino acids, organic acids and root exudates plays an important role in host pathogen interaction (Yao and Allen, 2006). Extracellular polysaccharides, secreted effectors via the type three secretion system, flagella propelled motility via the type four secretion system and cell wall degrading enzymes delivered through the type two section system are the multiple virulence factors produced by *Ralstonia solanacearum* to enable invasion (Liu *et al.,* 2005).

2.1.2. Survival of the pathogen

Coleman (1909), found that *R. solanacearum* persisted in the soils of Karnataka for two and half years. Kelman (1953) reported that the pathogen survivability varied with soils. Some soil can support the pathogen for longer periods, in others inspite of presence of the susceptible host, the organism did not survive. Das and Chattopadhayay (1955) observed that the *R. solanacearum* survived for 16 months in pot cultured soil. Rangaswami and Thirunakarasu (1964) found that *bacterium* can over winter for 250 days in free-state in soil or in the infected parts of plant from season to season. Crosse (1968), however reported that *R. solanacearum* survived upto six years in the bare soil as a free propagule.

Ralstonia solanacearum can exist in the soil for several years without a host by surviving on crop debris and infected plant roots which sustains the pathogen before its release back into the soil. Well drained soil with good water holding capacity are favourable for survival of the pathogen (Stall, 1991). Hayward (1991) proposed many explanations, such as association of bacteria with plant debris or with several weed hosts, which are symptomless carriers. The race 3, biovar 2, may survive in a latent form on weed hosts within the hosts or in their root areas in the soil. *R. solanacearum* strains are able to survive in water courses in roots of the weed *Solanum dulcamara* (Elphinstone *et al.*, 1998). The ability of a pathogen to enter a dormant like 'viable but not culturable' (VBNC) state, like many other soil microbes may also leads for the long-term survival of the bacterium (Grey and Steck, 2001).

Gowda *et al.* (1974) reported that the population of *R. solanacearum* in eggplant experimental plot was higher in the rhizosphere of wilting plants than in the rhizosphere of non-wilted plants. Rhizosphere of the wilted plants had 4 to 50 times higher virulent pathogen population than the avirulent population and the rhizosphere of non-wilted plants had 1 to 20 folds higher avirulent pathogen population than that of wilted plants. The rhizosphere soils of wilted plants showed a general increase in dehydrogenase activity. Granada and Sequeira (1983) studied the survival of pathogen in artificially inoculated soil and the result showed that race 1, 2 and 3 survived upto 21, 16 and 8 weeks respectively and race 1 survived in the soil longer than race 2 and race 3.

2.1.3. Host range

Ralstonia solanacearum has an unusually wide host range about 50 plant families (Hayward, 1991). The host range not only includes only herbaceous plants but also several trees and shrub hosts (e.g. mulberry, olive, cassava, rubber, eucalyptus), some plants of fabaceae family (groundnut, French bean), and a few monocotyledons (mainly banana and ginger). Deslandes *et al.* (1998) reported that *Arabidopsis thaliana*, most widely used model plant for genetic engineering is also vulnerable to infection by this pathogen. Over two hundred species, particularly tropical and subtropical crops are prone to attack of one or the other races of *Ralstonia*. Worldwide, the most important range of other host crops are *Tagetus erecta* (Marigold), *Anthurium spp.* (Anthurium), *Capsicum annuum* (chilli and capsicum), *Zingiber officinale* (ginger), *Hevea brasiliensis* (rubber), *Manihot esculenta* (tapioca), *Ricinus communis* (Castor bean) and *Arachis hypogea* (ground nut). Many weeds, *G. cilliata, Galinsoga flora, Solanum nigra, Polygonum capitate, Portulca oleracea* and *Solanum cinereum* are also serves as hosts to the bacteria. *Solanum nigrum* is the primary wild host for race 3 (Hayward, 1994).

2.1.4. Effect of environmental interactions on *R. solanacearum*

Most important factor that affects the host pathogen interaction as well as survival of organism in soils is temperature. In general increase in ambient temperature between 30 to 35^0C increases the occurrence and frequency of bacterial wilt in tomato. For many races, plants that are resistant at moderate temperature may become susceptible at a higher temperature. The resistance is temperature sensitive and strain specific (Tung *et al.*, 1990). Hingorani *et al.* (1956) noticed no bacterial wilt disease development at 15^0C. High moisture build up in soil due to either heavy precipitation or high water table favours occurrence of bacterial wilt (Abdullah *et al.*, 1983) and pathogen survival is highest in damp but well drained soils (Buddenhagen and Kelman, 1964).

Synergistic interaction between *Ralstonia solanacearum* and root knot nematode is widely documented on a range of host plants (Kelman, 1953). Magnitude of root infection by nematodes correlates positively with bacterial wilt occurrence as observed in wolf peach (Nirmaladevi and Tikoo, 1992). Increased wounding of roots by nematode worms provides purpose of entry to the microorganism or nematode could

modify the plant parts therefore so as to make it more suitable for bacterial colonisation. At high temperatures (27-32°C), *Meloidogyne incognita* prominently augmented wilt severity in susceptible Floradel and resistant Caraibo tomato cultivars. The study revealed that infection of tomato roots by *Meloidogyne incognita* lowered the genetic resistance to bacterial wilt (Deberdt *et al.*, 1999).

2.1.5. Infection and symptomology of bacterial wilt disease

Ralstonia solanacearum enters into the plant through wounds in the root system (Pradhanang, *et al.*, 2005). Stomata are the natural openings in the plant through which the pathogen can enter into the plant (Chupp and Sherf, 1960). Environmental factors like temperature play a vital role that effects multiple plant pathosystems and their interactions with their hosts (Hayward, 1991). The pathogen crosses the intercellular spaces of the cortex and enters into the pith and xylem vessel which leads to vascular plugging and finally leading to wilting of plant. Once bacteria are in xylem, through quorum sensing, they produce extracellular polysaccharides and cell wall degrading enzymes that ultimately cause xylem clogging and tissue maceration (Salie *et al.*, 1997). Stems and roots of the bacterial wilt disease infected plants looks normal from outside but vascular bundles (xylem and phloem) inside the stem turns brown along with formation of water soaked appearance in roots (Walker, 1952). Kelman (1953) noticed that the appearance of the slimy viscous ooze on transversely cut section of the stem at the site corresponding to vascular bundle due to dehydration of occluded xylem vessels and destruction of surrounding tissues leading to collapse and death of plant.

The visual symptoms in the infected plant, first appear in new growth and quickly spread to the rest of the plant causing the whole plant to wilt and die. Yellowing of the leaves and adventitious root formation on the stems of the infected plants were observed in some partially resistant cultivars (Stall, 1991). A milky white exudate can be seen streaming from the cut surface of the infected plant stem when placed in water for few minutes. This distinguishes the bacterial wilt from other wilt diseases. The presence of the pathogen can be verified by observation of vascular browning of infected plants and isolation of pathogen.

Smith (1920) and Kelman (1953) reported several external and internal symptoms characterizing the bacterial wilt disease. External symptoms of the infected

plants are wilting, stunting and yellowing of the foliage. Other symptoms are leaves benting downward showing leaf epinasty, adventitious roots growing on the stems, and the observance of narrow dark stripes corresponding to the infected vascular bundles beneath the epidermis. The common internal symptoms are progressive discoloration of the vascular tissue, mainly the xylem, at early stages of infection, and of portions of the pith and cortex, as disease develops, until complete necrosis. Elphinstone, (2005) found that *R. solanacearum* multiplies and moves systemically within the plant after invading a susceptible host before production of symptoms.

2.2. Screening bacterial wilt through artificial inoculation

Disease incidence through artificial inoculation methods depends on the concentration of the inoculum, age of the plants, environment where plants are kept and also the reaction of the host. So, in addition to the field evaluation study, development of disease through artificial inoculation is also necessary for confirmation of the pathogenicity of the causal organism as well as the host reactions.

Root dip, media drench, stem puncture method, transplanting into infested soil were frequently used as artificial inoculation methods. Winstead and Kelman (1952) differentiated bacterial wilt resistant and susceptible varieties by pouring the inoculum around the base of plant and cutting the roots by piercing a knife.

A wild brinjal (*Solanum torvum*) was completely resistant to *R. solanacearum* in soil drench and petiole inoculation methods. *S. torvum* is used as a potential rootstock in grafting to combat bacterial wilt disease since it is incompatible with cultivated brinjal for breeding programmes (Ramesh *et al.,* 2016).

Artal *et al.* (2013) screened tomato, brinjal and chilli plants for bacterial wilt resistance by using three artificial inoculation methods viz., soil drenching, leaf clipping and axial puncturing. The artificial inoculation through soil drenching recorded significantly higher bacterial wilt incidence in tomato, brinjal and chilli (98.0, 95.0, 90.0 per cent respectively) followed by inoculation through axil puncturing which recorded 78.0, 88.0 and 78.0 per cent wilt incidence. However, lowest wilt incidence of 74.0, 48.0 and 40.0 per cent, respectively was recorded in leaf clipping method.

Rahman *et al.* (2011) evaluated eight cultivars of brinjal *viz.*, Nayantara, Singhnath, Dhundul, Kazla, Marich Begun, Luffa-s, Kata Begun and Uttara in artificially inoculated field for bacterial wilt incidence. The result showed that the cultivar Luffa-s exhibited the highest (80%) and cultivar Kata Begun exhibited the lowest (30%) bacterial wilt incidence at 55 days after transplanting (DAT) among all the eggplant cultivars screened.

Kim *et al.* (2016) evaluated 285 tomato accessions at seedlings stage for bacterial wilt incidence caused by *R. solanacearum* under greenhouse. Disease severity of tomato accessions was investigated from 7 days to 14 days at an interval of 7 days after inoculation of *R. solanacearum.* They reported that 279 accessions were susceptible (70 to 90% wilt), two accessions were moderately resistant and only four accessions were highly resistant to bacterial wilt. Microscopic view of bacterial wilt resistant tomato stems infected with *R. solanacearum* revealed limited bacterial spread with thickening of pith membrane and gum production.

Thomas *et al.* (2015) conducted a study to screen susceptible and resistant genotypes of tomato against the *Ralstonia solanacearum.* A pure bacterial inoculum of 0.1OD;10^8 cfu ml^{-1} was used for inoculation. Five different inoculation methods such as seed-soaking in inoculum, seed-sowing followed by inoculum drenching, or at 2-week stage through petiole-excision inoculation, soaking of planting medium with inoculum either directly or after imparting seedling root-injury were used. The results revealed that seed-based inoculations or mere inoculum drenching at 2 weeks did not induce disease in seedlings but petiole inoculation induced 90–100% mortality in susceptible checks and 50–60% mortality in normally resistant genotypes within 7–10 days after inoculation. Root-injury inoculation in two week old seedlings appeared to be the best for early and clear distinction of resistant lines.

Sadarunnisa*et al.* (2018) screened fifty varieties of eggplant in a polyhouse for resistance to bacterial wilt caused by *Ralstonia solanacearum* by artificial inoculation of bacterial suspension both by soil drenching and axil puncturing method. Among the fifty eggplant varieties four varieties *viz.*, Arka Keshav, Surya, Arka Neelkanth and Arka Nidhi showed resistance, while 17 accessions were susceptible and 29 accessions

showed highly susceptible reaction to bacterial wilt. Arka Shirish was used as susceptible check which exhibited 90.67% wilt incidence.

2.3. Field evaluation of rootstocks for bacterial wilt

Sitaramiah *et al.* (1981) developed a scale for classification of varieties on the basis of plant survival percentage as immune (0% plants wilted: score 1), highly resistant (1% to 10% plants wilted: score 2), moderately resistant (11% to 50% plants wilted: score 3), moderately susceptible (51% to 70% plants wilted: score 4) and highly susceptible (75% to 100% plants wilted: score 5). Mukherjee and Mukopadhyay (1982) classified improved eggplant cultivars such as Pusa Purple Cluster as highly resistant, Muktakeshi as resistant, Pusa Kranti as moderately resistant, while Pusa Purple Long as highly susceptible and Black Beauty as susceptible cultivars of brinjal.

Gopimony and George (1979) reported that bacterial wilt incidence in certain improved varieties of brinjal like Arka Kusumakar and Banaras Giant was as high as 100 per cent whereas, in local cultivars it varied from 6 to 20 per cent in numerous districts and agricultural farms of Kerela. Gopalakrishnan and Gopalakrishnan (1985) found that eggplant cultivars such as SM 6-6 and Pusa Purple Cluster (4.76% and 4.69% wilt incidence respectively) were highly resistant to bacterial wilt. Ushamani and Peter (1987) screened 26 brinjal lines in bacterial wilt sick field to find out best rootstock resistant to bacterial wilt. The result showed that among all the eggplant lines evaluated only three lines viz., SM6-1SP, SM6-6M and SM6-7SP were found resistant.

Hanudin and Gaos (1992) screened 44 brinjal accessions in wilt sick field for bacterial wilt resistance and the study revealed that only one brinjal accession LV-209 found highly resistant, five accessions such as LV-266, LV-349, LV-740, LV-2806, and LV- 2810 were found moderately resistant, whereas all other accessions were found moderately susceptible or susceptible to bacterial wilt disease. Pathania *et al.* (1996) assessed fourteen cultivars of eggplant for bacterial wilt resistance including Pusa Purple Long as the susceptible check. They suggested Arka Neelkanth, Arka Keshav, Arka Nidhi and Pusa Purple Cluster for use in varietal improvement or for cultivation in bacterial wilt prone areas of the western Himalaya as resistant cultivars. Singh and Gopalakrishnan (1998) reported varieties Surya, Swetha, Annapurna, BB7, BB13-1, BB44 and Arka Keshav as resistant to bacterial wilt among fourteen elite

eggplant accessions evaluated in the bacterial wilt sick field of the warm humid tropical climate of Vellanikkara, Kerala, India.

Chaudhary and Sharma (2000) evaluated nine genotypes of eggplant such as Arka Kesav, Arka Neelkanth, Hissar Shyamal, Pusa Purple Cluster, Pusa Purple Long, SM 6-6, SM 6-7, Arka Nidhi and Punjab Barsati for the incidence of bacterial wilt. The result showed that Arka Kesav, Arka Neelkanth, Arka Nidhi and SM 6-6 were highly resistant to bacterial wilt. Rashid *et al.* (2002) carried out evaluation of selected brinjal genotypes for resistance against bacterial wilt disease. The results revealed that four varieties *viz*., BL-156, LG long II, S00-141 and Arka Nidhi were resistance to bacterial wilt.

Hussain *et al.* (2005) evaluated fifteen eggplant genotypes in wilt sick bed pre inoculated with *R. solanacearum*. The bacterial wilt incidence was observed daily up to 42 days from the date of transplanting. They reported that genotype EG 203 as a resistant with lowest wilt incidence, EG 193 as moderately susceptible while rest of the accessions were susceptible to *R. solanacearum*. Brinjal accessions such as Kazla, Dohazari, Barsati, Tal begun, EG 190 and S 90 were found highly susceptible to bacterial wilt.

Bora *et al.* (2011) screened fourteen eggplant cultivars for bacterial wilt resistance and they reported that Utsav exhibited the lowest incidence of bacterial wilt (2.23 per cent) in comparison to the susceptible check, Pusa Purple Long (65.8 per cent). Mondal *et al.* (2011) assessed six bacterial wilt resistant lines and found that BCB-14 and BCB-30 were resistant to bacterial wilt with high yield potential. Rahman *et al.* (2011) conducted a study on brinjal to screen out best rootstock resistant to bacterial wilt. They have evaluated eight varieties viz., Nayantara, Singhnath, Dhundul, Kazla, Marich Begun, Luffa, Kata Begun and Uttara. All the varieties showed low degree of wilt incidence at 25 days after transplanting (DAT) with average wilt incidence ranging from 20.00% to 41.00%, comparatively medium level of wilt incidence was recorded at 35 DAT and it varied from 30.00% to 51.00%. Higher level of wilt incidence was observed at 55 DAT (30.00% to 80.00%).

Mondal *et al.* (2013) evaluated eight local eggplant accessions for resistance to bacterial wilt. They reported that local eggplant accessions, Midnapore Local and

Bhangar were highly resistant to bacterial wilt disease. Gopalakrishnan and Reddy (2014) evaluated fifty varieties of eggplant for resistance to bacterial wilt. The result revealed that among all the varieties evaluated only four varieties, *viz.*, Arka Keshav, Surya, Arka Neelkanth and Arka Nidhi showed resistance, while 17 accessions were showed susceptible and 29 accessions were showed highly susceptible reaction to bacterial wilt. Pavithra *et al.* (2014) screened six improved eggplant varieties Arka Neelkanth, Arka Sheel, Pusa Purple Long, Pusa Purple Round, Arka Shirish and PB- 4 Improved for resistance to bacterial wilt. The results revealed that Arka Neelkanth showed moderately resistance (14% wilt incidence), Arka Shirish was highly susceptible (87.5% wilt incidence), Pusa Purple Round (54.68% wilt incidence) and PB-4 Improved (53.12% wilt incidence) were moderately susceptible.

Jhangta (2015) reported that brinjal cultivars Swarna Pratibha, Hissar Shyamal, Pusa Purple Cluster, Arka Keshav, Bhola Nath, Singh Nath, Arka Nidhi, BB- 54, SM 6-6, SM 6-7, BRBWRES-10, BRBWRES-9, BRBWRES-8, BRBWRES-7, BRBWRES-5, BRBWRES-2, BB-54 and DPBBWR-2 exhibited less than 10 per cent bacterial wilt incidence and they were classified as highly resistant, while varieties such as BRBWRES-6, BRBWRES-4, BRBWRES-3 and BRBWRES-1exhibited 50 per cent wilt incidence and they were classified as moderately resistant. Pusa Purple Long and Arka Kusumakar exhibited 100 per cent wilt incidence and were highly susceptible to bacterial wilt. Malshe *et al.* (2016) reported that bacterial wilt incidence in different varieties of brinjal varied from 1.53 to 68.67 per cent. Maximum bacterial wilt incidence of 66.50% was reported in Manjari Gota variety of brinjal.

Kumar *et al.* (2014) evaluated nine accessions of brinjal for bacterial wilt resistance in IET (Initial Evaluation Trial) and 8 accessions in AVT (Advance Varietal Trial) in a wilt sick plot. Among the accessions of brinjal evaluated in IET Arka Nidhi was found resistant. But in AVT, two entries BEBWRES-05 and Arka Nidhi were highly resistant with maximum wilt occurrence of only 7 and 19 % respectively while BEBWRES-2, BEBWRES- 4 and SM 6-6 (C) with less than 40 % wilt at 120 days after planting were moderately resistant to bacterial wilt.

Bhavana and Singh (2016) tested eight genotypes of eggplant in rainy season for bacterial wilt resistance. Only two genotypes *viz*; IC-261786 and IC-261793 were found

resistant to wilt 90 days after transplanting with 84% plant survival. Dutta and Rahman (2012) screened tomato varieties and hybrids against bacterial wilt of tomato. The variety All Rounder was recorded as resistant with a mortality of 8.98 per cent with lowest vascular bundle discolouration index (VBDI) (1.0) towards the disease. Four tomato varieties *viz*., Swarakhsha, Rakshak, Trishul and Arka Alok were recorded as moderately resistant (>10 to 20% mortality). Loknath and Arka Vikash were found highly susceptible (>70 to 100% mortality) with highest VBDI of 4 and 4.5 per cent, respectively. Tiwari *et al.* (2012) screened tomato genotypes against bacterial wilt (*R. solanacearum*) result showed that genotypes Cherry Jaspur had highly resistant reaction (HR); four genotypes *viz*., ATL- 01-19, Pant T-10 and CO-3 were recorded moderately resistance in field condition against bacterial wilt of tomato.

2.3.1. Spot planting technique

Narayanankutty and Peter (1986) conducted a study in tomato cultivars to confirm host reaction to bacterial wilt incidence caused by *R. solanacearum* using four inoculation methods *viz*., root dipping, stem injection, alternate row planting and spot planting with a susceptible genotype. The result revealed that among all the evaluation methods spot planting was the most effective for testing bacterial wilt incidence in tomato cultivars. They suggested that spot planting can be recommended for future field screening trials for bacterial wilt resistance in tomato.

2.3.2. Sources of resistance to bacterial wilt in brinjal

2.3.2.1. Potential source of bacterial wilt resistance germplasm from wild eggplant relatives.

Sources of resistance	**Reported from**	**Reference**
Solanum torvum	North Carolina	Thurston, 1976
Solanum melongena var insanum	India	Gopimany and George, 1979
Solanum toxicarium	Japan	Mochizuki and Yamakawa,

		1979
Solanum mammosum, Solanum rarense, Solanum aculeatissimum, Solanum torvum and Solanum juropeda	Lesser Antilles	Nowell, 1923
Solanum integrifolium, Solanum indicum, Solanum macrocarpon and Solanum sisymbrifolium	India	Sheela *et al.*, 1984
Solanum aethiopicum, Solanum incanum, Solanum nigrum, Solanum torvum, Solanum viarum and Solanum warscewiezii	Guadeloupe	Hebert, 1985
Solanum melongena var insanum, Solanum torvum, Solanum xanthocarpum, Solanum nigrum and *Solanum integrifolium*	India	Seshadri and Srivastava, 2002
Solanum integrifolium	India	Kalloo and Bergh, 1993
Solanum torvum	India	Bagnaresi *et al.*, 2013, : Ramesh *et al.*, 2016
Solanum torvum	Indonesia	Gousset *et al.*, 2005
Solanum torvum, Solanum khasianum and *Solanum torvum* × Pusa Shyamala	India	Kumar *et al.*, 2017

2.3.2.2. Brinjal germplasm/Varieties/ hybrids resistant to bacterial wilt

Resistant varieties	**Reference**
Ceylon and West Coast Green Round	Gowda *et al.*, 1990
Annamalai, Pusa Purple Cluster, JC 1 and JC 2	Deka *et al.*, 1992
BWR 34, Pusa Purple Cluster, Yein and Rathaiah	Bora *et al.*, 1993
BB 7 and BWR 12	Gill *et al.*, 1991
BB 11 and BB7	Sharma and Kumar, 1995
SM 6, KT 4 and Punjab Barasati	Sinha *et al.*, 1992

Arka Keshav, Arka Nidhi, Arka Neelkanta, BB 1, BB 44, BB 49, EP 143 and Surya	Ponnuswamy, 1997
Arka Keshav and Arka Neelakanta	Pathania *et al.*, 1996
CH 243, CH 245, CH 247, CH 249 and CH 309	Sharma *et al.*, 1995
BB 1 and BB 11	Mishra *et al.*, 1994
Surya, Shweta, Annapurna, BB7, BB 13-1, BB 44 and Arka Keshav	Singh and Gopalakrishnan, 1998
West Coast Green Round (WCGR), SM6, WCGR × Taiwan,WCGR × Ceylon and SM 6 × Taiwan Naga	Saraswathi and Shivashankar, 1998
Kopek, Black Beauty, SM-81, SM-6, SM 6-1, SM 6-1-M, Sm 6-7 SP, Pusa Purple Cluster, ARU 2C, MS-48, SM-56, SM-71, SM-72, Sm-74, H-8, IIHR 110, IIHR 121, IIHR 181-3 and IIHR 85	Seshadri and Srivastava, 2002
BB 11 and BB 7	Sarath Babu *et al.*, 1998
BWR-54 and Pusa Purple Cluster	Singh, 1991
Arka Keshav Sm 6-6 and IIHr-124	Sadashiva *et al.*, 2001a
EG 191, TS-3, EG 190, EG 192, EG 193, EG 203, EG 219, TS-7 AND TS-69	Sadashiva *et al.*, 2001b
Surya, Swetha and Sm 141	Sally *et al.*, 1997
Arka Kesav, Arka Neelkanth, Arka Nidhi and SM 6-6	Chaudhary and Sharma, 2000
BL-156, LG long II, S00-141 and Arka Nidhi	Rashid *et al.*, 2002
EG 203	Hussain *et al.*, 2005
Utsav	Bora *et al.*, 2011
BCB-14 and BCB-30	Mondal *et al.*, 2011
Nayantara, Singhnath, Dhundul, Kazla, Marich Begun, Luffa, Kata Begun and Uttara.	Rahman *et al.*, 2011
Midnapore Local and Bhangar	Mondal *et al.*, 2013
Arka Keshav, Surya, Arka Neelkanth and Arka Nidhi	Gopalakrinshnan and Reddy, 2014
Arka Neelkanth	Pavithra *et al.*, 2014

Swarna Pratibha, Hissar Shyamal, Pusa Purple Cluster, Arka Keshav, Bhola Nath, Singh Nath, Arka Nidhi, BB- 54, SM 6-6, SM 6-7, BRBWRES-10, BRBWRES-9, BRBWRES-8, BRBWRES-7, BRBWRES-5, BRBWRES-2, BB-54 and DPBBWR-2, BRBWRES-6, BRBWRES-4, BRBWRES-3 and BRBWRES-1	Jhangta, 2015
Arka Nidhi, BEBWRES-05, BEBWRES-2, BEBWRES- 4 and SM 6-6 (C)	Kumar *et al.*, 2014
IC-261786 and IC-261793	Bhavana and Singh, 2016
Luffa-s	Rahman *et al.*, 2011
Arka Keshav, Surya, Arka Neelkanth and Arka Nidhi	Sadarunnisa*et al.*, 2018
VI045276	Rana *et al.*, 2015
HAB-901	Bhavana *et al.*, 2016
Brinjal Purple Long, Brinjal Purple Round, Brinjal Green Round, Haritha and Ujjwala	Narayanankutty *et al.*, 2018

2.4. Field evaluation of grafts

2.4.1. Grafting in vegetables

Grafting is an ancient art and science that was adapted to herbaceous vegetables in Japan and Korea in the early 1900's (Munge *et al.*, 2009). Grafting is an art and technique in which two living parts of two different plants *i.e.*, rootstock and scion are joined together in such a manner that they would unite together and subsequently grow into a composite plant. Rootstock is the lower working part of the plant which interacts with soil to nourish the new plant. Scion is a detached upper part of a plant shoot joined to the rootstock in grafting. Grafting utilises valuable traits from a desirable rootstock variety such as vigour, increased yield, improved fruit quality and tolerance and resistance to both biotic and abiotic stresses (environmental stress). Grafting has been

widely adapted to polyhouse cultivation systems where plants are intensively cultivated to produce high yields on highly vigorous rootstocks (Munge *et al.*, 2009).

The common methods used for grafting in vegetables are cleft grafting (tomato, brinjal, chilli and capsicum), tongue approach grafting (melon and cucumber), hole insertion/top insertion grafting (water melon), one cotyledon/slant/splice grafting (water melon), splice/tube grafting (tomato, brinjal, chilli and capsicum), micro grafting (tomato) and pin grafting (Kumar *et al.*, 2018). Rivard and Louws, (2008) reported that highest grafting survival rates of 98 per cent was obtained by using humidity chambers for healing grafted plants.

Grafting in vegetables has emerged as a promising and alternative tool to the relatively long and slow conventional breeding methods aimed at increasing tolerance to biotic and abiotic stresses (Kumar and Sanket, 2017).

2.4.2. Management of bacterial wilt through grafting

Louws, *et al.* (2010) reported complete control of bacterial wilt was observed in tomato grafted on selected rootstocks. Cent percent control of bacterial wilt and better yield in grafted tomato, chilli and capsicum hybrids were reported by Narayanankutty *et al.* (2015). Ramesh *et al.* (2016) grafted brinjal seedlings of the cultivated local brinjal types, Agassaim, Taleigao and other lines from a segregated population on a wild genotype, *S. torvum*. Field evaluation of the grafts indicated the complete protection from bacterial wilt whereas the non-grafted seedlings recorded 60 to 74 per cent wilt incidence. Grafted plants yielded fruits similar to that of the seedling indicating its acceptability among the growers and consumers. Grafting susceptible tomato cultivars onto resistant tomato or other Solanaceous rootstocks has resulted in reduced incidence of bacterial wilt against Asian strains of *R. solanacearum* (Saddler, 2005).

Grafted plants on resistant rootstocks of Solanaceous vegetables were highly resistant to bacterial wilt and high yielding (Narayanankutty *et al.*, 2015). McAvoy *et al.* (2012) evaluated seven hybrid tomato rootstocks with resistance to bacterial wilt along with a known resistant cultivar as a rootstock to impart resistance to a bacterial wilt-susceptible cultivar, BHN 602. Polyhouse studies showed resistance to bacterial wilt in all the rootstocks and the grafting technology holds promise for decreasing the

incidence and impact of bacterial wilt on tomato cultivars as well as increased the overall productivity of tomato cultivars.

Rana *et al.* (2015) evaluated five rootstocks of capsicum and three rootstocks of brinjal for bacterial wilt resistance in bell pepper under greenhouse. They reported chilli rootstock PI-201232 as the most suitable bacterial wilt resistant rootstock for capsicum whereas brinjal rootstocks were not suitable for bell pepper scions. Lin *et al.* (1998) grafted two popular local tomato cultivars, Farmers 301 (susceptible to bacterial wilt) and Taichung ASVEG No. 4 (moderately resistant to bacterial wilt) onto 12 reportedly bacterial wilt resistant rootstocks including six tomatoes and six eggplants. Eggplant accession VI045276 (0% to 3% wilt incidence) and tomato accession VI043614 (0% to 23% wilt incidence) were the most stable rootstocks among the 12 tested, compared with heavy incidence in other susceptible rootstocks. The effect of scion was significant in all the trials with less incidence of wilting when a moderately resistant cultivar was used as the scion.

Kumar *et al.* (2017) screened four *Solanum* species (*S. torvum, S. khasianum, S. surathense and S. xanthocarpum)* and two varieties of eggplant (Pusa Shyamala and Pusa Hybrid-6) against bacterial wilt, the result showed that among all *Solanum* species and varieties tested, *S. torvum* and *S. khasianum* were found resistant. The highest graft compatibility was observed in plants grafted onto *Solanum torvum* followed by *Solanum surathense*. The highest bacterial wilt incidence was reported in non-grafted control plants (71.35%) followed by *Solanum surathense* on Pusa Shyamala (58.525%). The lowest infection rate was recorded in *Solanum torvum* on Pusa Shyamala (12.22%). *S. torvum* and *S. khasianum* were found to be superior based on mean performance of the grafted plants and they can be used for resistance against bacterial wilt.

Gousset *et al.* (2005) evaluated twenty -nine accessions of *S. torvum* and eggplant, cv Pusa Purple Long for resistance to *R. solanacearum* (race 1 biovar 3, strain T926) in greenhouse cultivation. The result showed that all inoculated plants of eggplant died within two weeks and all the accessions of *S. torvum* were highly tolerant to bacterial wilt. Bhavana *et al.* (2016) found that HAB-901as a highly resistant cultivar to bacterial wilt among the nine genotypes of brinjal (Swarna Sree, Swarna Shobha,

Swarna Mani, Swarna Pratibha, Swarna Shyamali, HAB-381, HAB-792, HAB-900 and HAB-901) tested.

2.4.3. Grafting to overcome other biotic stresses

In cucurbits grafting is widely practiced to control the soil borne fungal pathogens *Fusarium* and Verticillium, the rootstocks for cucurbits include bottle gourd and *Cucurbita moschata* × *C. maxima* hybrids both of which are highly resistant to the *Fusarium oxysporum* which causes severe losses to crop (King *et al.,* 2008). In grafted watermelon cultivar 'Crimson Sweet' *Verticillium* colonization was checked, possibly due to the grafting defence mechanism (King, *et al.* (2008). Verticillium wilt tolerant rootstocks postponed wilt symptoms till watermelon fruits reached maturity (Paplomates *et al.,* 2000). The 'Shintoza' rootstock increased fruit size compared to the non-grafted plants and improved yield stability. The rootstock had no effect on the soluble solids concentration of the central endocarp. Use of resistant viable rootstock is a alternative to soil fumigation by methyl bromide for the control of *Fusarium* wilt in watermelon production, as it is cheaper and safer, and the yields are higher and more reliable (Miguel *et al.*, 2004).

Vitale *et al.* (2014) studied the effect of different tomato scion-rootstock combinations on the susceptibility of plants to *Fusarium oxysporum f. sp. radicis-lycopersici (FORL),* the causal agent of crown and root rot. The extent of vascular discoloration caused by FORL in tomato plants grafted on "Natalia" (0.12-0.37 cm) was significantly lower than that of plants grafted on sensitive "Cuore di Bue" (1.75-6.50 cm). Shoot fresh weight of inoculated "Costoluto Genovese"/"Cuore di Bue" combination was decreased by 39%, whereas that of "Costoluto Genovese"/"Natalia" to that of 11%, when compared to control plants. Proteomic studies showed a higher representation of proteins associated with pathogen infection in the tolerant rootstocks, compared to the sensitive one, showing a direct involvement of plant defence mechanism in the crop response to the pathogen challenge.

Thies and Levis (2007) reported that watermelon plants grafted onto wild watermelon rootstocks (*C. lanatus* var. *citroides*), were resistant or moderately resistant to the nematode, *M. incognita*. Pumpkin (*C. moschata)* is a potential rootstock used for cucurbits, having a high intensity of tolerance to root knot nematode (Siguenza, *et al.,*

2005). Thies *et al.* (2010) evaluated a four bottle gourd (*Lagenaria siceraria*) cultivars, one squash (*Cucurbita moschata* × *C. maxima*) hybrid, five wild watermelons (*Citrullus lanatus* var. *citroides*) germplasm lines, and one commercial wild watermelon (*C. lanatus* var. *citroides*) cultivar as rootstocks for cultivated watermelon (*C. lanatus* var. *lanatus*) in fields infested with the southern root-knot nematode (*Meloidogyne incognita*). The result showed that plants grafted onto *C. lanatus* var. *citroides* rootstocks exhibited significantly less root galls than plants with the bottle gourd and squash hybrid rootstocks. The fibrous root production by *C. lanatus* var. *citroides* accessions and breeding lines were associated to resistance to nematodes.

2.4.4. Grafting to overcome abiotic stresses

Fruit weight of grafted tomato F_1 hybrid increased significantly than non-grafted plants under salinity (Koleska *et al.*, 2018). Grafted cucumber showed increased taste, flavour and nutrient contents compared to non-grafted control plants (Zhou *et al.*, 2007). Goreta, *et al.* (2008) reported watermelon cv. Fantasy grafted onto Strongtosa rootstock (*C. maxima Duch* × *C. moschata Duch*) increased the shoot weight and leaf area even under saline conditions. Watermelons grafted onto saline-tolerant rootstocks produced higher yield under greenhouse production (Colla *et al.*, 2010). Estan *et al.* (2009) grafted the Boludo variety of tomato on salt tolerant line *S. pimpinellifolium* and *S. cheesmaniae* crossed with the salt-sensitive *S. lycopersicum var. cerasiformae*. The result showed that grafting improved the productivity, particularly with respect to number of fruits per plant under saline conditions. Ahmad and Prasad, (2011) reported higher level of antioxidants in grafted plants than normal plants which prevented the negative effect of ROS (Reactive Oxygen Species).

Rengel *et al.* (2016) reported that aluminium concentration in the range of 1–2 mgL^{-1} inhibited the root elongation by damaging the cell structure of the root apex and reduced water and nutrient uptake. Studies conducted in acidic soils revealed that cucumber plants grafted on pumpkin rootstock exhibited lower yield reduction when compared to plants grafted on fig leaf gourd and non- grafted control (Rouphael *et al.*, 2016).

A survey conducted in Japan showed that 7% of eggplant fruits contain high cadmium than the internationally acceptable limit. (Takeda *et al.*, 2007). Heavy metal

stress causes oxidative damage to plant through ROS formation and excess Zn alter mitotic activity, affect permeability and membrane integrity. Rootstocks have ability to limits the heavy metal accumulation in aerial parts of plant (Kusvuran *et al.*, 2016). Heavy metals like cadmium restricts the photosynthesis, nitrogen metabolism, water transport, phosphorylation in mitochondria and chlorophyll content (Suvas *et al.*, 2010). It negatively affects plant growth and alters the uptake of minerals from the soil. Grafted plants were found to reduce the translocation of cadmium from plant roots to shoot and fruits (Arao *et al.*, 2008).

Grafting on a low-temperature tolerant rootstock (*e.g. Solanum habrochaites)* appeared to be a useful tool in tomato to increase shoot growth at suboptimal cultivation temperatures due to stimulation of leaf expansion rate (Venema *et al.*, 2008). High temperature induces the accumulation of phenolics in tomato plants by activating their biosynthesis as well as inhibiting their oxidation. The concentration of total phenol was higher in non-grafted than in grafted tomato plants. Grafted plants showed no massive accumulation of phenolic compounds, this being directly reflected in greater biomass production and better development than non-grafted plants (Rivero *et al.*, 2003). Eggplants (*S. melongena* cv. Yuanqie) grafted onto a heat-tolerant rootstock (cv. Nianmaoquie) resulted in a prolonged growth phase and the total yield increased up to 10% (Wang et al., 2007). Abdelmageed *et al.* (2004) grafted heat tolerant tomato cultivars 'Summer Set' and 'Black Beauty' onto less heat tolerant cultivar UC-82-B under high temperature condition consisting of two different temperature regimes $38/27^0$C and $30/22^0$C to know electrolyte leakages. The result showed that UC-82-B grafted onto Black Beauty showed lowest electrolyte leakage under both temperature regimes.

Watermelon plants grafted onto pumpkins and grown in high pH soil had a higher exudation of organic acids by roots, consequently facilitating the uptake of nutrients (Colla *et al.*, 2010). Mohsenian *et al.*, (2012) studied the effect of a number of rootstock species *viz.* eggplant (*Solanum melongena*), datura (*Datura patula*), orange nightshade (*Solanum luteum*), tobacco (*Nicotiana tabacum*) and tomato (*S. lycopersicon*) grafted onto tomato cv. Cal.jn3. The result showed that among all the species evaluated datura rootstock showed alkalinity tolerance as measured by lower leaf area, plant dry weight and shoot Fe content, sodium bicarbonate concentrations

compared to non-grafted controls. Tolerance was achieved by a better translocation of iron from the roots to the shoots in the grafted plants.

Tomato can be successfully grafted over waterlogging tolerant brinjal rootstocks and the crop should be saved from waterlogging stress upto 7 days in early growth stage (Singh *et al.,* 2017). Ethylene helped in the formation of adventitious roots at the sub-surface region of plant and which in turn helped the plants to absorb oxygen from air and enhanced nutrient assimilation (Schwarz *et al.*, 2010). Accumulated ethylene in sub-merged parts of plants stimulated the formation of aerenchymatous tissues, which favours the longitudinal transport of oxygen from aerial parts to the submerged parts of plants under anoxia condition (Roy and Basu, 2009).

Sanchez-Rodriguez *et al.* (2012) grafted two tomato cultivars Zarina (drought tolerant) and Josefina (drought sensitive) onto themselves and reciprocally. The results showed that the Zarina rootstock resulted in a larger number of fruits per plant, higher level of sugars as well as important minerals (K and Mg), which increased tomato nutritional quality under drought stress conditions. Rana Munns, (2011) reported that plants started osmotic adjustment by active accumulation of solutes within plant tissue in response to lowering of soil water potential and maintain the turgor of cell and leaf water potential (lwp) under water stress condition

2.4.5. Performance of grafted plants

Major vegetative and yield characters studied in brinjal are plant height, plant spread, stem girth, number of primary branches, total marketable and non-marketable yield, number of harvests, number of fruits per plant, fruit length, fruit girth, fruit circumference, root length, root spread and root dry matter. Studies conducted in the various parts of the country have recorded wide variations among the genotypes for morphological characters. Studies on evaluation of grafted genotypes for their vegetative growth and its relation to yield are reviewed here

Gisbert *et al.* (2011) studied the effect of grafting on growth, yield and quality parameters of eggplant (*Solanum melongena*) cultivar Black Beauty grafted on interspecific hybrid rootstocks developed from crosses of *S. melongena* with *Solanum incanum* L. (SI×SM) and *Solanum aethiopicum* L. (SM×SA). The results showed that

Black Beauty cultivar grafted on SI × SM are significantly taller (127cm) than non-grafted (114.5cm) and self-grafted (119.7cm) and gave the highest vigour to the scion, which resulted in the highest values for fruit earliness and early total yield. Phenolic content was higher in fruits from plants grafted onto SM × SA rootstock.

Moncada *et al.* (2013) reported that grafting of eggplant cultivars onto *Solanum torvum* rootstock significantly increased the size of the fruits and average marketable fruit weight but reduced the lightness and the saturation of fruit colour and total phenolic content compared to non-grafted control plants.

Bletos (2003) investigated the effect of grafting on growth and yield of brinjal (*Solanum melongena* L.) seedlings (Tsakoniki) grafted on *Solanum torvum* (GST) and *Solanum sisymbrifolium* (GSS). The results showed that grafted plants were more vigorous, as measured by the main stem diameter, root system weight and plant height than non-grafted control 'Tsakoniki'. Grafting resulted in higher early early production (GST, 45.5 per cent; GSS, 18.4 per cent) and late production (GST, 69.3 per cent; GSS, 59.2 per cent) as compared to non-infected controls.

Kumar (2015) studied the effect of grafting on different parameters of brinjal such as survival rate of grated plants, plant height, number of leaves at 60 days after grafting, number of fruits per plant, fruit length, diameter of fruit, circumference of fruit, weight of individual fruit, weight of fruit per plant, total yield, root length, fresh weight and dry weight of roots, biochemical parameters like total soluble solids and glyco-alkaloids in fruits and percentage bacterial wilt infection. The results showed that grafted plants of eggplant on *Solanum torvum* and *Solanum Khasianum* exhibited significant differences for all characters except total soluble solids compared to non-grafted control.

Kumar (2016) investigated the impact of grafting on chilli and brinjal rootstocks for growth, yield and quality of capsicum under protected conditions. The results showed that chilli rootstock PI-201232 was the most suitable rootstock for bell pepper. They also studied the impact of combination of different grafting methods with chilli and brinjal rootstocks. The results showed that combination of chilli rootstock PI-201232 with tongue approach grafting resulted in minimum days to first flowering (47.33), minimum days to first harvest (72.00) and maximum number of fruits per plant

(27.80) and combination of chilli rootstock AVPP0205 with cleft grafting recorded higher average fruit weight (105.05 g), higher marketable fruit yield per plant (2.80 kg) and maximum fruit length (8.66 cm) and combination of chilli rootstock PI-201232 with tube grafting recorded highest capsaicin content (0.65%) than brinjal rootstocks.

Khah (2011) studied the effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L.) in greenhouse and open-field. Seedlings of eggplant (*Solanum melongena* L.) cv. 'Rima' were grafted on two tomato hybrids 'Heman' (*Lycopersicon hirsutm*) and 'Primavera' (*Lycopersicon esculentum*). Non-grafted and grafted plants were grown in the greenhouse and in the open-field. The results showed that plants grafted onto Heman (RH) produced 53% more fruits in the polyhouse and 60% in open field than non-grafted (R) control plants. Yield of the non-grafted plants was found similar to plants grafted on Primavera (RP) rootstock. Aubergine plants grafted on RH and RP rootstocks were more vigorous than non-grafted (control), as indicated by their plant height, main stem and leaf weight. This resulted in early harvest with less number of seeds per fruit than control, indicating better fruit quality.

Alexopoulos *et al.* (2007) studied the fruit yield and quality of watermelon in relation to grafting. Watermelon cv. Crimson Sweet was grafted onto four rootstocks (Early Max, Long gourd, F-14 gourd and Max-2). The study revealed that grafting significantly increased rind thickness, fruit size and total fruit yield but slightly lowered total soluble solids (TSS) content than non-grafted control. Sakata *et al.* (2007) found that, watermelon grafted onto bottle gourd stimulates early female flower production compared with other rootstocks and non-grafted. Yamasaki *et al.* (1994) reported that flowering is delayed in pumpkin, ash gourd, bottle gourd and watermelon when grafted on watermelon, especially in plants with 'Shintozwa' type of rootstocks.

Davis and Perkins-Veazie (2005) found that watermelon grafted on pumpkin and squash rootstocks increased lycopene content, firmness, total carotenoids, amino acids, especially citrulline when compared to non-grafted control. Ioannou, *et al.* (2002) found that grafted plants were taller and more vigorous than self-rooted ones and had a larger central stem diameter. Reid and klotzbach grafted brinjal plants yielded more than non-grafted ones.

Alan *et al.* (2007) studied the effect of different rootstocks on watermelon plant growth, fruit yield and quality by comparing non-grafted control and grafted plants under low tunnel for early production and later open field conditions. The watermelon cultivar Crispy was grafted onto TZ-148, RS-841and hybrids of *C. maxima* × *C. moschata*. Grafting significantly affected plant growth and yield by increased stem diameter, root dry weight and more number of lateral vines without any harmful effects on fruit quality than non-grafted plants. Turhan, *et al.* (2011) reported that grafting in tomato significantly increased fruit index (diameter/length), number of fruits/truss and fruit weight when tomato cultivars were grafted on beaufort and Arnold rootstocks. Eltyab *et al.* (2013) reported that grafting of brinjal and chilli onto tomato seedlings had a positive effect on morphological change on leaves and flowers of both plants. Bekhradi *et al.* (2011) reported significant increase in stem length, number of lateral branches, number of internodes, fresh and dry weights of stem and leaves in watermelon cv. 'Charleston Gray' grafted onto three cucurbits rootstocks (*Cucurbita pepo*, *Lagenaria siceraria* and *Cucurbita maxima* x *C. moshata*) compared to non-grafted control plants. Passam *et al.* (2005) found that brinjal cv. Delica grafted onto tomato rootstock grew better and produced higher yield than non-grafted and self-grafted.

Curuk *et al.* (2009) reported that grafting resulted in a significant reduction (9%) in average oxalic acid content in cultivars of brinjal (Faselis and Pala). In contrast grafting of *Solanum melongena* on *Solunum torvum* and *Solanum Sisymbriifolium* negatively affected ascorbic acid content, firmness and some sensory attributes but overall performance was not influenced (Arvanitoyannis *et al.,* 2005). Graft incompatibility induced undergrowth and/or overgrowth of the scion, leading to decreased water and nutrient flow through the graft union, ultimately causing wilting (Davis *et al.,* 2008). Pogonyi *et al.* (2005) reported that fruit yield of tomato was significantly higher on grafted plants than on non-grafted plants indicated by increased fruit number (14%) and fruit weight (45%).Increased yield in tomato due to grafting has also been reported by Marsic and Osvald, 2004; Pogonyi *et al.,* 2005; Khah *et al.,* 2006 and Kleinhenz *et al.,*2009.

Sabatino *et al.* (2016) grafted four Sicilian eggplant landraces onto *Solanum torvum* to study the effect of grafting on agronomical, yield and qualitative characteristics of brinjal. Grafting significantly increased total fruit production,

marketable fruit production and number of marketable fruits of eggplant regardless of landraces tested compared to non-grafted plants. Landrace 2 (Sciacca) grafted onto *S. torvum* not only produced higher yield than non-grafted plants, but also exhibited a higher phenolic antioxidant content and Landrace 4 (Sicilia) exhibited significant increase in antioxidant content of fruit than non-grafted plants.

Marsic *et al.* (2014) studied the influence grafting eggplant on tomato rootstock (Beaufort F_1). Three commercial cultivars (Blackbell F_1, Epic F_1 and Galine F_1) and one landrace (Domaci srednje dolgi) were used as scions. The result showed that grafting significantly improved total marketable yield, total number of fruits/plant, average fruit weight and decreased the presence of calyx prickles compared to self-grafted and non-grafted plants. Major phenolic constituents in grafted brinjal fruit was unreliable: less solar radiation and lower mean daily air temperatures in a year reduced phenolic content in commercial variety and landrace compared to non-grafted and vice-versa.

Kumar *et al.* (2017) studied the effect of grafting tomato onto various eggplant and tomato rootstocks under Green house in mid hills of NW Himalayan region. The popular cultivar Avtar was grafted onto seven rootstocks such as Hawaii 7996 (Tomato), Hawaii 7998 (Tomato), Palam Pink (Tomato), Palam Pride (Tomato), VI047335 (Brinjal), VI034845 (Brinjal) and VI45276 (Brinjal). Grafting significantly affected the yield as well as quality of the tomato and among all the rootstocks used, brinjal rootstock VI034845 exhibited maximum plant height (205.66 cm), fruit yield (2.14kg), number of fruits (35.66), highest ascorbic acid (31.25 mg/100gf), TSS (6.23% and pericarp thickness (4.16mm) compared to self-grafted and non-grafted control plants.

Sabatino *et al.* (2018) studied the effect of grafting on vigour, yield and overall fruit quality traits when hybrids and allied species were used as a rootstock for eggplant. Rootstocks such as *S. torvum, S. macrocarpon S. aethiopicum*, *S. paniculatum* and *S. indicum* were grafted on popular eggplant F_1 hybrid Birgah. Among all the rootstocks *S. paniculatum* exhibited higher vigour and yield without effecting fruit quality traits and overall fruit composition compared to non-grafted plants.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1. Experimental site

The present investigation on "Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)" was conducted in Agricultural Research Station, Mannuthy and Centre for Hi-Tech Horticulture and Precision farming, Vellanikkara, Thrissur during the year 2018-2019. The experimental site was situated at $76^0$10'E longitude and $10^0$32'N latitude (ARS, Mannuthy) and $76^0$26' E longitude and $10^0$54'N latitude (CHT-Vellanikkara) at an altitude of 22.5 m above MSL. The site selected was a bacterial wilt sick plot with facilities for mulching, drip irrigation and fertigation.

The experimental area is bestowed with tropical humid climate and during the experimental season the area received an average rainfall of 1760 mm. meteorological observations *viz.,* temperature, sunshine, rainfall and relative humidity are furnished in APPENDIX I.

3.2. Treatments (Genotypes)

Ten available rootstocks comprising of two local collections of *Solanum torvum* (2 collections-a local collection and a collection from TNAU), *Solanum sisymbrifolium* (one collection) and *Solanum melongena* (7 Collections-Surya, Haritha, SM1, SM2, SM3, SM116 and SM398) were used for the study. The details of the genotypes used for the study are given in Table 1.

The investigations were carried out in three experiments *viz.,*

1. Field evaluation of rootstocks

2. Artificial inoculation

3. Field evaluation of grafts

Table 1. List of genotypes and their sources

Genotypes	Name of the genotype	Specification	Sources
1	Surya	Released variety	Agricultural Research Station, Mannuthy, Kerala
2	Haritha	Released variety	Agricultural Research Station, Mannuthy, Kerala
3	SM 1 (Brinjal Local Purple Round)	Local variety	Agricultural Research Station, Mannuthy, Kerala
4	SM 2 (Brinjal Local Purple Long)	Local variety	Agricultural Research Station, Mannuthy, Kerala
5	SM 3 (Brinjal Local Green Round)	Local variety	Agricultural Research Station, Mannuthy, Kerala
6	SM 116	Local collection	Agricultural Research Station, Mannuthy, Kerala
7	SM 398 (Vengeri Local)	Local variety	Department of Vegetable Science, COH, Vellanikkara, Kerala
8	*Solanum torvum* KAU1	*Solanum* species	Agricultural Research Station, Mannuthy, Kerala
9	*Solanum torvum* TNAU 1	*Solanum* species	TNAU, Tamil Nadu
10	*Solanum sisymbrifolium*	*Solanum* species	Regional Station, NBPGR, Vellanikkara, Kerala

3.3. Field evaluation of rootstocks

The work was carried out during September 2018 to December 2018. For the experiment ten available rootstocks were grown in a wilt sick field. The susceptible tomato variety Pusa Ruby was spot planted along with all the genotypes raised in wilt sick field Bacterial load in the field was estimated by serial dilution and plating technique. General view of the experiment was illustrated in Plate 1 and layout of experiment in Figure 1.

Design - RBD

Treatments - Ten rootstocks spot planted with Pusa Ruby

No. of replications - 3

Spacing - 75 × 60 cm

Plot size - 3 × 2.4 m

Observations were on number of days to bacterial wilt incidence and percentage of bacterial wilt incidence.

For evaluation of reaction of rootstocks to bacterial wilt disease, daily field inspection was carried out to identify the wilt affected plants and number of plants wilted due to bacterial wilt was recorded after confirming through ooze test. The bacteria were isolated on TTZ (2, 3, 5, Triphenyl Tetrazolium Chloride) medium and identified as *Ralstonia solanacearum* and pathogenicity was established by artificial inoculation and Koch's postulates were proved (Plate 2). The severity of the disease incidence was calculated based on the accumulated observation up to 90 days after transplanting for statistical analysis. Selected genotypes were scored into five categories as per the score chart followed by Sitaramiah *et al.* (1981) (Table 2).

R_1		R_2		R_3
T_1		T_9		T_5
T_2		T_7		T_9
T_3		T_5		T_1
T_4		T_3		T_6
T_5		T_1		T_8
T_6		T_{10}		T_2
T_7		T_8		T_3
T_8		T_6		T_4
T_9		T_4		T_{10}
T_{10}		T_2		T_7

T_1: Surya	**T_6:** SM116
T_2: Haritha	**T_7:** SM398
T_3: SM1	**T_8:** *Solanum sisymbrifolium*
T_4: SM2	**T_9:** *Solanum torvum* KAU1
T_5: SM3	**T_{10}:** *Solanum torvum*TNAU1

Figure 1. Layout of experimental plot for field evaluation of rootstocks

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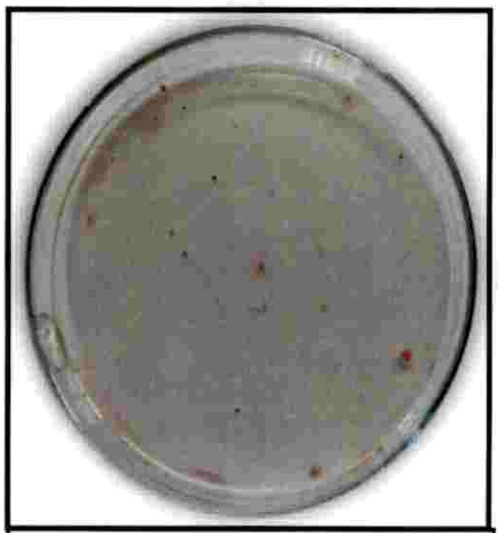
Plate 1. General view of the experimental field for field evaluation of rootstocks

Presence of pathogen by ooze test



Isolated bacteria on TTZ media

Causing disease in healthy seedling

Pathogen re-isolated from diseased seedling

Plate 2. Confirmation of bacterial wilt by Koch's postulates

Table 2. Score chart for bacterial wilt incidence

Reaction	Per cent plants wilting
Immune	0- <1
HR (Highly Resistant)	1-10
MR (Moderately Resistant)	>10-50
MS (Moderately susceptible)	>50-75
HS (Highly susceptible)	>75-100

Observations

The following observations were recorded on field evaluation of rootstocks

3.3.1. Number of days to bacterial wilt incidence (days after planting):

Number of days taken for wilting of any plant due to bacterial wilt after transplanting in the wilt sick field was noted.

3.3.2. Incidence of bacterial wilt:

The number of plants showing the disease incidence was expressed in terms of per cent disease incidence (PDI). The PDI in the plants is calculated by following formula,

$$PDI = \frac{\text{Number of plants wilted}}{\text{Total number of plants}} \times 100$$

3.4. Artificial inoculation

The experiment was conducted during July 2018 to August 2018. Seedlings of the ten genotypes were raised in pro trays filled with sterilized soilless medium

comprising of coco peat + perlite + vermiculite in 3:1:1 ratio and 30 days old seedlings were transplanted to the pots filled with sterilized soilless medium. The pots were kept in a mist chamber (temperature- 28-30^{0}C and relative humidity - 95-100%) (Plate 3). Seedlings of all the genotypes were artificially inoculated with *Ralstonia solanacearum* suspension containing bacterial population at 38 $\times 10^3$ cfu ml^{-1}. Three methods of inoculation *viz.*, media drenching, stem inoculation and root dipping were carried out. For each genotype, five pots were kept as a control without inoculation.

Design	- CRD
Methods of inoculation	- 3
No. of genotypes	- 10
No. of treatments	- 30
No. of pots/treatment	- 5
No. of replications	- 3

3.4.1. Inoculation methods

Different methods used for artificial inoculation of the bacterium are illustrated in Plate 4.

1. **Media drenching:** In this method of inoculation 1 cm of root tip of seedlings were trimmed with sterile scissors before planting in pots and 10ml inoculum was poured into the pots near base of plants after planting (Xian-Gui *et al.*, 2006). One day after planting, the pouring of inoculation was repeated at the rate of 15 ml per pot.

2. **Stem inoculation:** In this method small prick was made on main stem close to the leaf axils by using a syringe. Small piece of cotton was dipped in the bacterial suspension and kept in the leaf axil and the cotton was kept moist by periodically spraying bacterial suspension.

3. **Root dip:** Seedlings were uprooted and root system was thoroughly washed prior to inoculation. Root tips were trimmed with sterile scissors in order to

make a wound and then immediately dipped in 50 ml of bacterial suspension for 2 minutes and planted in pots.

The inoculated plants kept in mist chamber were watered with 20 ml of distilled water when the media was dry. No nutrients were provided to the plants during the study. The plants were monitored daily for a period of 42 days from the date of inoculation (DAI). The wilted plants of each genotypes were collected and bacterial wilt was confirmed through ooze test and isolation of *R. solanacearum* on TTZ medium.

Severity of disease incidence in selected genotypes was scored according to the standard score chart (Sitaramiah *et al.*, 1981) as done in the previous experiment.

Observations

The following observations were recorded on artificial inoculation

3.4.2. Number of days to bacterial wilt incidence (days after planting):

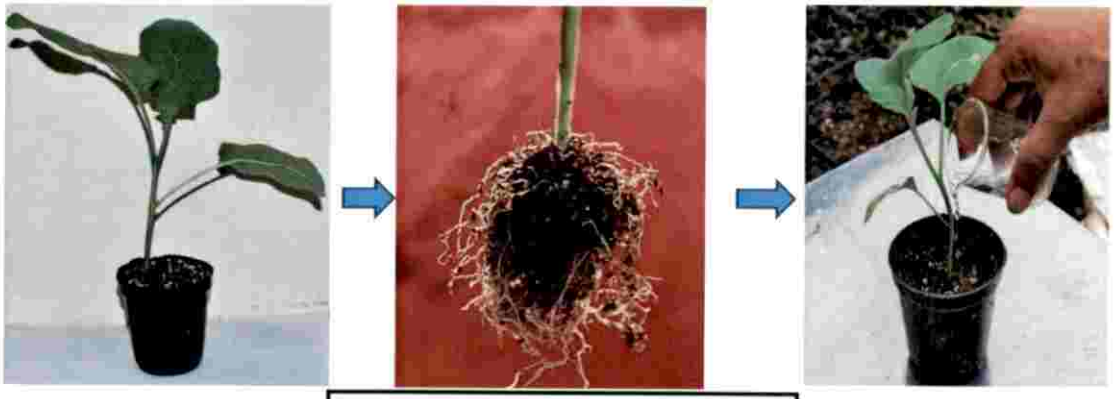
Number of days taken for death of any plant due to bacterial wilt after transplanting in the wilt sick field was noted.

3.4.3. Incidence of bacterial wilt (%):

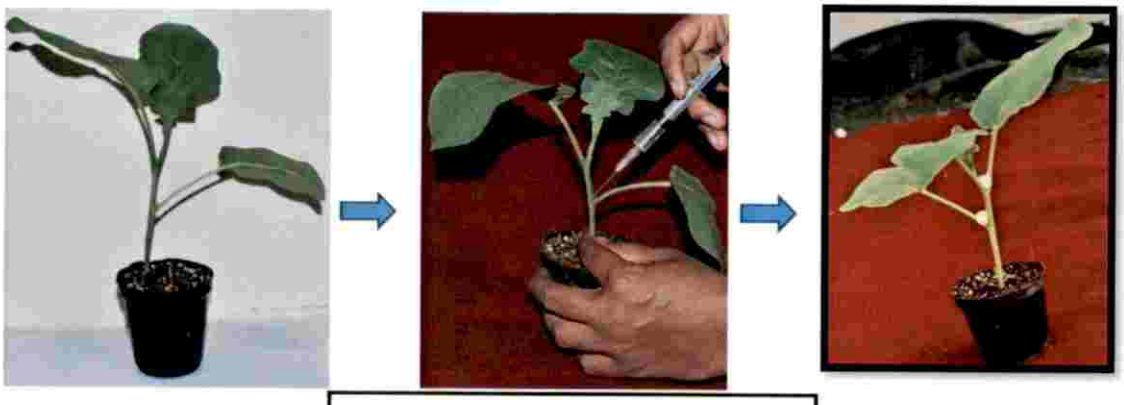
The number of plants showing the disease incidence was expressed in terms of per cent disease incidence (PDI). The PDI in the plants is calculated by following formula,

$$PDI = \frac{\text{Number of plants wilted}}{\text{Total number of plants}} \times 100$$

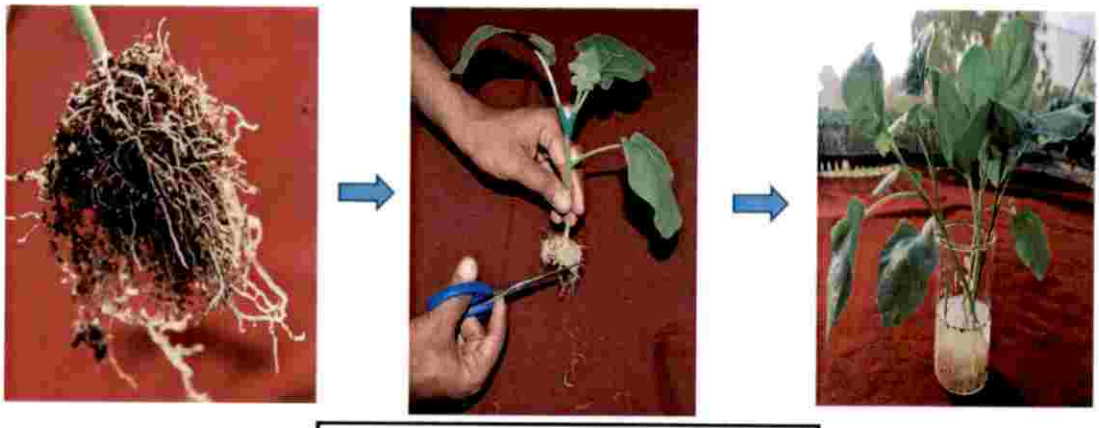
Plate 3. Mist chamber houseing of artificially inoculated plants



Media Drench method



Stem inoculation method



Root dip method

Plate 4. Procedure for artificial inoculation

3.5. Field evaluation of grafts

The work was carried out during January 2019 to May 2019 at the Centre for Hi-tech Horticulture and Precision Farming, Vellanikkara. Rootstocks which showed resistance to bacterial wilt in the field evaluation studies as well as artificial inoculation experiments were selected for the study. Green Long hybrid a commercial popular hybrid (M/S Songro Seeds, West Bengal) was used as a scion material for grafting and grafted plants (Plate 6a and plate 6b) were evaluated in the field following adhoc package of practice under precision farming for yield and quality parameters.

Design - RBD

Treatments - Grafts brinjal hybrid Green Long on 9 resistant rootstocks

No. of replications – 4

Spacing - 75 × 60 cm

Plot size - 3 × 2.4 m

3.5.1. Nursery practices

Seeds of the eggplant genotypes were sown in protrays filled with potting mixture comprising of coco peat, vermiculite and perlite in 3:1:1 ratio. Seedlings were maintained healthy by controlling pest and diseases.

3.5.2. Grafting

Cleft or wedge method of grafting was followed. Staggered date of sowing was followed for sowing the seeds of rootstocks and scion to maintain age. 40 days old rootstocks and 30 days old scion with same stem girth (pencil thickness) were grafted by using wedge method of grafting. In this method of grafting top part of scion plants are cut and removed retaining 3-4 true leaves, base of scion plants are made into the shape of wedge by giving a slant cut from sides. Vertical slit was made in the rootstock and the wedge shaped scion was inserted into the vertical slit made on the rootstock and the joint secured by using a grafting clip. The procedure for grafting is illustrated in Plate 5. Immediately after grafting, the grafted plants were transferred to a mist chamber maintained at a temperature of 28-30^{0}C, 95 - 100% relative humidity for one week for

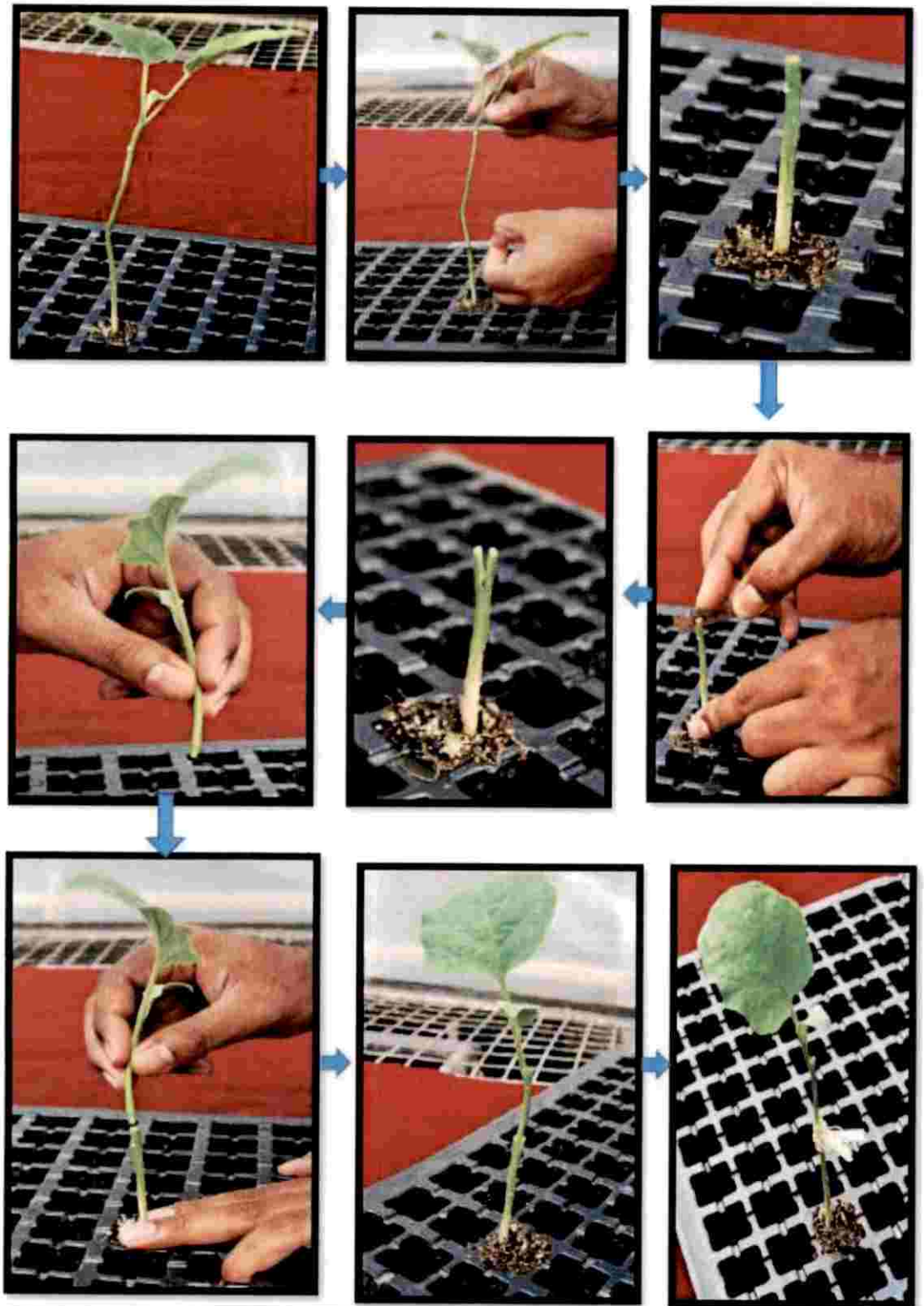


Plate 5. Procedure for wedge/cleft grafting method

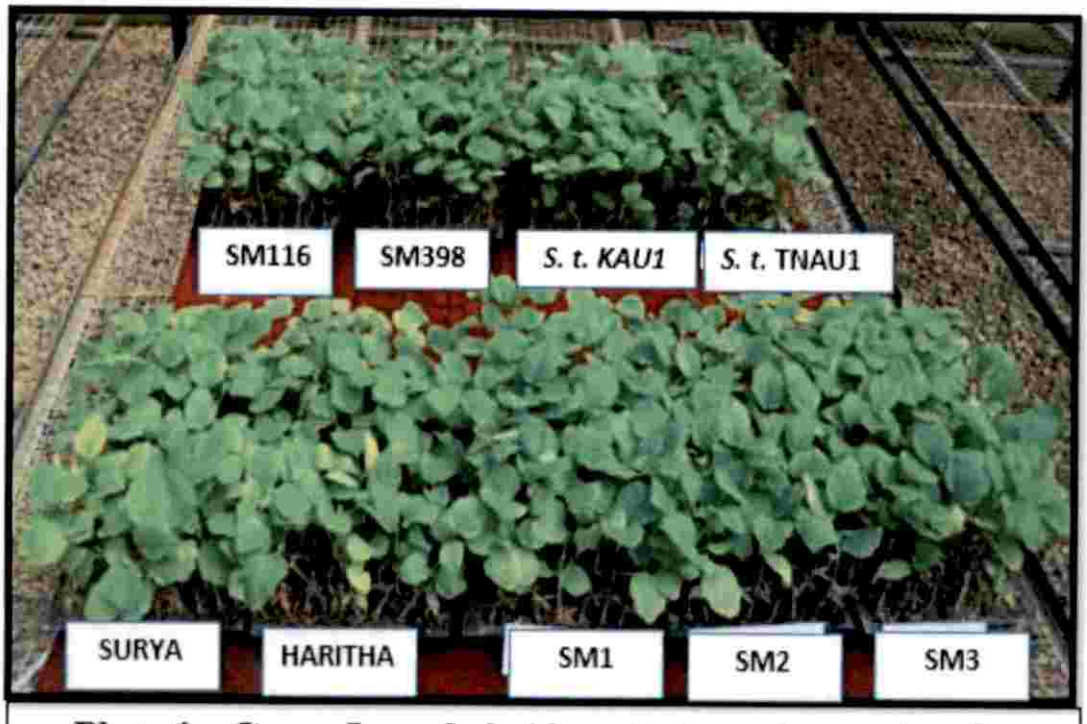


Plate 6a. Green Long hybrid grafted on nine rootstocks

Plate 6b. Grafted seedlings

healing of graft union (Plate 7). After that grafted plants were transferred to acclimatization chamber for hardening. Hardened grafted plants were transplanted to the main field for field evaluation of grafts.

3.5.3. Preparation of main field

The experimental area was cleared and made into beds of size 45 m × 0.9 m × 15 cm. A spacing of 1 m was provided between adjacent beds. The beds were mulched with 30 μ silver black polythene film. Grafted seedlings were transplanted in the well prepared main field at a spacing of 1.0 m × 1.0 m. The field was laid out in Randomized Block Design (RBD) with four replications. There were 20 plants per treatment per replication. The layout of the experimental field is given in Figure 2 and general view of the experimental field was given in the Plate 8.

3.5.4. Application of manures and fertilizers

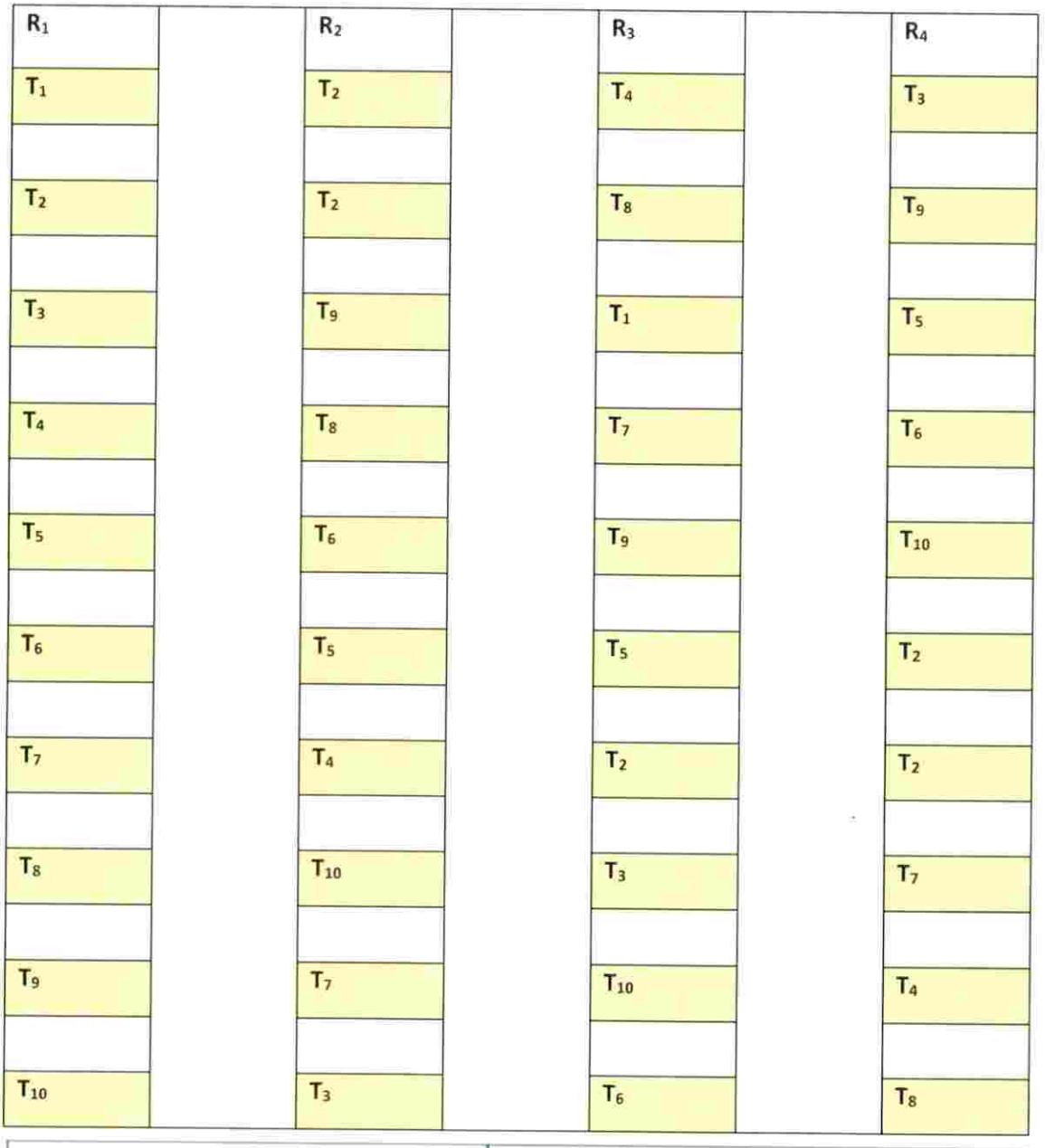
Fertilizer application was done as per the adhoc package of practices for brinjal. For the main field, land was dug and FYM @ 25t/ha was incorporated into the soil. The crop was irrigated through drip irrigation and fertigation was started one week after planting with a dose of 250 g 19:19:19, 157 g 12:16:0, 71 g 13: 0: 45 and 121 g urea per fertigation. Total number of fertigations given were 45 at three days intervals during the entire duration of the crop.

3.5.5. Intercultural operations

Staking of plants was provided to the plants one month after planting. Removal of root suckers (suckers which arrived from below graft union) was done at regular interval to avoid the diversion of nutrients to the water shoots. Weeding the interspaces of experimental plot was done at regular interval to keep the field clean. Plant protection measures were undertaken to control aphids, whiteflies, jassids, thrips, red spider mite and shoot and fruit borer.

3.5.6. Harvesting

Harvesting was done at weekly intervals as and when fruits attained marketable stage. Harvested fruits were used for recording the observations.



T1: Green Long hybrid grafted on Surya

T2: Green Long hybrid grafted on Haritha

T3: Green Long hybrid grafted on SM1

T4: Green Long hybrid grafted on SM2

T5: Green Long hybrid grafted on SM3

T6: Green Long hybrid grafted on SM116

T7: Green Long hybrid grafted on SM398

T8: Green Long hybrid grafted on *S. torvum* KAU1

T9: Green Long hybrid grafted on *S. torvum*. TNAU1

Figure 2. Layout of experimental plot for field evaluation of grafts

Plate 7. Grafted seedlings kept in Mist chamber

Plate 8. General view of the experimental field for field evaluation of grafts

3.5.11. Days to first flowering:

The number of days taken for first flower anthesis in a plant was observed for five individual plants per treatment per replication. The mean number of days to flower opening was calculated.

3.5.12. Number of fruits per plant:

The number of fruits harvested from five plants in each genotype per replication was recorded and mean number of fruits per plant were worked out.

3.5.13. Fruit length (cm):

The fruit length was taken from blossom end to stalk end in each harvest from one randomly selected fruit from a individual plant. Observations were recorded for five individual plants per treatment per replication and the mean fruit length was work out in cm.

3.5.14. Fruit girth (cm):

Girth of the fruit was measured by measuring the circumference of the fruit at the posterior end in each harvest from one randomly selected fruit from a individual plant. Observations were taken for five individual plants per treatment per replication and the mean fruit girth was calculated and expressed in cm.

3.5.15. Average fruit weight (g):

The average fruit weight was calculated for five individual plants per treatment per replication and the mean average fruit weight was worked out in g. Formula used for calculating the average fruit weight was,

$$\text{Average fruit weight} = \frac{\text{Total fruit weight}}{\text{Total number of fruits}}$$

3.5.16. Number of harvests:

Total number of harvests of fruits at edible maturity from the day of first harvest to the last harvest was expressed as number of harvests.

3.5.17. Yield per plant (kg):

The fruit yield obtained from individual plants of each genotype per replication was recorded and mean fruit yield was worked out in kg.

3.5.18. Crop duration (days):

The duration of the crop was being taken from the first day of planting to the final harvest.

3.5.19. Total phenolics (mg/100g):

Estimation of phenols was done according to method suggested by Sadashivam (1991). The sample extract was prepared by grinding 1g sample in pestle and mortar with 10-times the volume of 80% ethanol. Centrifuged the homogenate at 10,000 rpm for 20 min. saved the supernatant and re-extracted the residue with five times the volume of 80% ethanol, again centrifuged and pooled the supernatants. Evaporated the supernatant to dryness in the water bath and dissolved the residue in 5ml of distilled water. Pipetted out different aliquots of standards (0.1- 0.5ml and blank) and sample (0.2 ml) into the test tubes and made the volume in each test tube to 3 ml with distilled water. 0.5 ml of folin-ciocalteau reagent was added and after 3 minutes, 2 ml of 20% sodium carbonate was added to each test tubes. Mixed thoroughly and kept each test tubes in the dark for one hour at room temperature and measured the absorbance at 650nm against a reagent blank by using spectrophotometer. Standard curve was prepared by using different concentrations of catechol. The mean was calculated and expressed in mg/100g.

3.5.20. Dry matter (%):

Dry matter of brinjal fruits was determined by using hot air oven method. 5g of sample was dried in oven at 105 ^{0}C for 2hr, then dried sample was kept in desiccator for 20 min. Weight of dried sample was noted. Again dried sample was kept in oven at 105 ^{0}C for 1hr, then dried sample was kept in desiccator for 20 min. This procedure was

repeated till to get constant weight of dried sample. Mean was worked out and expressed in percent.

3.5.21. Total soluble solids (%):

The total soluble solids was determined by using refractometer (0-32 range). Mean was calculated and expressed in percent.

3.5.22. Number of wilted plants:

The number of wilted plants were recorded as and when they wilt in the experimental plot in each genotype and each replication.

3.5.23. Percent disease incidence:

The number of plants showing the disease incidence was expressed in terms of per cent disease incidence (PDI). The PDI in the plants is calculated by following formula,

$$PDI = \frac{\text{Number of plants wilted}}{\text{Total number of plants}} \times 100$$

3.5.24. Incidence of pest and diseases:

The number of pests and diseases (except bacterial wilt) which attacked the crop were noted and control measures were taken.

3.5.25. Root length and spread (cm):

The root length and root spread of five individual plants per treatment per replication were recorded after last harvest of the crop. Mean was calculated and expressed in cm.

RESULTS

4. RESULTS

The present investigation on "Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)" was conducted at Agricultural Research Station, Mannuthy and Centre for Hi-Tech Horticulture and Precision Farming, Vellanikkara, Thrissur during the year 2018-2019. The site selected was a bacterial wilt sick plot with facilities like mulching, drip irrigation and fertigation. Ten available rootstocks of *Solanum* species comprising of *Solanum torvum* (2 collections-a local collection and a collection from TNAU), *Solanum sisymbrifolium* (one collection) and *Solanum melongena* (7 Collections-Surya, Haritha, SM1, SM2, SM3, SM116 and SM 398) were used for the study. The investigations were carried out in three experiments namely 1. Field evaluation of rootstocks 2. Artificial inoculation and 3. Field evaluation of grafts.

4.1. Field evaluation of rootstocks

In this experiment ten available rootstocks were grown in a wilt sick field. The susceptible tomato variety Pusa Ruby was spot planted along with all the genotypes. Bacterial load in the field was estimated by serial dilution and plating technique before planting. Population of *Ralstonia solanacearum* in the four beds of wilt sick field were 18×10^5 cfu/ml, 19×10^5cfu/ml, 18×10^5 cfu/ml and 20×10^5 cfu/ml respectively. The results of the observations recorded during the study (number of days to bacterial wilt incidence (after planting) and per cent incidence of bacterial wilt (PDI)) are presented in the Table 3 and Table 4.

4.1.1. Number of days to bacterial wilt incidence (days after planting)

Among the ten rootstocks, *Solanum sisymbrifolium* spot planted with Pusa Ruby took minimum number of days to wilt incidence *i.e.* 23.40 days whereas the spot planted Pusa Ruby took24.80 days to wilt. Among the rootstocks SM 398 took maximum days to wilt (32.3 days) followed by SM1(30.3 days), *Solanum torvum* TNAU 1 (29.0 days), SM2 (28.7 days) and *Solanum torvum* KAU1 (26.8 days). Average number of days to bacterial wilt incidence for susceptible check genotype Pusa Ruby was ranged from 18.1 to 24.8 days but in the susceptible rootstocks it ranged from 23.4 to 32.3days. Rootstocks such as Surya, Haritha, SM3 and SM116 did not showed any wilt symptoms till the end of crop duration (90 DAT) (Table 3).

4.1.2. Incidence of bacterial wilt (%)

Susceptible check Pusa Ruby recorded hundred per cent wilt incidence when spot planted with *Solanum sisymbrifolium* and *Solanum torvum* TNAU1 genotypes. *Solanum sisymbrifolium* showed the highest per cent of bacterial wilt incidence (96.6 per cent) among all the genotypes and it was categorised as highly susceptible. SM398 and SM2 genotypes showed 40 per cent wilt incidence whereas SM 1, *Solanum torvum* KAU1 and *Solanum torvum* TNAU 1 exhibited 23.3 per cent, 16.6 per cent and 20 percent wilt incidence respectively and they were categorised as moderately resistant to bacterial wilt (Plate 9). Surya, Haritha, SM3 and SM116 were found highly resistant to bacterial wilt with zero (nil) percent wilt incidence in the spot planting technique. The Percentage Disease Incidence (PDI) in check genotype Pusa Ruby ranged from 86.67 percent to 100 percent (Table 3).

4.2. Artificial inoculation

Performance of various genotypes against bacterial wilt when artificially inoculated by three methods of inoculation *viz.,* media drenching, stem injection and root dipping with the bacterial suspension of *Ralstonia solanacearum* (38×10^3CFU/ml) is presented in the Table 5 and Table 6.

4.2.1. Number of days to bacterial wilt incidence (days after planting)

Significant differences were observed among the genotypes and the various inoculation techniques for number of days to exhibit wilt symptoms and to reach maximum disease incidence. When averages of all the methods were taken, the genotype *Solanum sisymbrifolium* took maximum number of days to wilt (16.81 days) when compared to the susceptible check Pusa Ruby (9.77 days). *Solanum sisymbrifolium* took 26.5 days, 12.25 days and 11.7 days to wilt in media drenching, stem inoculation and root dipping method respectively whereas susceptible check Pusa Ruby took 11.25 days, 10.86 days and 7.2 days to wilt. The root dip method took minimum number of days to wilt (1.71days) compared to media drenching (3.43 days) and stem inoculation method (2.10 days) in all the susceptible genotypes when averages of all the methods were taken (Table 5).

Bacterial wilt in *S. sisymbrifolium*

Bacterial wilt in SM2

Bacterial wilt in SM1

Bacterial wilt in SM398

Plate 9. Bacterial wilt in spot planted genotypes during field evaluation of rootstocks

Table 3. Reactions of different genotypes of brinjal to bacterial wilt under field evaluation in sick plot

Genotypes	**No. of days to bacterial wilt incidence**	**Percentage disease incidence (PDI) (%)**
Surya	0.0 (22.66)	0.0 (93.33)
Haritha	0.0 (20.23)	0.0 (90.00)
SM1	30.3 (20.46)	23.3 (93.33)
SM2	28.7 (18.1)	40.0 (86.66)
SM3	0.0 (20.33)	0.0 (93.33)
SM116	0.0 (20.03)	0.0 (90.00)
SM398	32.3 (22.6)	40.0 (90.00)
Solanum sisymbrifolium	23.4 (24.8)	96.6 (100.0)
Solanum torvum KAU1	26.8 (23.06)	16.6 (96.66)
Solanum torvum TNAU1	29.0 (19.73.0)	20.0 (100.0)
CD (0.05)	**4.93 (N/A)**	**15.64 (N/A)**
S.E(m±)	1.65 (2.26)	5.22 (4.56)

( )- Values in the parenthesis are no. of days to bacterial wilt incidence and Per cent Disease Incidence (PDI) of check variety Pusa Ruby

Table 4. Classification of genotypes based on bacterial wilt incidence as per the score chart given by Sitaramiah *et al.* (1981)

Genotypes	PDI (%)	Reaction
Surya	0.00 (0.70)	Immune
Haritha	0.00 (2.29)	Immune
SM1	23.33 (6.27)	Moderately resistant
SM2	40.00 (0.70)	Moderately resistant
SM3	0.00 (3.26)	Immune
SM116	0.00 (9.16)	Immune
SM398	40.00 (4.20)	Moderately resistant
Solanum sisymbrifolium	96.66 (2.61)	Highly susceptible
Solanum torvum KAU1	16.66 (0.70)	Moderately resistant
Solanum torvum TNAU1	20.00 (0.70)	Moderately resistant
CD (0.05)	15.64	
S.E(m±)	5.22	

( ) - Values in the parenthesis are transformed data

Table 5. Reactions of different genotypes of brinjal against *R. solanacearum* on artificial inoculation

Genotypes	Number of days to wilt incidence			
	Media drenching	Stem injection	Root dip	Mean A (Genotypes)
Surya	0	0	0	**0**
Haritha	0	0	0	**0**
SM1	0	0	0	**0**
SM2	0	0	0	**0**
SM3	0	0	0	**0**
SM116	0	0	0	**0**
SM398	0	0	0	**0**
Solanum sisymbrifolium	26.5	12.25	11.7	**16.817**
Solanum torvum KAU1	0	0	0	**0**
Solanum torvum TNAU1	0	0	0	**0**
Pusa Ruby (susceptible check)	11.25	10.861	7.2	**9.77**
Mean B (Methods)	**3.432**	**2.101**	**1.718**	
Factors		**C.D. (0.01)**		
Factor (A)		**0.482**		
Factor (B)		**0.922**		
Factor (A × B)		**1.598**		

Table 6. Reactions of different genotypes of brinjal against *R. solanacearum* on artificial inoculation

Genotypes	Per cent disease incidence			
	Media drenching	Stem injection	Root dip	Mean A (Genotypes)
Surya	0	0.00 (1)	0.00 (1)	**0.00 (1)**
Haritha	0	0.00 (1)	0.00 (1)	**0.00 (1)**
SM1	0	0.00 (1)	0.00 (1)	**0.00 (1)**
SM2	0	0.00 (1)	0.00 (1)	**0.00 (1)**
SM3	0	0.00 (1)	0.00 (1)	**0.00 (1)**
SM116	0	0.00 (1)	0.00 (1)	**0.00 (1)**
SM398	0	0.00 (1)	0.00 (1)	**0.00 (1)**
Solanum sisymbrifolium	26.5	60.00 (7.73)	86.67 (9.35)	**73.33 (8.56)**
Solanum torvum KAU1	0	0.00 (1)	0.00 (1)	**0.00 (1)**
Solanum torvum TNAU1	0	0.00 (1)	0.00 (1)	**0.00 (1)**
Pusa Ruby (susceptible check)	11.25	73.33 (8.60)	100.00 (10.05)	**86.67 (9.33)**
Mean B (Methods)	**3.432**	**12.12 (2.30)**	**16.97 (2.58)**	
Factors		**C.D. (0.01)**		
Factor (A)		**0.157**		
Factor (B)		**0.301**		
Factor (A × B)		**0.522**		

( ) - Values in the parenthesis are transformed dat

4.2.2. Incidence of bacterial wilt (%)

Significant differences were observed with respect to per cent disease incidence or incidence of bacterial wilt among the genotypes, irrespective of the inoculation methods (Table 6). The genotype *Solanum sisymbrifolium* exhibited 73.33 per cent disease incidence and was classified as highly susceptible to bacterial wilt whereas susceptible check Pusa Ruby exhibited 86.6 per cent disease incidence (Plate 10a and Plate 10b). The susceptible check Pusa Ruby recorded 100 per cent, 86.67 per cent, 73.33 per cent disease incidence in root dip, media drenching and stem inoculation methods respectively whereas susceptible genotype *Solanum sisymbrifolium* recorded 86.67 per cent, 73.33 per cent, 60.00 per cent disease incidence in root dip, media drenching and stem inoculation methods respectively. The root dip method recorded the highest per cent of disease incidence in both susceptible genotype *Solanum sisymbrifolium* (86.67 per cent) and the susceptible check Pusa Ruby (100 per cent) when compared to media drenching (*Solanum sisymbrifolium* - 73.33 per cent and the susceptible check Pusa Ruby – 86.67 per cent) and stem injection (*Solanum sisymbrifolium* - 60 per cent and the susceptible check Pusa Ruby – 73.33 per cent) methods. Un-inoculated control plants in all the genotypes did not show any wilt incidence. Except *Solanum sisymbrifolium* and Pusa Ruby, all other genotypes *viz.,* Surya, Haritha, SM1, SM2, SM3, SM116 and SM398, *Solanum torvum* KAU1and *Solanum torvum* TNAU1 did not show any wilt incidence (Plate 11) and hence these were classified as highly resistant to bacterial wilt in artificial inoculation.

4.3. Field evaluation of grafts.

Rootstocks which showed resistance to bacterial wilt in the field evaluation studies as well as under artificial inoculation experiments, namely Surya, Haritha, SM1, SM2, SM3, SM116 and SM398, *Solanum torvum* KAU1and *Solanum torvum* TNAU1 were used as rootstocks for grafting studies. A commercial F1 hybrid cultivar Green Long (M/s Sungro seeds, West Bengal) which was susceptible to bacterial wilt was used as scion. Performance of grafted and non-grafted control (Green Long hybrid) plants were evaluated in the field following adhoc package of practices for precision farming. Data were recorded on important morphological, quantitative and qualitative characters (Table 7, 8, 9 and 10).

Plate 10a. Bacterial wilt in artificially inoculated Pusa Ruby

Plate 10b. Bacterial wilt in artificially inoculated *Solanum sisymbrifolium*

Plate 11. Genotypes resistant to bacterial wilt in artificial inoculation

4.3.1. Plant height at monthly intervals (cm)

At 30 DAT, irrespective of the rootstocks used all the grafted plants produced significantly higher plant height than control plants (Table 7). Green Long hybrid grafted onto SM116 rootstock produced maximum plant height of 36.65 cm among all the rootstocks used and non-grafted control. Haritha rootstock produced 35.5 cm plant height which was statistically on par with Surya (35.1 cm) and SM398 (35.1 cm) rootstocks. Lowest plant height was recorded in non-grafted control (30.55 cm).

Irrespective of the rootstocks used all the grafted plants were significantly taller than control plants at 60 DAT. Maximum plant height was recorded in SM116 rootstock (109.4 cm) followed by *Solanum torvum*TNAU1 rootstock (108.2 cm). Plant heights of Haritha (107.1 cm) and *Solanum torvum* KAU1 (106.5 cm) rootstocks were on par with each other. Plant heights of SM3 (102.15 cm) and SM1 (101.65 cm) rootstocks were also statistically identical with each other. Minimum plant height was recorded in non-grafted control (95.6 cm).

At 90 DAT, also similar trend was observed and irrespective of the rootstocks used all the grafted plants produced significantly maximum plant height than non-grafted control plants. Among all the grafted and control plants SM116 rootstock produced highest plant height (118.25 cm). Plant heights of Haritha (112.8 cm), SM398 (112.75 cm) and Surya (111.5 cm) rootstocks were statistically on par with each other. Plant height of SM3 (107.15 cm) was closely followed by SM1 (104.75 cm). Lowest plant height was recorded in the non-grafted control (102.7 cm).

Irrespective of the rootstocks used all the grafted plants were significantly taller than control plants at 120 DAT. Maximum plant height was recorded in SM116 rootstock (128.7 cm) followed by *Solanum torvum* TNAU1 rootstock (127.1 cm) and these were statistically identical with each other. Plant heights of Haritha (123.05 cm), Surya (122.8 cm), SM398 (122.75 cm), *Solanum torvum* KAU1(121.95 cm) and SM3 (120.7 cm) rootstocks were also on par with each other. Minimum plant height was recorded in non-grafted control (111.35 cm).

4.3.2. Plant spread at monthly intervals (cm)

Irrespective of the rootstocks used all the grafted plants significantly produced higher plant spread than non-grafted control plants (Table 7).

At 30 DAT, all grafted plants produced significantly higher plant than control plants. Green Long hybrid grafted onto Haritha rootstock produced maximum plant spread of 46.62cm among all the rootstocks used and non-grafted control which was statistically on par with SM398 (45.05 cm) and Surya (45.82 cm). Minimum plant spread was recorded in control plant (38.17 cm).

Irrespective of the rootstocks used all the grafted plants produced more plant spread than non-grafted control plants at 60 DAT. Haritha rootstock produced maximum plant spread of 110.13 cm among all the rootstocks used and non-grafted control. Plant spreads of *Solanum torvum* KAU1 (105.60 cm), Surya (106.00 cm), SM2 (106.55 cm) and SM398 (106.43 cm) were on par with each other. Minimum plant spread was recorded in non-grafted control plants (101.73 cm).

At 90 DAT, irrespective of the rootstocks used all the grafted plants produced higher plant spread than control plants. Haritha rootstock produced maximum plant spread of 117.53 cm among all the rootstocks and non-grafted control. Plant spreads of SM398 (113.50 cm), *Solanum torvum* TNAU1 (114.50 cm), SM1 (114.08 cm) and SM3 (114.25 cm) were statistically on par with each other. Minimum plant spread of 104.98 cm was recorded in non-grafted control plants

Irrespective of the rootstocks used all the grafted plants produced more plant spread than non-grafted control plants at 120 DAT. Maximum plant spread was recorded when Green Long hybrid grafted onto Haritha rootstock (128.63 cm) which was statistically on par with SM398 (127.05 cm), SM116 (126.88 cm) and SM3 (124.30 cm). Minimum plant spread was recorded in non-grafted control plant (117.63 cm).

Table 7. Performance of grafted brinjal plants under field evaluation

Genotypes	Plant height (cm)				Plant spread (cm)			
	30 days	60 days	90 days	120 days	30 days	60 days	90 days	120 days
Surya	35.10 ^{ab}	100.00 ^{e}	111.55 ^{b}	122.80 ^{b}	45.82 ^{a}	106.00^{b}	112.75^{cd}	122.08^{bc}
Haritha	35.50^{ab}	107.10 ^{abc}	112.80 ^{b}	123.05 ^{b}	46.62^{a}	110.13 ^{a}	117.53 ^{a}	128.63 ^{a}
SM1	33.85 ^{abc}	101.65 ^{de}	104.75 ^{ef}	115.05 ^{c}	43.27 ^{abc}	107.90 ^{ab}	114.08^{bcd}	120.60^{c}
SM2	34.00^{abc}	104.15 ^{cd}	108.65 ^{cd}	117.05 ^{c}	43.57 ^{ab}	106.55 ^{b}	112.53^{d}	123.30^{b}
SM3	31.90^{cd}	102.15 ^{de}	107.15 ^{de}	120.70 ^{b}	41.42^{bcd}	107.60 ^{ab}	114.25 ^{bcd}	124.30 ^{a}
SM116	36.35^{a}	109.40^{a}	118.25 ^{a}	128.70 ^{a}	43.32 ^{abc}	107.63 ^{ab}	114.88^{bc}	126.88 ^{a}
SM398	35.10 ^{ab}	106.20 ^{bc}	112.75 ^{b}	122.75 ^{b}	46.05 ^{a}	106.43 ^{b}	113.50 ^{bcd}	127.05 ^{a}
***S. torvum* KAU1**	33.85 ^{abc}	106.50 ^{abc}	110.85 ^{bc}	121.95 ^{b}	39.87^{bcd}	105.60 ^{b}	115.50^{ab}	123.93^{b}
***S. torvum* TNAU1**	33.10 ^{bcd}	108.20 ^{ab}	110.90 ^{bc}	127.10 ^{a}	39.62^{cd}	104.68^{bc}	114.50 ^{bcd}	120.60^{c}
Control	30.55^{d}	95.60 ^{f}	102.70 ^{f}	111.35 ^{d}	38.17^{d}	101.73^{c}	104.98^{e}	117.63^{d}
CD (0.05)	3.00	3.13	2.558	2.47	3.81	3.38	2.16	2.47
S.E(m±)	1.03	1.08	0.88	0.85	1.30	1.16	0.74	0.85

4.3.3. Stem girth at monthly intervals (cm)

Stem girth recorded on 30 DAT varied significantly among the grafted and control plants. All the grafts produced significantly higher stem girth than the non-grafted control plants (Table 8). Haritha rootstock produced maximum stem girth of 3.25 cm among all the rootstocks and control. Stem girth of SM116 (3.17 cm) and SM1 (3.17 cm) rootstocks were statistically identical with each other. Lowest stem girth was recorded in non-grafted control (2.62 cm).

At 60 DAT, all the grafted plants produced significantly higher stem girth than control plants. Maximum stem girth of 7.52 cm was recorded in Haritha rootstock among all the rootstocks used and control plants followed by SM116 (7.45 cm), SM3 (7.35 cm) and SM2 (7.35 cm) rootstocks. Minimum stem girth was recorded in non-grafted control (6.00 cm).

Stem girth recorded on 90 DAT varied significantly among all the grafted and control plants. Irrespective of the rootstocks used all the grafts produced significantly higher stem girth when compared to control plants. SM116 and Haritha rootstocks produced maximum stem girth of 8.70 cm which was closely followed by SM398 (8.50 cm) rootstock. Non-grafted control plants produced lowest stem girth of 7.0 cm.

At 120 DAT, also all the grafts produced significantly maximum stem girth than control plants. Maximum stem girth of 10.17 cm was recorded in Haritha rootstock among all the rootstocks used and control plants followed by SM116 (9.82 cm), *Solanum torvum* KAU1(9.62 cm), SM398 (9.62 cm), Surya (9.57 cm), *Solanum torvum* TNAU1 (9.50 cm), SM3 (9.32 cm), SM1 (9.22 cm) and SM2 (9.20 cm) rootstocks. Minimum stem girth of 8.02 cm was recorded in control.

4.3.4. Number of primary branches

The average number of primary branches recorded on 30 DAT varied significantly among all the grafted and control plants. All the grafts produced significantly higher number of primary branches than the control plants (Table 8). Haritha rootstock produced maximum number of primary branches (3) among all the rootstocks used and which was statistically on par with SM116 (2.95), Surya (2.65) and SM398 (2.60) rootstocks. Lowest number of primary branches was recorded in non-grafted control (1.0). At 60 DAT, irrespective of the rootstocks used all the grafted

plants produced more number of primary branches than control plants. Haritha rootstock produced higher number of primary branches (8.20) among all the rootstocks used which was statistically on par with SM116 (8.05) rootstock. Lowest numbers of primary branches were recorded in non-grafted control (5.25) plants.

Number of primary branches recorded on 90 DAT varied significantly among all the grafted and control plants. All the grafts produced significantly higher number of primary branches than control plants. Haritha rootstock produced maximum number of primary branches (8.85) among all the rootstocks used which was statistically on par with SM116 (8.7) rootstock. Lowest numbers of primary branches were recorded in non-grafted control (7.00) plants.

At 120 DAT, irrespective of the rootstocks used all the grafted plants produced more number of primary branches than control plants. Haritha rootstock produced higher number of primary branches (10.3) among all the rootstocks used which was statistically on par with SM116 (10.0) rootstock. Lowest numbers of primary branches were recorded in non-grafted control (7.5) plants (Plate 12).

4.3.5. Days to first flowering

Significant differences were observed for number of days taken for first flower opening among all the grafted and control plants irrespective of the rootstocks used (Table 8). Compared to the control Surya, Haritha and SM398 rootstocks took lesser and *Solanum torvum* TNAU1, *Solanum torvum* KAU1, SM3 and SM2 rootstocks took higher number of days to first flower opening (Plate 13). Non-grafted control plants took 41.85 days for first flower opening. Surya (41.80 days), Haritha (41.45 days) and SM398 (41.00 days) rootstocks took lesser number of days whereas *Solanum torvum* TNAU1 (48.65 days), *Solanum torvum* KAU1(47.65 days), SM3 (43.6 days) and SM2 (42.85 days) rootstocks took higher number of days to first flower opening compared to control (41.85 days). Surya (41.80 days) and *Solanum torvum* TNAU1 (48.65 days) rootstocks took minimum and maximum days to first flowering respectively compared to control plants (41.85 days).

Plate 12. Number of primary branches

Plate 13. Days to first flowering

Table 8. Performance of grafted brinjal plants under field evaluation

Genotypes	Stem girth (cm)				Number of primary branches (No.)				Days to first flowering
	30 days	60 days	90 days	120 days	30 days	60 days	90 days	120 days	
Surya	3.10 bc	7.30 bcd	8.08 bc	9.58 c	2.65 a	7.30 cd	8.05 c	9.30 bcd	41.80 bcd
Haritha	3.25 a	7.53 a	8.70 a	10.18 a	3.00 a	8.20 a	8.85 a	10.30 a	41.45 cd
SM1	3.18 ab	7.28 cd	7.93 c	9.23 e	1.95 b	7.15 cd	7.55 d	9.00 d	42.10 bcd
SM2	3.10 bc	7.35 bc	7.93 c	9.20 e	2.05 b	7.85 ab	8.30 bc	9.35 bc	42.85 bc
SM3	2.95 de	7.35 bc	8.15 b	9.33 de	2.10 b	7.00 d	7.45 d	9.05 cd	43.60 b
SM116	3.18 ab	7.45 ab	8.70 a	9.83 b	2.95 a	8.05 a	8.70 a	10.00 a	42.80 bcd
SM398	3.03 cd	7.15 de	8.50 a	9.63 bc	2.60 a	7.45 bc	8.65 ab	9.55 b	41.00 d
S. torvum KAU1	2.90 e	7.00 e	8.25 b	9.63 bc	2.00 b	7.40 cd	8.55 ab	9.20 cd	47.65 a
S. torvum TNAU1	2.90 e	7.18 d	8.23 b	9.50 cd	2.05 b	7.05 cd	8.50 ab	9.20 cd	48.65 a
Control	2.63 f	6.00 f	7.03 d	8.03 f	1.00 c	5.25 e	7.00 e	7.50 e	41.85 bcd
CD (0.05)	0.105	0.161	0.200	0.233	0.436	0.413	0.378	0.343	1.808
S.E(m±)	0.03	0.05	0.06	0.08	0.15	0.14	0.13	0.11	0.62

4.3.6. Number of fruits per plant

Rootstocks had significant influence on the number of fruits per plant and all the grafts produced significantly higher number of fruits per plant than the non-grafted control plants (Table 9). Rootstock Haritha produced maximum number of fruits per plant (94.80) which was on par with SM398 (94.35) followed by SM116 (91.20) and Surya (79.30) respectively. Number of fruits per plant of SM2 (78.00) and SM3 (77.85) rootstocks were on par but varied significantly from fruits per plant of *Solanum torvum* KAU1(70.05) and *Solanum torvum* TNAU1 (70.00), which were statistically on par with each other. Minimum number of fruits per plant (63.55) was recorded in non-grafted control plants.

4.3.7. Yield per plant (kg)

Significant differences were observed with respect to yield per plant among all the grafted and control plants irrespective of the rootstocks used (Table 9). All the grafted plants produced significantly higher yield per plant when compared to control plants. Maximum yield per plant was recorded on Haritha rootstock (6.70 kg). This was followed by SM116 rootstock (6.29 kg) and SM398 (6.17 kg) rootstock but they were statistically on par (Plate 14). The rootstocks also recorded higher yield/plant (Surya (5.47 kg), SM3 (5.41 kg), SM2 (5.30 kg) and SM1 (5.17 kg) rootstocks). Yield per plant on *Solanum torvum* KAU1and *Solanum torvum* TNAU1 rootstocks were comparatively lower than *Solanum melongena* rootstocks (Surya, Haritha, SM1, SM2, SM3, SM116 and SM398). The two *Solanum torvum* rootstocks *viz.*, *Solanum torvum* KAU1and *Solanum torvum* TNAU1 yielded 4.84 kg/plant and 4.81 kg/plant respectively, which were statistically on par. Minimum yield per plant was recorded in non-grafted control (4.08 kg) plants.

4.3.8. Fruit length (cm)

Rootstocks had significant influence on the fruit length and all the grafts produced significantly higher fruit length when compared to non-grafted control plants (Table 9). Haritha rootstock exhibited the maximum fruit length of 22.22 cm which was statistically identical with SM116 (22.16 cm) and SM398 (22.15 cm) rootstocks respectively. Fruit length of Surya (21.73 cm) and SM3 (21.73 cm) rootstocks was also

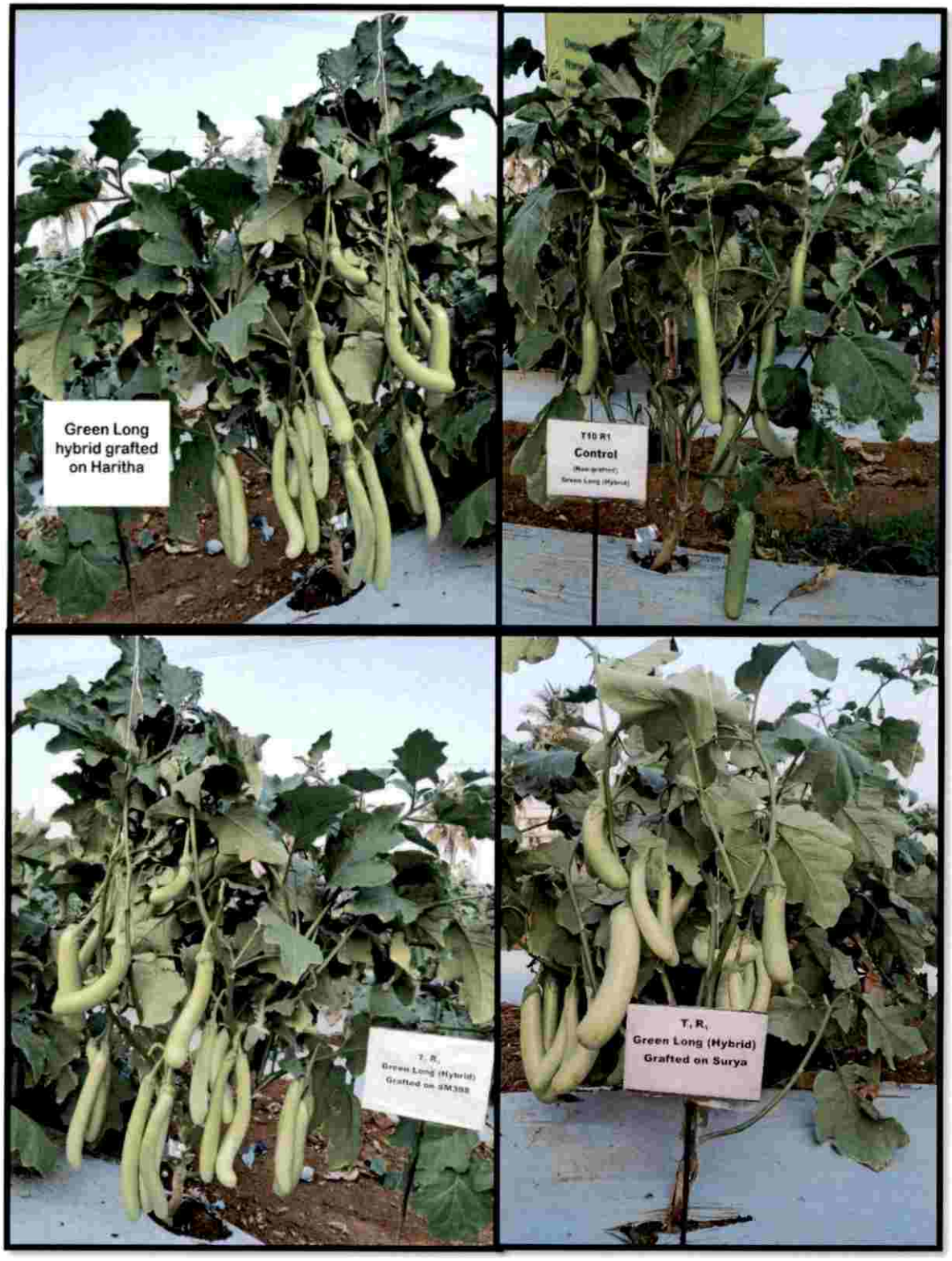


Plate 14. Yield per plant in grafted and non-grafted plants

statistically on par with each other. Control plants exhibited the minimum fruit length of 20.31 cm.

4.3.9. Fruit girth (cm)

Significant differences were observed with respect to fruit girth in grafted and control plants irrespective of the rootstocks used. All the grafts produced significantly higher fruit girth when compared to control plants (Table 9). Maximum fruit girth was recorded in SM116 rootstock (10.97 cm) which was on par with Haritha rootstock (10.94 cm). Fruit girth of SM398 (10.91 cm) and SM3 (10.86 cm) rootstocks were statistically on par with each other. Minimum fruit girth was recorded in non-grafted control (10.43 cm) plants.

4.3.10. Average fruit weight (g)

Rootstocks significantly influenced the average fruit weight and all the grafts recorded significantly higher average fruit weight when compared to non-grafted control plants (Table 9). The highest average fruit weight was recorded in SM116 rootstock (78.00 g) which was on par with Haritha rootstock (76.00 g). Average fruit weight of *Solanum torvum* KAU1(71.65 g), SM3 (71.38 g) and SM2 (70.89 g) rootstocks were statistically on par with each other. Average fruit weight was found minimum in non-grafted control (67.85 g) plants.

4.3.11. Number of harvests

There was no significant difference was observed with respect to number of harvests either among the rootstocks or grafted plants and control plants (Table 9). Number of harvests recorded in all the rootstocks and control plants were 10.

4.3.12. Crop duration (days)

There was no significant difference observed with respect to crop duration among the grafted plants and the control (Table 9). The grafts and non-grafted control plants lasted for150 days in the field.

Table 9. Performance of grafted brinjal plants under field evaluation

Genotypes	Yield per plant (Kg)	No. of fruits per plant	Fruit length (cm)	Fruit girth (cm)	Average fruit weight	Number of harvests	Crop duration (days)
Surya	5.48 ^{c}	79.80 ^{c}	21.73 ^{b}	10.76 ^{bc}	69.49 ^{bc}	10.00	150.00
Haritha	6.70 ^{a}	94.80 ^{a}	22.22 ^{a}	10.95 ^{a}	76.00 ^{a}	10.00	150.00
SM1	5.17 ^{e}	76.75 ^{d}	20.93 ^{c}	10.63 ^{cd}	69.90 ^{bc}	10.00	150.00
SM2	5.30 ^{de}	78.00 ^{cd}	21.22 ^{c}	10.59 ^{cde}	70.89 ^{b}	10.00	150.00
SM3	5.42 ^{cd}	77.85 ^{cd}	21.73 ^{b}	10.87 ^{ab}	71.39 ^{b}	10.00	150.00
SM116	6.29 ^{b}	91.20 ^{b}	22.16 ^{a}	10.97 ^{a}	78.00 ^{a}	10.00	150.00
SM398	6.17 ^{b}	94.35 ^{a}	22.15 ^{a}	10.92 ^{ab}	69.28 ^{bc}	10.00	150.00
***S. torvum* KAU1**	4.84 ^{f}	70.05 ^{e}	20.96 ^{c}	10.52 ^{de}	71.65 ^{b}	10.00	150.00
***S. torvum* TNAU1**	4.82 ^{f}	70.00 ^{e}	21.17 ^{c}	10.63 ^{cd}	69.94 ^{bc}	10.00	150.00
Control	4.08 ^{g}	63.55 ^{f}	20.32 ^{d}	10.44 ^{e}	67.85 ^{c}	10.00	150.00
CD (0.05)	0.156	2.905	0.359	0.182	2.845	-	-
S.E(m±)	0.05	1.00	0.12	0.06	0.98	-	-

4.3.13. Total phenolics (mg/100g)

Significant differences were observed with respect to total phenolic content of fruits when Green Long hybrid grafted onto SM3, SM116, SM2, SM1 and *Solanum torvum* KAU1rootstocks. All the grafts recorded higher total phenolics when compared to non-grafted control (Table 10). Maximum total phenolics was found in SM3 (113.30 mg) rootstock followed by SM116 (103.2 mg), SM2 (97.20 mg), SM1 (90.20 mg) and *Solanum torvum* KAU1(89.47 mg) rootstocks. Total phenolic content of Surya (63.2 mg), Haritha (66.35 mg), SM398 (66.15 mg) and *Solanum torvum* TNAU1 (68.6 mg) were statistically on par with non-grafted control (61.9 mg). Minimum total phenolic was found in control (61.90 mg) plants.

4.3.13. Dry matter (%)

Except Surya and SM3rootstocks, all the grafts significantly influenced the dry matter content of fruits when compared to control plants (Table 10). Highest dry matter was found in fruits of SM398 (11.12 per cent) rootstock which was closely followed by *Solanum torvum* TNAU1 (11.12 per cent) rootstock. Dry matter recorded in the fruits of SM2 (9.97 per cent), Haritha (9.97 per cent) and SM1 (9.8 per cent) rootstocks were on par with each other. Surya and SM3 rootstock (8.85 per cent) recorded the lowest dry matter among all the grafts and control plants.

4.3.14. Total soluble solids (%)

There was no significant difference observed with respect to total soluble solids (TSS) of fruits among all the grafted and control plants (Table 10). Maximum TSS was recorded in the fruits of SM116 (4.42 per cent) rootstock and minimum TSS was recorded in the fruits of control (4.27 per cent) plants.

4.3.15. Number of wilted plants

Maximum numbers of wilted plants were observed in non-grafted control (5.75) plants whereas Green Long hybrid grafted on *Solanum torvum* KAU1and *Solanum torvum* TNAU1 rootstocks recorded 1 and 1.25 wilted plants respectively. Except *Solanum torvum* KAU1and *Solanum torvum* TNAU1 all other rootstocks did not show any wilt symptoms till the end of crop (Table 10).

4.3.16. Percent disease incidence

Non-grafted control plants recorded maximum percent of wilt incidence (28.75 per cent). Bacterial wilt in non-grafted control plant was given in Plate 15. Green Long hybrid grafted on to *Solanum torvum* KAU1 and *Solanum torvum* TNAU1 recorded 6.25 and 5.00 per cent wilt incidence respectively. All other grafted plants did not showed any wilt incidence (Table 10).

4.3.17. Root length and spread (cm)

Rootstocks had significant influence on the root length and all the grafted plants produced significantly higher root length than non-grafted control plants (Table 10). Maximum root length was produced on Haritha (63.65 cm) rootstock followed by *Solanum torvum* TNAU1 (62.20 cm) and SM116 (61.05). Root length of SM398 (60.2 cm), SM3 (59.85 cm) and *Solanum torvum* KAU1 (59.60 cm) rootstocks were statistically on par with each other. Minimum root length was recorded in control (46.05 cm) plants.

Rootstocks significantly influenced the root spread and all the grafted plants produced significantly higher root spread than non-grafted control plants (Table 10). Haritha rootstock produced maximum root spread of 87.05 cm among all the grafted and control plants. Root spread of *Solanum torvum* TNAU1 (82.30 cm), SM116 (82.20 cm), SM398 (81.95 cm), *Solanum torvum* KAU1 (81.80 cm) and SM3 (81.60 cm) rootstocks were statistically on par with each other. Minimum root spread was recorded in control (63.45 cm) plants. Effect of grafting on root length and spread when compared to control was given in Plate 16a and Plate 16b.

4.3.18. Incidence of pest and diseases

Major pests reported during the study were aphids, white flies, jassids, mites and fruit and shoot borer. These pests were recorded in all the grafted and control plants. Pests were controlled by spraying plant protection chemicals (pesticides). No severe diseases were observed during the experiment.

Plate 15. Bacterial wilt in non-grafted control (Green Long hybrid)

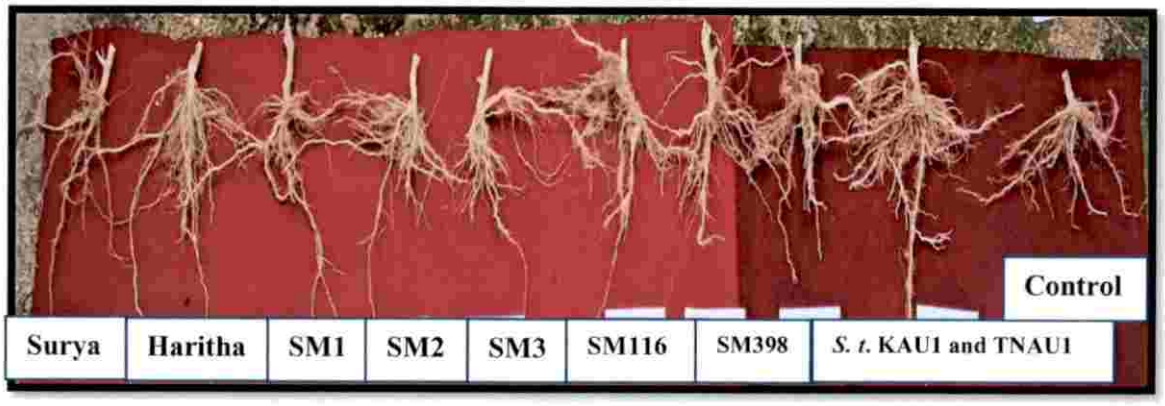


Plate 16a. Root length and spread in grafted and non-grafted control plants

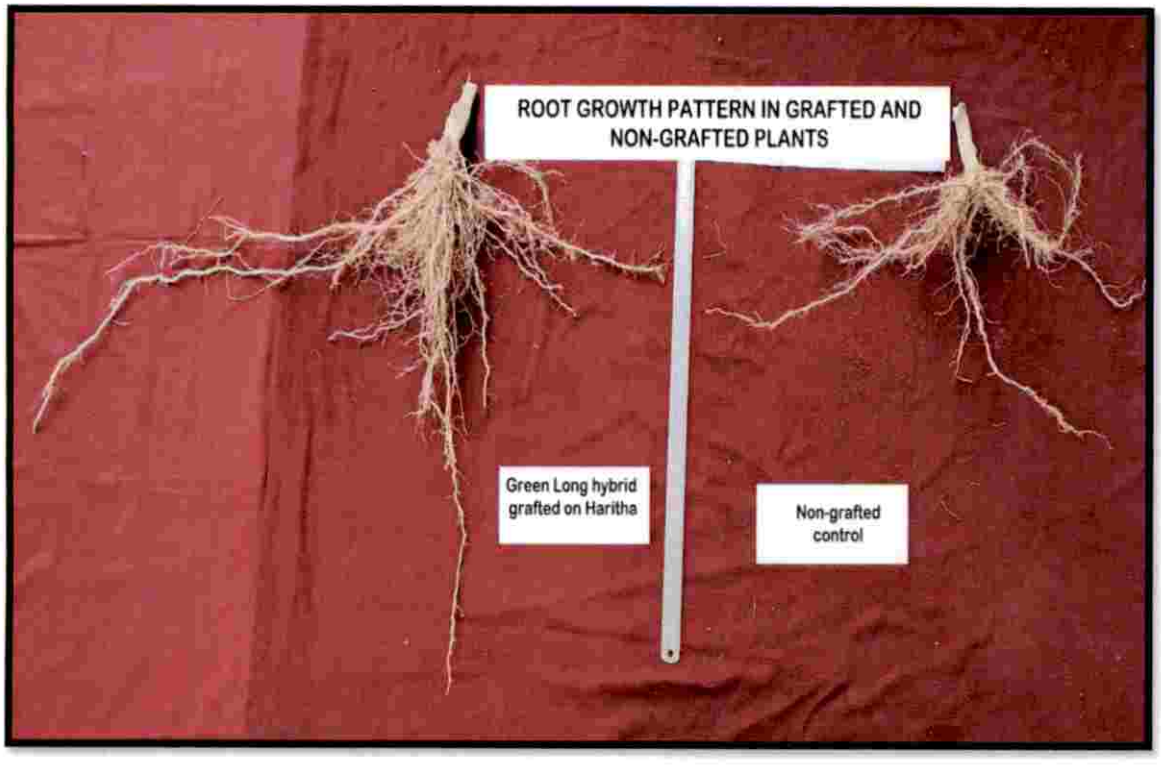


Plate 16b. Root length and spread on Haritha rootstock when compared to non-grafted control

Table 10. Performance of grafted brinjal plants under field evaluation

Genotypes	Total phenolics (mg/100g)	Dry matter (%)	Total soluble solids (%)	Number of wilted plants	PDI (%)	Root length (cm)	Root spread (cm)
Surya	63.20 ^{e}	8.85 ^{d}	4.35	0.00 ^{b}	0.00 ^{b}	55.65 ^{d}	75.00 ^{c}
Haritha	66.35 ^{e}	9.98 ^{b}	4.38	0.00 ^{b}	0.00 ^{b}	63.65 ^{a}	87.05 ^{a}
SM1	90.20 ^{cd}	9.80 ^{b}	4.35	0.00 ^{b}	0.00 ^{b}	51.20 ^{e}	70.80 ^{d}
SM2	97.20 ^{bc}	9.98 ^{b}	4.30	0.00 ^{b}	0.00 ^{b}	52.05 ^{e}	71.95 ^{d}
SM3	113.30 ^{a}	8.85 ^{d}	4.35	0.00 ^{b}	0.00 ^{b}	59.85 ^{c}	81.60 ^{b}
SM116	103.20 ^{b}	9.48 ^{bc}	4.43	0.00 ^{b}	0.00 ^{b}	61.05 ^{bc}	82.20 ^{b}
SM398	66.15 ^{e}	11.43 ^{a}	4.33	0.00 ^{b}	0.00 ^{b}	60.20 ^{c}	81.95 ^{b}
S. torvum KAU1	89.48 ^{d}	9.15 ^{cd}	4.35	1.25 ^{b}	6.25 ^{b}	59.60 ^{c}	81.80 ^{b}
S. torvum TNAU1	68.63 ^{e}	11.13 ^{a}	4.30	1.00 ^{b}	5.00 ^{b}	62.20 ^{ab}	82.30 ^{b}
Control	61.91 ^{e}	8.98 ^{cd}	4.28	5.75 ^{a}	28.75 ^{a}	46.05 ^{f}	63.45 ^{e}
CD (0.05)	7.037	0.544	-	2.049	10.29	1.804	2.077
S.E(m±)	2.42	0.18	0.07	0.70	3.53	0.62	0.71

4.3.19. Correlation studies

Correlation studies were conducted between various qualitative and quantitative characters observed in the study. Seventeen characters used for correlation studies *viz.*, plant height, plant spread, stem girth, number of primary branches, days to first flowering, yield per plant, number of fruits per plant, fruit length, fruit girth, average fruit weight, number of harvests, crop duration, root length, root spread, total phenolics, dry matter and total soluble solids TSS (Table 11).

Plant height exhibited positive correlation with plant spread, stem girth, number of primary branches, fruit length, root length and root spread. Significant positive correlation was found between plant height and yield per plant, number of fruits per plant, fruit girth, average fruit weight and TSS.

Plant spread recorded positive significant correlation with root length and root spread. Significant positive correlation was found between plant spread and number of primary branches, yield per plant and fruit length.

Strong positive significant correlation was observed between stem girth and number of primary branches, yield per plant, fruits per plant, fruit length, fruit girth, root length and root spread. Stem girth exhibited significant positive correlation with plant spread, average fruit weight and TSS.

Number of primary branches significant positive correlation with plant height, stem girth, root length and root spread. Significant positive correlation was also observed between number of primary branches and plant spread, yield per plant, fruits per plant and fruit length.

Yield per plant expressed significant positive correlation with stem girth, number of fruits per plant, fruit length and fruit girth. Significant positive correlation was also observed between yield per plant, plant height, plant spread, number of primary branches, average fruit weight, root length and root spread.

Fruits per plant exhibited significant positive correlation with stem girth, yield per plant, fruit length and fruit girth. Significant positive correlation was also observed between number of fruits per plant and plant height, number of primary branches and TSS.

Fruit length expressed significant positive correlation with plant height, stem girth, yield per plant, fruits per plant and fruit girth. significant positive correlation was also observed between fruit length and plant spread, number of primary branches, root length, root spread and TSS.

Fruit girth exhibited significant positive correlation with stem girth, yield per plant, fruits per plant and fruit length. There was significant positive correlation was observed between fruit girth, plant height, average fruit weight, root length, root spread and TSS. Significant positive correlation was also observed between average fruit weight and plant height, stem girth, yield per plant, fruit girth and TSS.

Root length expressed significant positive correlation with plant height, plant spread, stem girth, number of primary branches and root spread. Significant positive correlation was also observed between root length and yield per plant, fruit length and fruit girth.

Root spread recorded significant positive correlation with plant height, plant spread, stem girth, number of primary branches and root length. Significant positive correlation was also observed between root spread, yield per plant, fruit length and fruit girth.

Total soluble solids (TSS) expressed significant positive correlation with average fruit weight. There was significant positive correlation between total soluble solids (TSS), plant height, plant spread, stem girth, number of fruits per plant, fruit length and fruit girth.

Table 11. Correlation analysis

	Plant height	Plant spread	Stem girth	No. of 1^0 branches	Days to first flowering	Yield /plant	No. of fruits /plant	Fruit length	Fruit girth	Average fruit weight	No. of harvests	Crop duration	Root length	Root spread	Total phenolics	Dry matter	TSS
Plant height	1																
Plant spread	0.639**	1															
Stem girth	0.86**	0.9**	1														
No. of primary branches	0.862**	0.756*	0.853**	1													
Days to first flowering	0.066	0.279	0.081	0.202	1												
Yield per plant	0.737*	0.661*	0.847**	0.685*	-0.435	1											
No. of fruits per plant	0.701*	0.56	0.783**	0.644*	-0.529	0.981**	1										
Fruit length	0.791**	0.637*	0.865**	0.662*	-0.333	0.949**	0.927**	1									
Fruit girth	0.695*	0.566	0.799**	0.506	-0.402	0.923**	0.908**	0.967**	1								
Average fruit weight	0.724*	0.59	0.712*	0.582	-0.051	0.708*	0.615	0.626	0.636*	1							
No. of harvests	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00						
Crop duration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00					
Root length	0.765**	0.815**	0.912**	0.781**	0.331	0.659*	0.573	0.748*	0.692*	0.592	0.00	0.00	1				
Root spread	0.744**	0.836**	0.927**	0.788**	0.287	0.693*	0.608	0.758*	0.7*	0.615	0.00	0.00	0.992**	1			
Total phenolics	0.062	0.331	0.21	-0.081	0.143	0.091	0.026	0.096	0.156	0.39	0.00	0.00	0.096	0.134	1		
Dry matter	0.279	0.331	0.343	0.528	0.125	0.282	0.355	0.265	0.212	-0.085	0.00	0.00	0.37	0.35	-0.325	1	
TSS	0.705*	0.613	0.745*	0.465	-0.186	0.729	0.661*	0.687*	0.723*	0.856**	0.00	0.00	0.552	0.573	0.387	-0.204	1

DISCUSSION

5. DISCUSSION

Brinjal (*Solanum melongena* L.) is an important and widely cultivated warm season vegetable crop. Due to easy cultivation practices and wide adaptability it is widely grown by the farmers. The unripe tender and soft fruits are primarily used as a cooked vegetable for the preparation of various dishes throughout India. Round fruits are baked or boiled for the preparation of a smashed product called Bhartha. It has huge potential as a raw material for pickle and dehydration industries (Goiterogenic principle). In Kerala demand for this crop has increased in the recent years and brinjal cultivation in the state has gained momentum. Choice of a variety for cultivation is very important as it determines the production, demand and marketability of the produce. But there are several problems arising due to lack of scientific studies related to selection of best genotypes with high yield and resistance to pest and diseases. The most destructive and uncontrollable disease noticed in brinjal in Kerala is the bacterial wilt caused by *Ralstonia solanacearum.* There are many high yielding varieties and hybrids, both from public and private sector, released for commercial cultivation but in Kerala, all of them are highly prone to the bacterial wilt disease. Hence an identification of genotypes having desirable morphological characters, with good yield potential and quality along with resistance to bacterial wilt is highly essential for successful cultivation of brinjal in the state.

Genetic potential of genotype decides yield potential in any crop but in turn yield is influenced by a number of biotic and abiotic stresses. Major abiotic stresses are caused by environmental and non-biological factors whereas biotic stresses are caused by living organisms. Hence, evaluation of genotypes/cultivars under uniform environment providing similar crop management practices will help to identify the best genotype with respect to yield and resistance to biotic stresses. Among the biotic stresses bacterial wilt is most difficult to control. The management practices recommended are either to choose wilt resistant cultivars/varieties/hybrids for cultivation or to adopt grafting on bacterial wilt resistant rootstocks. Grafting in vegetables has emerged as a promising and surgical alternative tool to the relatively long and slow conventional breeding methods aimed at increasing tolerance/resistance to biotic and abiotic stresses. Grafting is widely practiced in Solanaceous vegetables

(Tomato, Brinjal, Chilli and Capsicum) all over the world. Yet, in India potential of this technique has not been commercially exploited so far. Grafted plants on resistant rootstocks of Solanaceous vegetables were highly resistant to bacterial wilt and high yielding (Narayanankutty *et al.*, 2015).

The present investigation was undertaken with the objective to evaluate ten available rootstocks comprising of *Solanum torvum* (2 collections-a local KAU collection and a collection from TNAU), *Solanum sisymbrifolium* (one collection) and *Solanum melongena* (7 Collections-Surya, Haritha, SM1, SM2, SM3, SM116 and SM398) for resistance to bacterial wilt in both artificial inoculation and field evaluation. To study the field performance of grafted brinjal plants on bacterial wilt resistant rootstocks. The results of the study are briefly discussed hereunder:

5.1. Field evaluation of rootstocks

Bacterial wilt is most destructive and devastating disease caused by a wide spread phyto-phathogenic, gram negative, rod shaped flagellated bacterium *Ralstonia solanacearum.* It is a soil born bacterium which persists in the soil for many years even without host. It disseminates in many ways *viz.*, water flow in soil, infected plant material and contaminated soil, water, implements and also due to human interventions.

Bacterial wilt in brinjal can be effectively managed by identifying genotypes that are resistant to bacterial wilt. The resistant genotypes can be further used as a rootstock for grafting onto high yielding commercial hybrids. Hence field evaluation of genotypes for resistance to bacterial wilt in a wilt sick plot is highly essential to identify resistant rootstocks.

Among the 10 genotypes evaluated *Solanum sisymbrifolium* expressed highest per cent of bacterial wilt incidence (96.6 per cent) and followed by SM398 (40 percent), SM2 (40 percent), SM1 (23.3 percent), *Solanum torvum* TNAU 1 (20 percent) and *Solanum torvum* KAU1(16.6 per cent). *Solanum sisymbrifolium* was classified as highly susceptible to bacterial wilt whereas rootstocks *viz.*, SM398, SM2, SM1, *Solanum torvum* TNAU 1 and *Solanum torvum* KAU1 classified as moderately resistant to bacterial wilt as per the score chart given by Sitaramiah *et al.* (1981). Susceptible check Pusa Ruby expressed hundred per cent wilt incidence when spot planted with *Solanum sisymbrifolium* and *Solanum torvum* TNAU 1 genotypes. Genotypes such as Surya,

Haritha, SM3 and SM116 were found highly resistant to bacterial wilt and no wilt incidence was observed throughout cropping period (Figure 3). Spot planted Pusa Ruby showed wilting irrespective of the genotypes studied. Bora *et al.* (2011), Rahman *et al.* (2011), Pavithra *et al.* (2014), Kumar *et al.* (2014), Jhangta (2015) and Malshe *et al.* (2016) were also reported variation in percent disease incidence while screening the brinjal genotypes.

The bacterium (*R. solanacearum*) enters the plants through root injuries. Inside the plant, bacteria multiply and block the vascular bundles, the chief conducting tissue of water and nutrients, thereby causing sudden wilting of plants in the susceptible genotypes. Clain *et al.* (2004) reported that latent infection was generally absent in the roots of resistant genotypes, suggesting that mechanisms of resistance might involve mechanical barriers developed in the roots which limit the diffusion of bacterial population from roots to stem via collar and/or limits the capacity to multiply within the stem.

Per cent disease incidence is not only enough to determine the performance of genotypes in the field. It also depends on the number of days the genotypes survived in the field. Among all the rootstocks, SM398 spot planted with Pusa Ruby took maximum number of days to wilt incidence (32.3 days) followed by SM1 (30.3 days), *Solanum torvum* TNAU 1 (29.0 days), SM2 (28.7 days), *Solanum torvum* KAU1(26.8 days) and *Solanum sisymbrifolium* (23.40 days) whereas the spot planted Pusa Ruby took24.80 days to wilt (Figure 4).This variation in the number of days to wilt incidence was might be due to mechanical barriers developed in the roots which limit the diffusion of bacterial population from roots to stem via collar and/or limits the capacity to multiply within the stem. Rahman *et al.* (2011) reported variation in number of days to wilt incidence in brinjal genotypes while screening against bacterial wilt disease. Similar results were also reported in the study conducted by Hussain *et al.* (2005), Kumar *et al.* (2014) and Bhavana and Singh (2016).

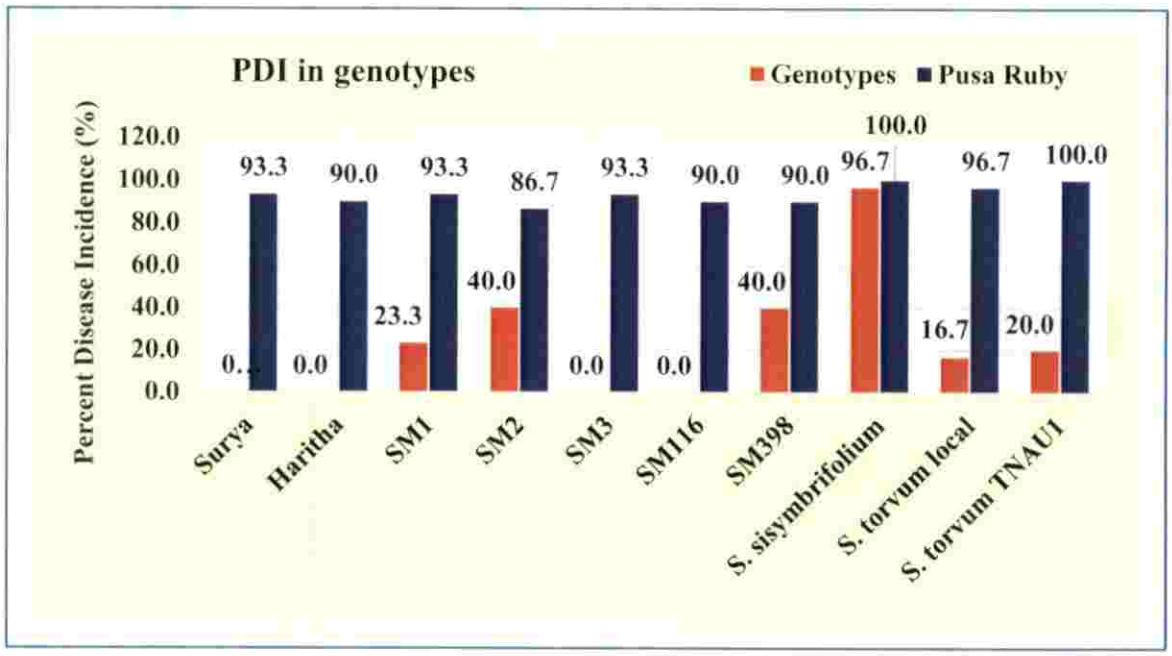


Figure 3. Percent disease incidence (PDI) in genotypes during field evaluation of rootstocks

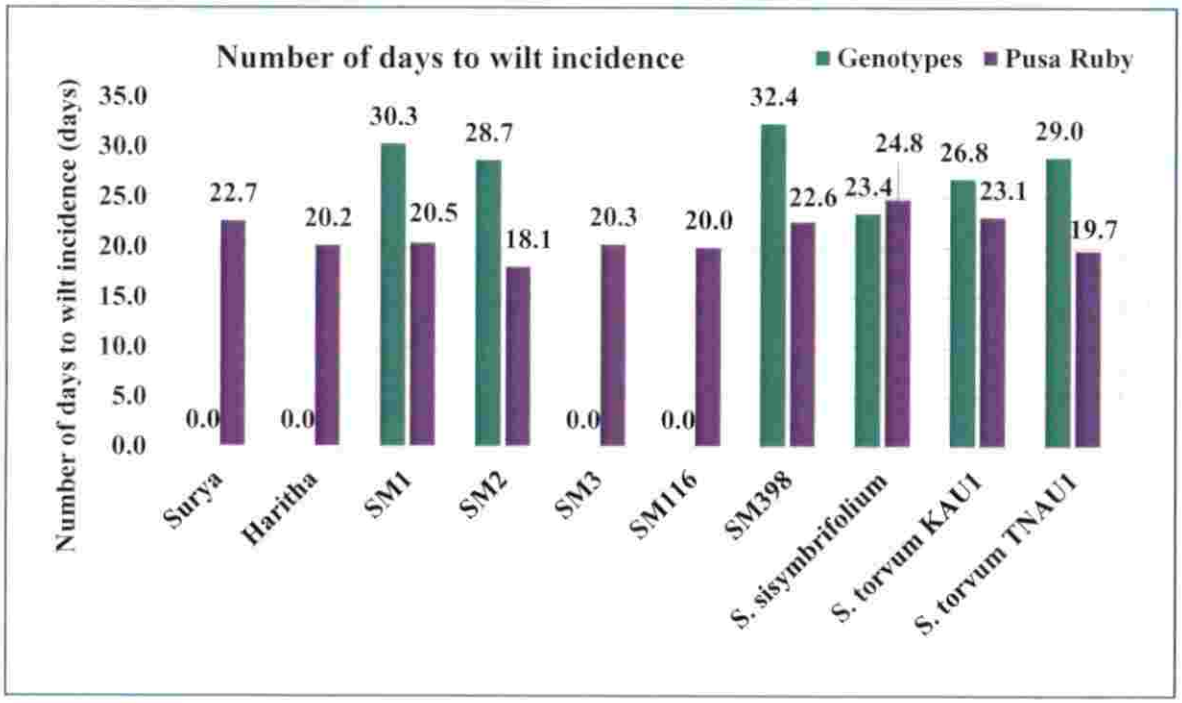


Figure 4. Number of days to wilt incidence during field evaluation of rootstocks

5.2. Artificial inoculation

Disease incidence through artificial inoculation methods depends on the concentration of the inoculum, age of the plants, environment in which plants are kept and also the reaction of the host. So, in addition to the field evaluation, development of disease through artificial inoculation is also necessary for confirmation of the pathogenicity of the causal organism as well as the host reactions.

Significant difference was observed with respect to per cent disease incidence among the genotypes, irrespective of the inoculation methods (Table 4.2 b). The genotype *Solanum sisymbrifolium* exhibited 73.33 per cent disease incidence and was classified as highly susceptible to bacterial wilt. The susceptible check Pusa Ruby exhibited 86.6 per cent disease incidence. Except *Solanum sisymbrifolium* and Pusa Ruby, all other genotypes *viz.*, Surya, Haritha, SM1, SM2, SM3, SM116 and SM398, *Solanum torvum* KAU1and *Solanum torvum* TNAU1 did not showed any wilt incidence and hence these were considered as highly resistant to bacterial wilt in artificial inoculation (Figure 5). Such varying reactions towards bacterial wilt incidence under artificial inoculation have been reported by Dutta and Rahman (2012), Rahman *et al.* (2011), Kim *et al.* (2016) and Sadarunnisa *et al.* (2018) under artificial inoculation.

Variation in the percent disease incidence in screening genotypes for resistance to bacterial wilt in wilt sick field was might be due to non-uniform distribution of the pathogen in the entire wilt sick field. Hence screening for resistance under field condition in the wilt sick soil may not give a uniform result. Disease incidence through artificial inoculation methods depends on the concentration of the inoculum, age of the plants, and environment in which plants are kept and also the reaction of the host. Hence, inoculation of plants under artificial inoculation by bacterial ooze collected from diseased plants show variation in percent disease incidence as the suspension contains both virulent and avirulent colonies and also the exo-polysaccharides with other micro flora (Artal *et al.*, 2013).

Significant difference was observed among the genotypes for the number of days to wilt incidence. When averages of all the methods were taken, the genotype *Solanum sisymbrifolium* took maximum number of days to wilt (16.81 days) when compare to susceptible check Pusa Ruby (9.77 days) (Figure 6). Such variation in

number of days to wilt incidence were also reported by Thomas *et al.* (2015) and Rahman *et al.* (2011)

Significant differences were observed among the three inoculation methods (root dip, stem inoculation and media drenching) in inducing bacterial wilt incidence in the genotypes with respect to number of days to wilt incidence and percent disease incidence (PDI). The root dip method recorded highest per cent of disease incidence in both susceptible genotype *Solanum sisymbrifolium* (86.67 per cent) and the susceptible check

Pusa Ruby (100 per cent) when compared to media drenching (*Solanum sisymbrifolium* - 73.33 per cent and the susceptible check Pusa Ruby - 86.67 per cent) and stem injection (*Solanum sisymbrifolium* - 60 per cent and the susceptible check Pusa Ruby – 73.33 per cent) methods. Minimum number of days to wilt incidence was also the lowest in root dip method in both susceptible genotype *Solanum sisymbrifolium* (11.7 days) and the susceptible check Pusa Ruby (7.2 days) when compared to media drenching (*Solanum sisymbrifolium* – 26.5 days and the susceptible check Pusa Ruby – 11.25 days) and stem injection (*Solanum sisymbrifolium* – 12.25 days and the susceptible check Pusa Ruby – 10.86 days) methods. Hence, root dip method was found most efficient inoculation method when compared to media drenching and stem inoculation methods in artificial inoculation of brinjal genotypes. Artal *et al.* (2013) reported media drenching was most effective method of inoculation in Solanaceous vegetables (tomato, eggplant, hot pepper and sweet pepper) when compared to leaf clipping and axial puncturing methods. Hence, it clearly shows that inoculation methods may also rely upon host. Thomas *et al.* (2015) found that petiole inoculation was the best method for checking bacterial wilt incidence under artificial inoculation in tomato genotypes when compared to five different inoculation methods such as seed-soaking in inoculum, seed-sowing followed by inoculum drenching, petiole-excision inoculation in two week old seedlings, soaking of seedlings root in inoculum either directly or after imparting seedling root-injury.

5.3. Field evaluation of grafts

Grafted plants have been extensively used in the polyhouse cultivation and open precision farming of vegetable crops to produce high yield on vigorous rootstocks.

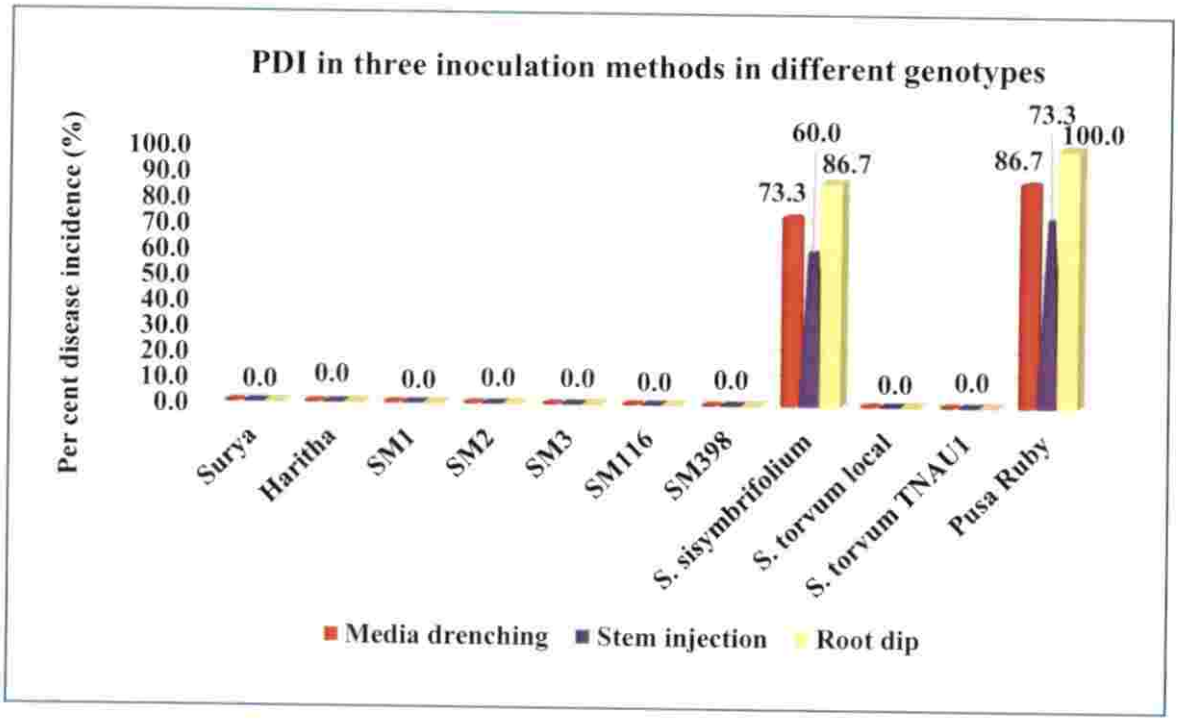


Figure 5. Percent disease incidence (PDI) in genotypes during artificial inoculation

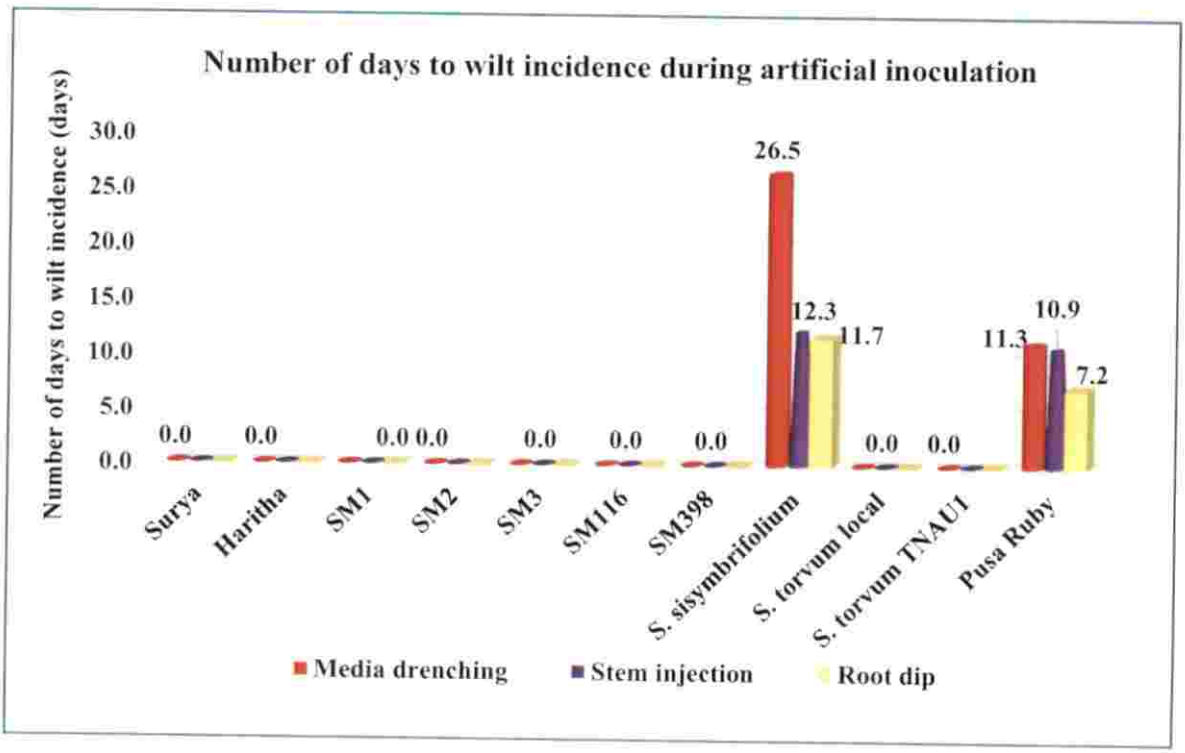


Figure 6. Number of days to wilt incidence in genotypes during artificial inoculation

Grafting utilises valuable traits of a desirable rootstock such as vigour, increased yield, improved fruit quality and tolerance and resistance to both biotic and abiotic stresses (environmental stress). Grafted plants of eggplant on *Solanum torvum* and *Solanum khasianum* rootstocks showed 100 per cent bacterial wilt resistance and exhibited significant differences for important quantitative characters *viz.,* plant height, number of fruits per plant, fruit length, diameter of fruit, weight of individual fruit, fruits per plant, yield per plant, total yield, root length, fresh weight and dry weight of roots when compared to non-grafted control (Kumar, 2015). In the present study also significant differences were observed with respect to plant height among the rootstocks when compared to non-grafted control. Irrespective of the rootstocks used all the grafted plants produced significantly higher plant height than control plants at 30, 60, 90 and 120 DAT (days after transplanting). Plant height, which may be considered as an indicator of vigour was highest in SM116 when compared to all other rootstocks and non-grafted control at 30 (36.65 cm), 60 (109.4 cm), 90 (118.25 cm) and 120 DAT (128.7 cm) followed by Haritha rootstock. This shows that rootstocks have significant influence in conferring vigour to the scions. Minimum plant height was recorded in non-grafted control at 30 (30.55 cm), 60 (95.6 cm), 90 (102.7 cm) and 120 DAT (111.35 cm). Increased plant height in grafted plants at 90 DAT was given in Figure 7. This increased plant height in grafted plants may be due to significantly longer roots length and spread in all the grafted plants compared to non-grafted control plant. The results of this study are in conformity with the results of Bletsos (2003), Passam *et al.* (2005) and Khah *et al.* (2006) who observed increased plant height and vigour in grafted vegetable crops when compared to non-grafted plants. They have reported that increased plant height and vigour in grafted plants was due to healthy root system which helped the grafts in efficient absorption of water, minerals and nutrients.

Significant differences were observed with respect to plant spread among the rootstocks when compared to non-grafted control. Irrespective of the rootstocks used all the grafted plants produced significantly higher plant spread when compared to control at 30, 60, 90 and 120 DAT. Increased plant spread in grafted plants at 90 DAT was given in Figure 8. Highest plant spread was recorded in Haritha rootstock and lowest plant spread was recorded in non-grafted control. It was also observed that rootstocks which produced more height exhibited higher plant spread and this was might be due to

direct relationship between plant height and root spread. Increased plant spread in grafted plants may be due to increased vigour of grafted seedlings and also due to better and improved root system which helped the grafted plants for better absorption of water, minerals and essential nutrients. These results are in conformity with the study conducted by Mora *et al.* (1999), Bletos (2003) and Bekhradi *et al.* (2012).

There was significant difference with respect to stem girth among the rootstocks when compared to control. Irrespective of the rootstocks used all the grafted plants produced significantly higher stem girth than control plants at 30, 60, 90 and 120 DAT. Increased stem girth in grafted plants at 90 DAT was given in Figure 9. Rootstock Haritha produced maximum stem girth among all the rootstocks and control at 30 (3.25 cm), 60 (7.52 cm), 90 (8.70 cm) and 120 DAT (10.17 cm). Minimum stem girth was recorded in non-grafted control at 30 (2.62 cm), 60 (6.00 cm)), 90 (7.0 cm) and 120 DAT (8.02 cm). Increased stem girth in grafted plants may be due to increased vigour exhibited by grafted plants with respect to plant height and spread by higher root length and root spread (vigorous root system) which helped the grafts for efficient absorption of water, minerals and nutrients (Bletsos, 2003). The results of this study are in conformity with the results of Gisbert *et al.* (2011), Davis and Perkins-Veazie (2005) and Alan *et al.* (2007) who observed increased stem girth in grafted vegetable crops when compared to non-grafted plants.

Number of primary branches recorded on 30, 60, 90 and 120 DAT varied significantly among all the grafted and control plants. All the grafts produced significantly higher number of primary branches than control plants (Figure 10). Haritha rootstock produced the highest number of primary branches among all the rootstocks at 30 (3), 60 (8.20), 90 (8.85) and 120 (10.3) DAT. Minimum number of primary branches were recorded in non-grafted plants at 30 (1), 60 (5.25), 90 (7.0) and 120 (7.5) DAT. This might be attributed due to increased vigour determined by increased plant height and plant spread. Khatun, (2011) also reported significant positive correlation in brinjal genotypes between plant height, number of primary branches, Days to 50% flowering, days to first harvest, number of fruits per plant, fruit diameter and yield per plant.

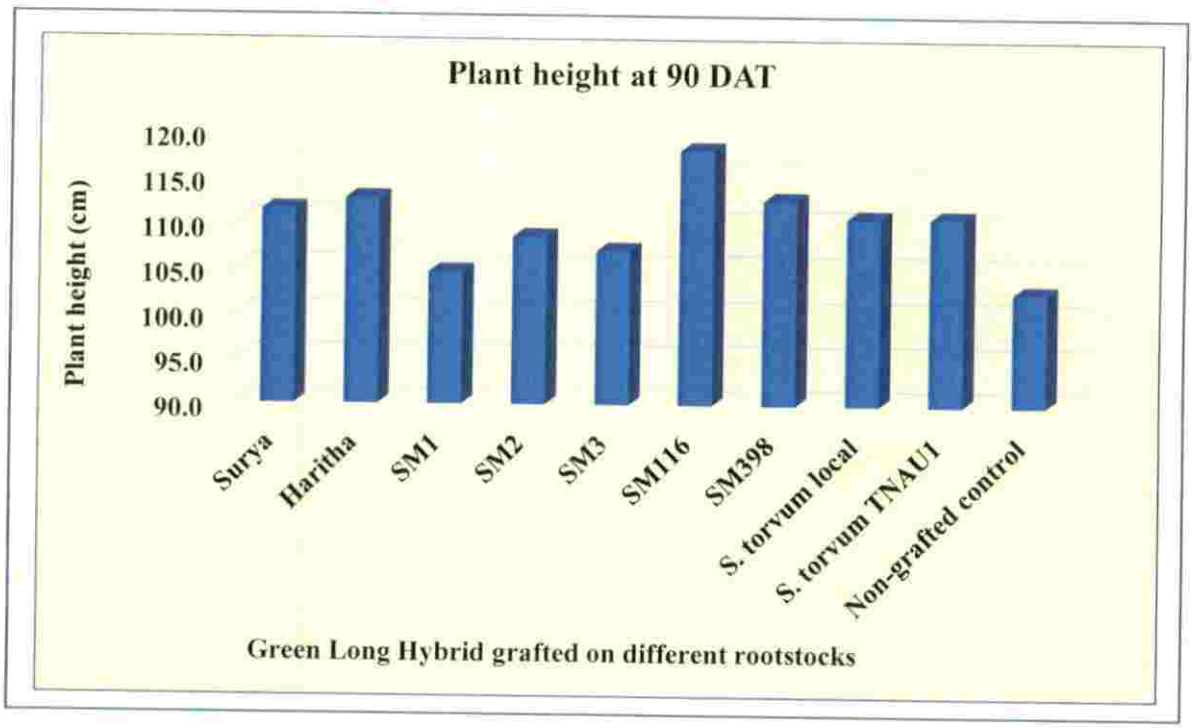


Figure 7. Plant height at 90 DAT during field evaluation of grafts

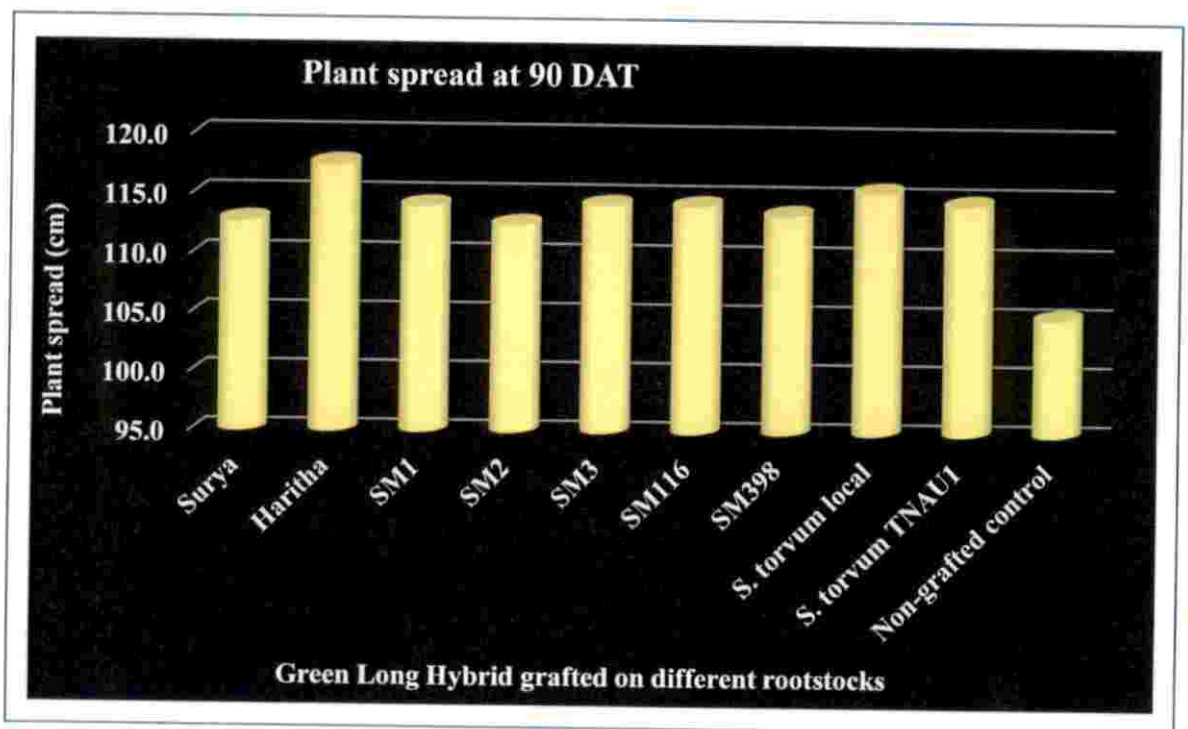


Figure 8. Plant spread at 90 DAT during field evaluation of grafts

Significant differences were observed with respect to days taken for first flower opening among all the grafted plants and control irrespective of the rootstocks used (Figure 11). Surya (41.80 days), Haritha (41.45 days) and SM398 (42.85 days) rootstocks produced early flowering whereas SM1 (42.10 days), SM2 (42.85 days), SM3 (43.60 days), SM116 (42.8 days), *Solanum torvum* KAU1(47.65 days) and *Solanum torvum* TNAU1 (48.67 days) rootstocks were late flowering when compared to the non-grafted control (41.85 days). Surya (41.80 days) and *Solanum torvum* TNAU1 (48.65 days) rootstocks were took minimum and maximum days to first flower opening respectively compared to control (41.85 days) plants. In grafted plants the movement of endogenous flowering substances across the graft union is easy. These results are in conformity with the findings of Ibrahim *et al.* (2014). They attributed that early flowering in grafted plants may be due to healthy root system of the rootstocks used, which has resulted in increased water and nutrient uptake. Kumar (2016) reported early flowering in grafted chilli (PI-201232 rootstock) when compared to control. Khan *et al.* (2006) reported increased earliness in eggplant grafted onto two tomato hybrids. Increased earliness in melon plants when grafted onto *Cucurbita* rootstocks has also been reported by Cohen *et al.* (2002) and Fita *et al.* (2007).

Rootstocks significantly affected the number of fruits per plant and all the grafts produced significantly higher number of fruits per plant than non-grafted control (Figure 12). Rootstock Haritha produced maximum number of fruits per plant (94.80) which was on par with SM398 (94.35) followed by SM116 (91.20) and Surya (79.30). Minimum number of fruits per plant (63.55) was recorded in non-grafted control plants. Grafting fruit vegetables on vigorous rootstocks improves the content of phytohormone (cytokinins) in scion which are transported through the xylem from rootstock to scion and this in turn improved the number of fruits per plant (Fernandez *et al.*,2013). Similar results were also reported by Khah *et al.* (2006), Gisbert *et al.* (2010) and Djidonou *et al.* (2013).

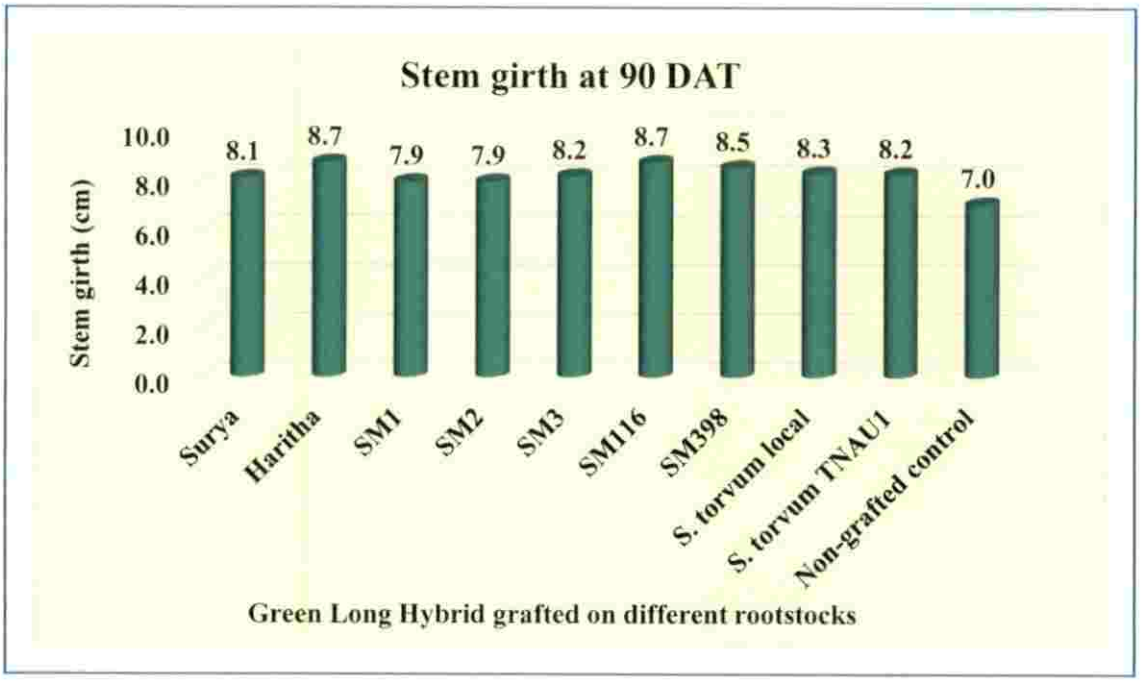


Figure 9. Stem girth at 90 DAT during field evaluation of grafts

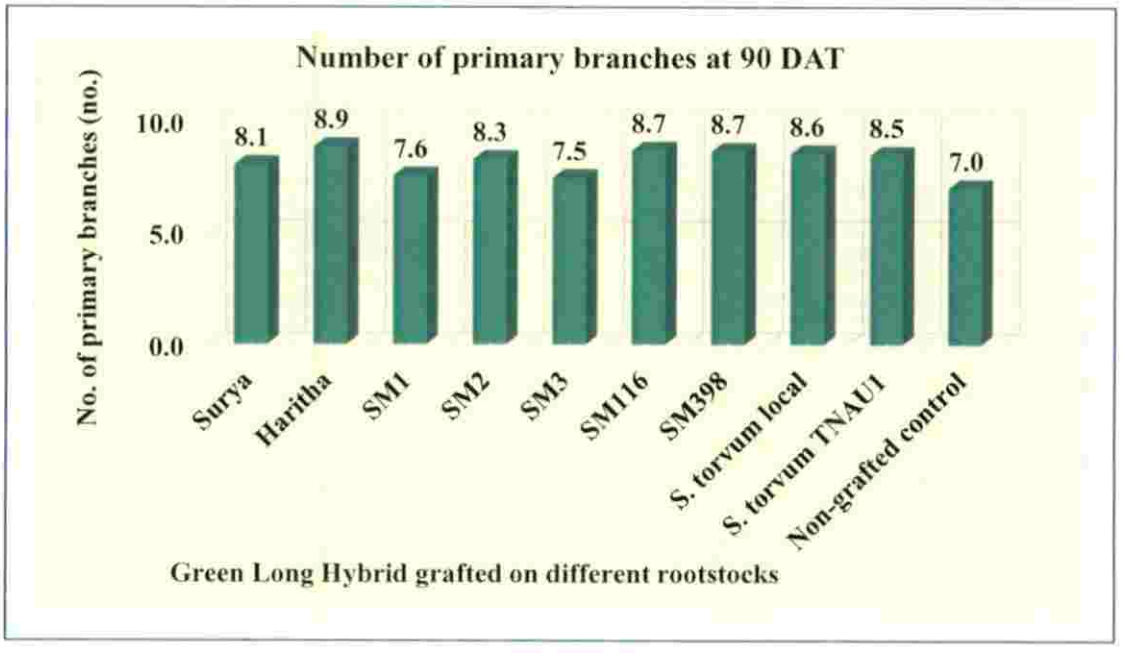


Figure 10. Number of primary branches at 90 DAT during field evaluation of grafts

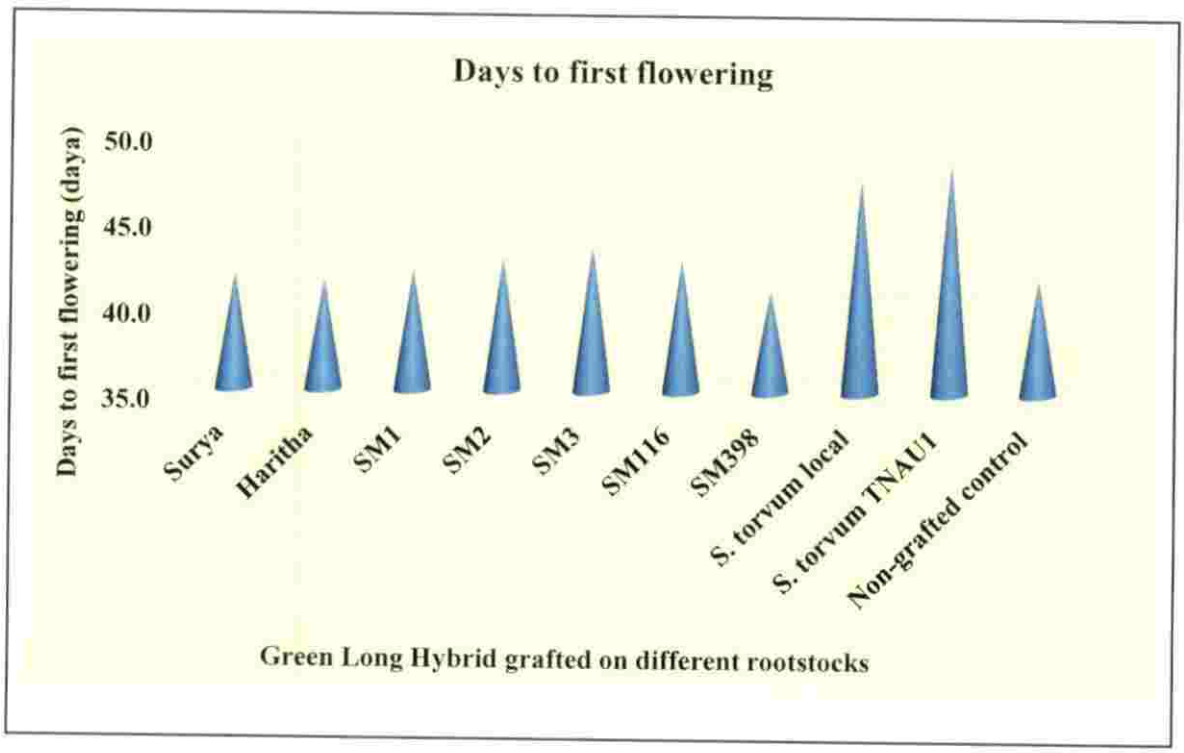


Figure 11. Days to first flowering during field evaluation of grafts

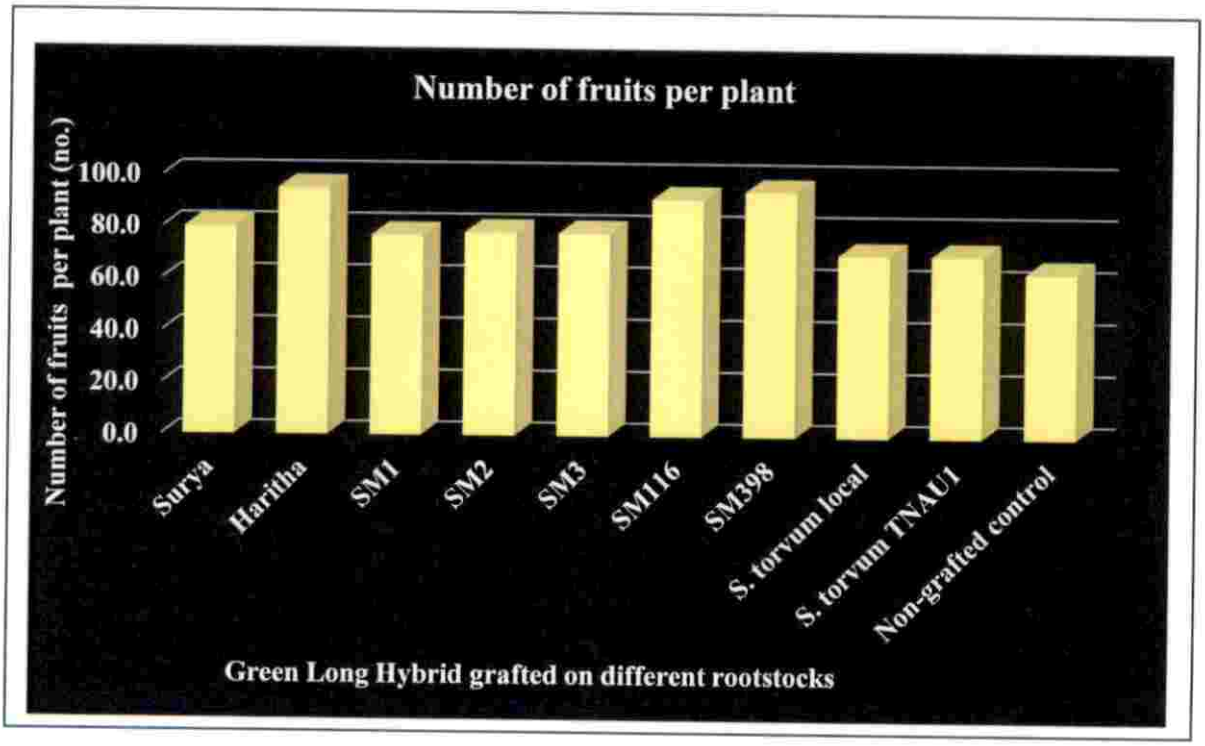


Figure 12. Number of fruits during field evaluation of grafts

Significant differences were observed with respect to yield per plant among the grafted plants and control irrespective of the rootstocks used. All the grafts produced significantly higher yield per plant when compared to non-grafted plants (Figure 13). Maximum yield per plant was recorded in Haritha rootstock (6.69 kg). Yield per plant of SM116 (6.62 kg) and SM398 (6.17 kg) rootstocks were statistically on par with each other followed by Surya (5.47 kg), SM3 (5.41 kg), SM2 (5.30 kg) and SM1 (5.17 kg) rootstocks. Minimum yield per plant was recorded in non-grafted control (4.08 kg) plants. Yield per plant expressed significant positive correlation with plant height, plant spread (East-West), plant spread (North-South), number of primary branches, stem girth, number of fruits per plant, fruit length, fruit girth, average fruit weight, root length and root spread. The rootstock (Haritha) which recorded the highest yield per plant also recorded the highest plant spread in both the direction (East-West and North-South), stem girth, number of primary branches, fruits per plant, yield per plant, fruit length, root length and root spread. Khatun, (2011) reported significant positive correlation in brinjal genotypes among plant height, number of primary branches, Days to 50% flowering, days to first harvest, number of fruits per plant, fruit diameter and yield per plant. The highest yield in grafted plants may be due to better and strong root system which helped the grafts with efficient absorption of water, minerals and nutrients, increased vigour and increased photosynthesis. The studies conducted by Lee (1994), Attia *et al.* (2003), Bletos (2003), Marsic and Osvald (2004), Davis *et al.* (2008b), Khah (2011), Voutsela *et al.* (2012), Moncada *et al.* (2013), Kumar (2015) and Sabatino *et al.* (2018), corroborate the above results.

Rootstocks significantly affected the fruit length and all the grafts produced significantly higher fruit length when compared to non-grafted control plants. Haritha rootstock exhibited maximum fruit length of 22.22 cm which was statistically on par with SM116 (22.15 cm) and SM398 (22.14 cm) rootstocks. Control plants exhibited minimum fruit length of 20.31 cm. Increase in the fruit length may be influenced by the changes in the concentration of plant growth regulators induced by the rootstock. Results were in conformity with the study conducted by Gisbert *et al.* (2011a), Kumar (2015) and Jang *et al.* (2012).

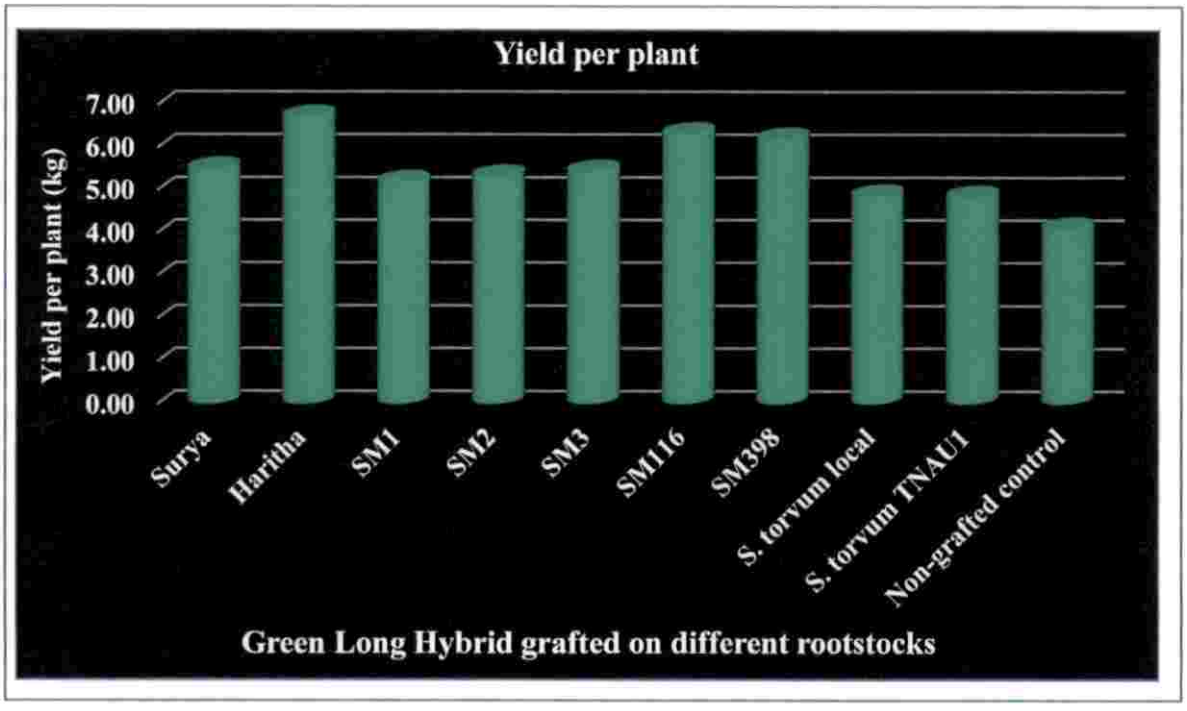


Figure 13. Yield per plant during field evaluation of grafts

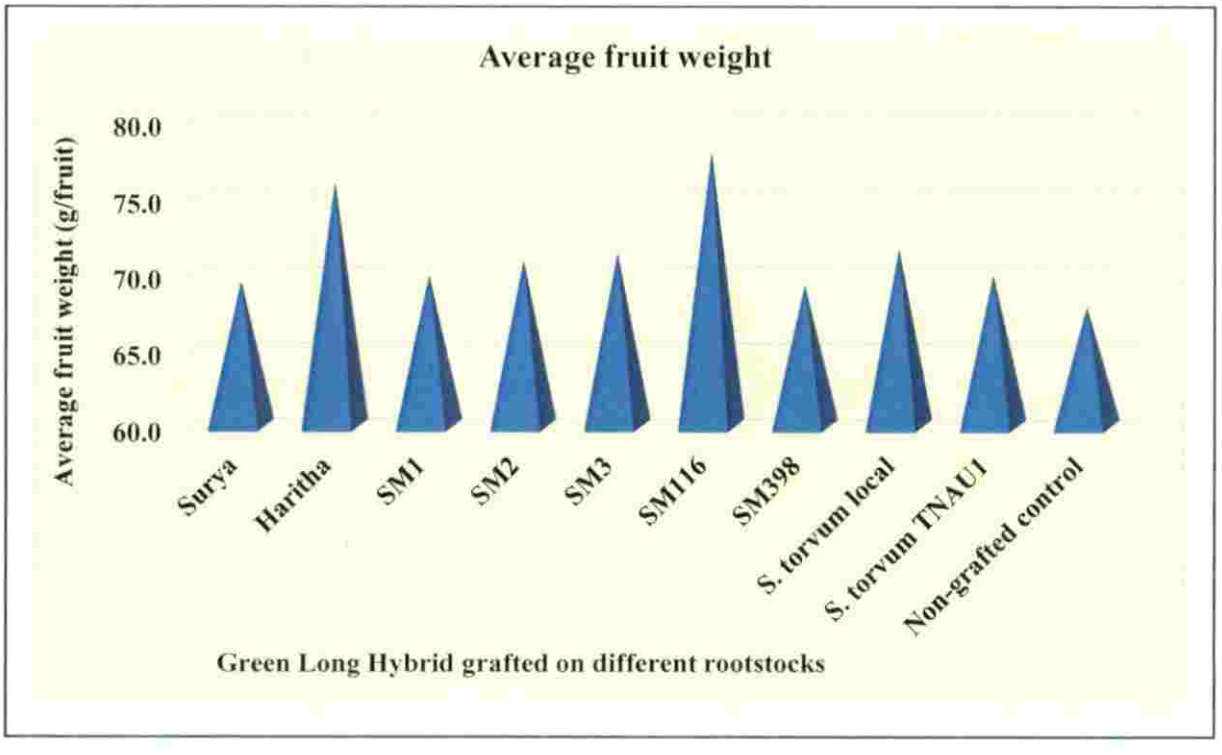


Figure 14. Average fruit weight during field evaluation of grafts

Significant difference was observed with respect to fruit girth in grafts when compared to control plants irrespective of the rootstocks used. All the grafts produced significantly higher fruit girth when compared to control plants. Maximum fruit girth was recorded in SM116 rootstock (10.97 cm) which was closely followed by Haritha rootstock (10.94 cm). Fruit girth of SM398 and SM3 were statistically on par with each other. Minimum fruit girth was recorded in non-grafted control (10.43 cm) plants. Rootstock induce modifications in the concentration of plant growth regulators which resulted in enhanced fruit girth compared to control. Results were inconformity with the study conducted by Jang *et al.* (2012), Kumar (2015), Gisbert *et al.* (2011a) and Moncada *et al.* (2013)

Rootstocks significantly influenced the average fruit weight and all the grafts recorded significantly higher average fruit weight when compared to non-grafted control plants (Figure 14). Average fruit weight was found maximum in SM116 rootstock (78.00 g) which was closely followed by Haritha rootstock (76.00 g). Average fruit weight was found minimum in non-grafted control (67.85 g) plants. Enhanced uptake of minerals, nutrients and water were influenced by rootstock-scion interaction which eventually led to increased fruits length and girth in plants grafted onto SM116 and Haritha rootstocks. The increased fruit length and girth in turn resulted in increased fruit weight. The findings of Khah *et al.* (2006), Davis *et al.* (2008), Djidonou *et al.* (2013), Fernandez *et al.* (2013) and Kumar (2015) were supported the above conclusions

No significant difference was observed among the grafts and control plants with respect to number of harvests. Hence it could be inferred that number of harvests is not either influenced by grafting in brinjal genotypes. The above results are contradictory to Kumar (2015) and Sabatino *et al.* (2018) who reported more number of harvests in grafted brinjal when compared to non-grafted control

No significant difference observed with respect to crop duration among all the rootstocks and control plants. Hence it could be inferred that to crop duration is not either influenced by genetic makeup or by grafting in genotypes. The above results are contradictory to Lee (1994) and King *et al.* (2008) who reported extended crop duration due to grafting in Solanaceous and Cucurbitaceous vegetables.

Rootstocks significantly influenced total phenol content in fruits (Figure 15). SM3, SM116, SM2, SM1 and *Solanum torvum* KAU1 rootstocks showed higher total phenolic content in fruits when compared to control. Surya, Haritha, SM398 and *Solanum torvum* TNAU1 rootstocks showed no significant variation in the phenol content when compared to control. Higher total phenolic content in grafted plants may be due to additional stress in rootstock/scion combination. Sabatino *et al.* (2016) reported increased phenolic content in fruits when eggplant genotypes were grafted onto *Solanum torvum* rootstock when compared to other rootstocks and non-grafted control plants. Dixon and Paiva (1995) and Moglia *et al.* (2008) reported accumulation of higher phenolics in grafted plants under stress condition. Moncada *et al.* (2013) reported decreased total phenol content in fruits of grafted plants when compared to non-grafted plants. Stommel and Whitaker (2003) documented divergence between allied eggplant species for fruit phenolic constituents.

Significant difference was observed with respect to dry matter content of fruits in grafted plants when compared to control (Figure 16). Highest dry matter was found in fruits of SM398 (11.12 per cent) rootstock which was closely followed by *Solanum torvum* TNAU1(11.12 per cent) rootstock. Surya rootstock (8.85 per cent) recorded lowest dry matter among all the grafts and control plants. Miceli *et al.* (2014) reported increased dry matter content of fruits in Birgah cultivar of brinjal grafted onto *Solanum torvum* rootstock. Raigon *et al.* (2008) found significant positive correlation between yield and dry matter of eggplant landraces and genotypes.

There was no significant difference observed with respect to total soluble solids (TSS) among all the rootstocks and control plants. TSS content in fruits ranged from 4.27 to 4.42 percent. Soluble solids content of fruits was may be not influenced by grafting or rootstocks. Similar results were also obtained by Miguel *et al.* (2004), Davis *et al.* (2008), Rouphael *et al.* (2010), Sabatino *et al.* (2013) and Kumar (2015).

Maximum number of wilted plants (5.75) and maximum PDI (28.75 %) were observed in non-grafted control plants and only one plant wilted in grafted plants of *Solanum torvum* KAU1 and *Solanum torvum* TNAU1 rootstocks. This might be due to genetic effect of rootstocks which showed resistance to bacterial wilt disease in grafted plants when compared to control.

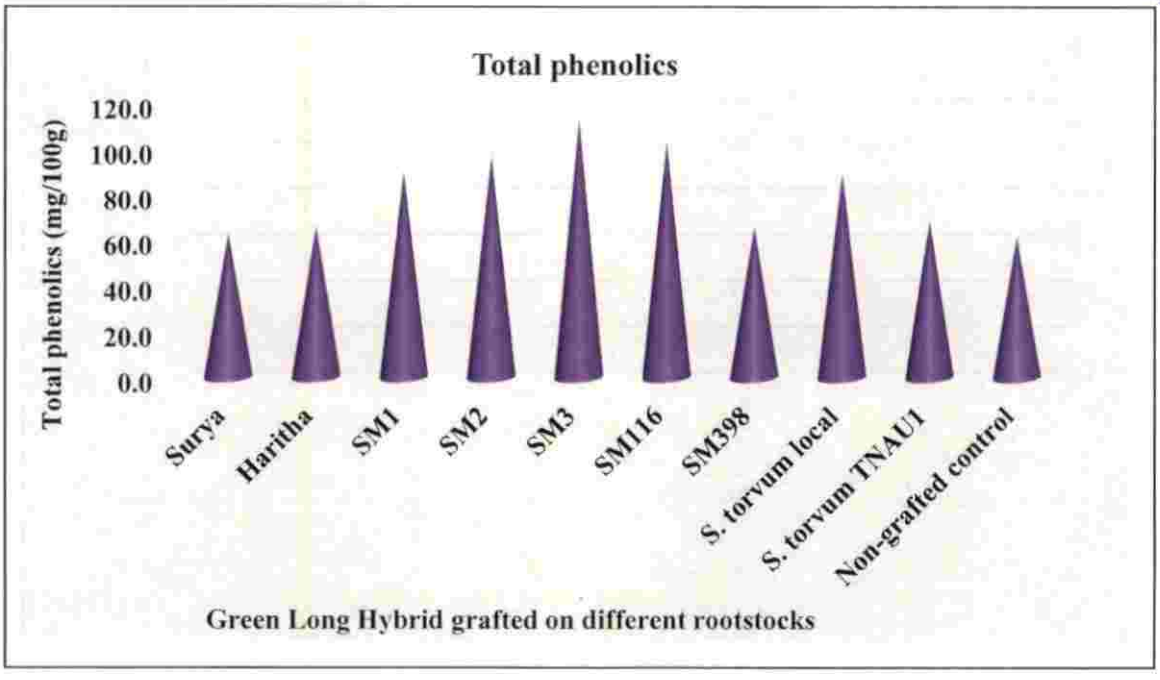


Figure 15. Total phenolic from fruits during field evaluation of grafts

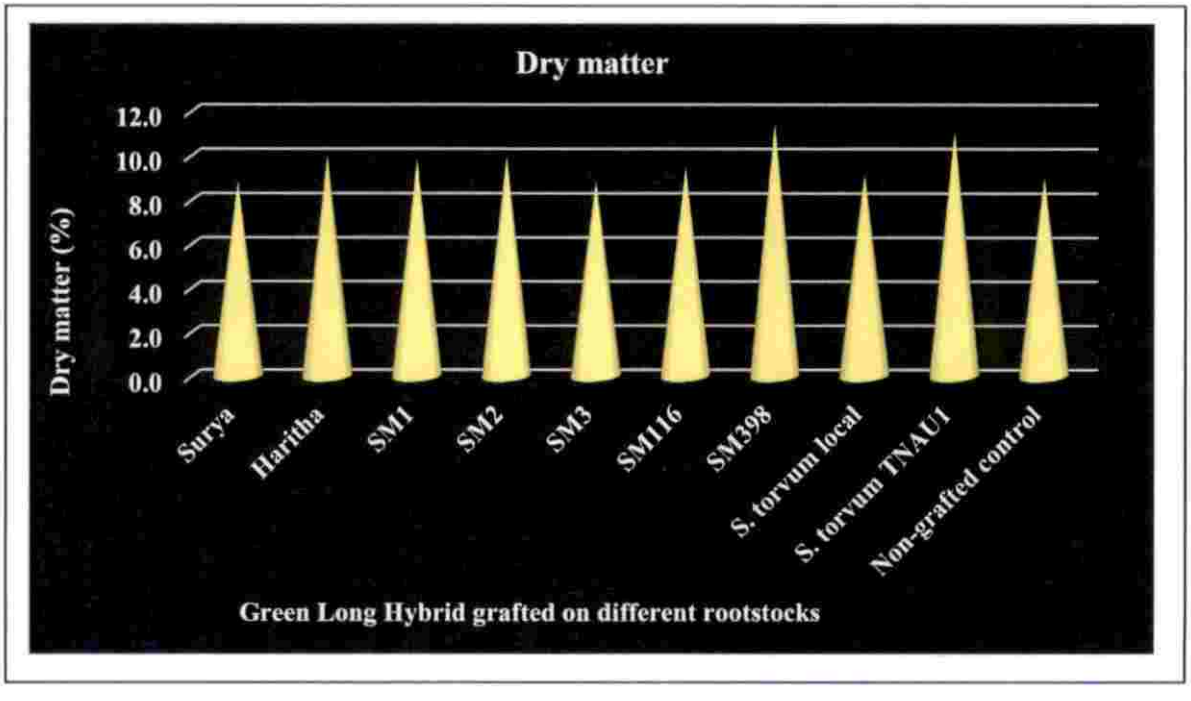


Figure 16. Dry matter content from fruits during field evaluation of grafts

Higher number of wilted plants in non-grafted plants of brinjal when compared to grafts was reported by Gisbert *et al.* (2011), Kumar (2015) and Bhavana and Singh (2016).

Rootstocks significantly and highly influenced the root length. All the grafted plants produced significantly longer root length than non-grafted control plants (Figure 17). Maximum root length was produced on Haritha (63.65 cm) rootstock followed by *Solanum torvum* TNAU1 (62.20 cm) and SM116 (61.05). Root length of SM398 (60.2 cm), SM3 (59.85 cm) and *Solanum torvum* KAU1(59.60 cm) rootstocks were statistically on par with each other. Minimum root length was recorded in control (46.05 cm) plants.

Rootstocks significantly influenced the root spread and all the grafted plants produced significantly higher root spread than non-grafted control plants (Figure 18). Haritha rootstock produced maximum root spread of 87.05 cm among all the grafted and control plants. Root spread of *Solanum torvum* TNAU1(82.30 cm), SM116 (82.20 cm), SM398 (81.95 cm), *Solanum torvum* KAU1(81.80 cm) and SM3 (81.60 cm) rootstocks were statistically on par with each other. Minimum root spread was recorded in control (63.45 cm) plants. Root length and spread expressed significant positive correlation with plant height, plant spread (East-West), plant spread (North-South), stem girth, number of primary branches, yield per plant, fruit length and fruit girth. It is well known that the root system of the plants affects vegetative growth and yield. Increased root length and spread may be due to interaction between rootstocks and scions resulting in high vigour of the root system and efficient uptake of water, mineral and nutrients by the roots, or even to the distribution of growth regulators leading to increased yield and fruit enhancement. Similar results were reported by many researchers Lee, (1994), Ioannou, *et al.* (2002); Marsic and Osvald, (2004), Bletos (2003), Alan *et al.* (2007), Miceli *et al.* (2014) and Kumar (2015).

Rootstocks did not influence the incidence of pest and diseases because major pests of brinjal such as fruit and shoot borer, jassids, aphids, white flies and mites were reported in all the grafted and non-grafted control plants. There was no severe disease incidence was reported throughout the experimental period. Hence it could be inferred

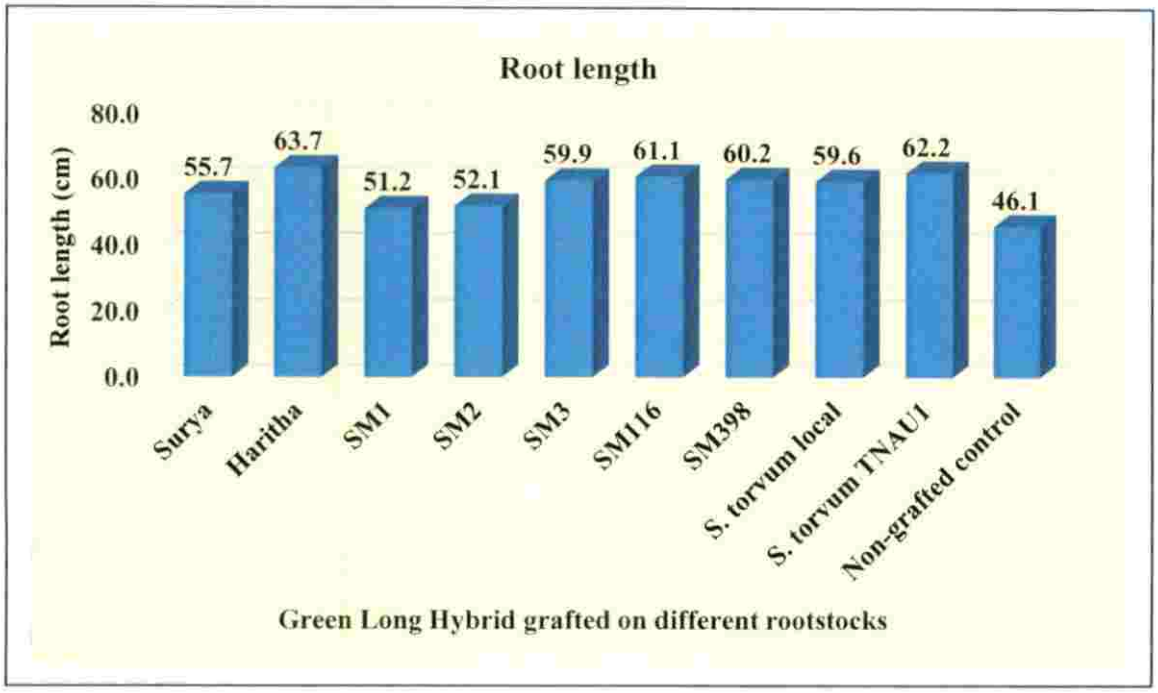


Figure 17. Root length during field evaluation of grafts

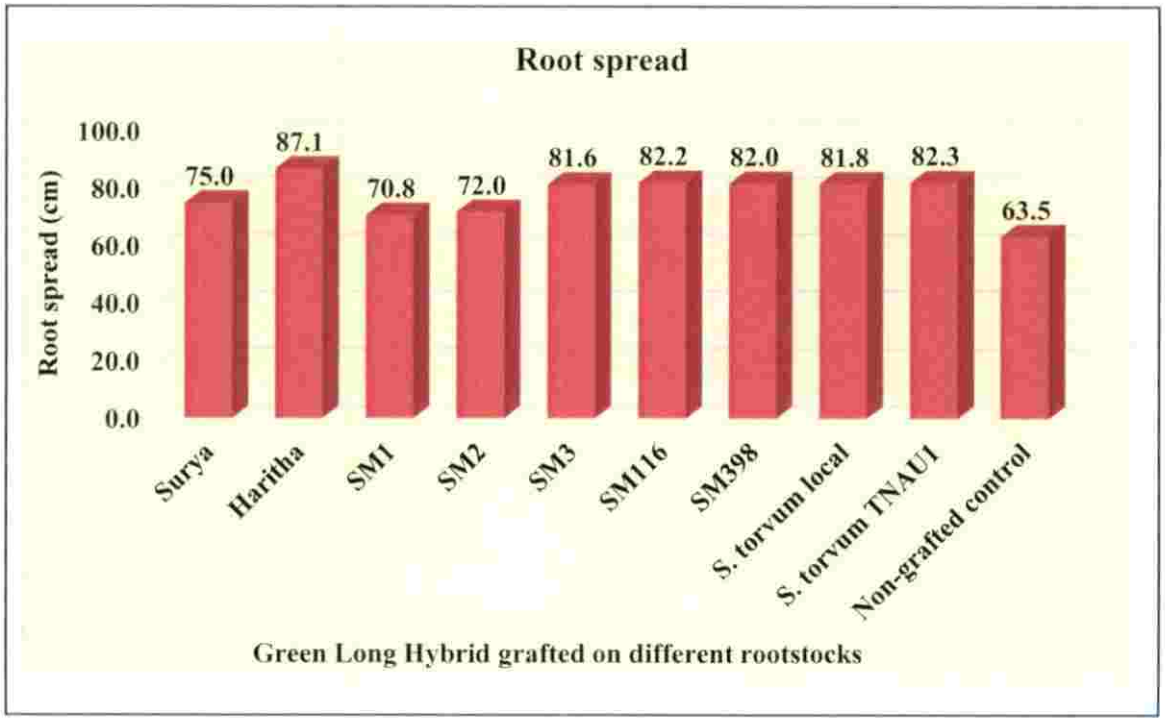


Figure 18. Root spread during field evaluation of grafts

that incidence of pest and diseases is not either influenced by rootstocks or by grafting in brinjal.

Yield per plant expressed significant positive correlation with stem girth, number of fruits per plant, fruit length, fruit girth, plant height, plant spread, number of primary branches, average fruit weight, root length and root spread. Fruit girth exhibited significant positive correlation with stem girth, yield per plant, fruits per plant, fruit length, plant height, average fruit weight, root length, root spread and TSS. Significant positive correlation was also observed between average fruit weight and plant height, stem girth, yield per plant, fruit girth and TSS. Fruits per plant exhibited significant positive correlation with stem girth, yield per plant, fruit length, fruit girth, plant height, number of primary branches and TSS. The results of the present study were in agreement with the results obtained by previous studies for various qualitative and quantitative characters conducted by Baswana *et al.* (2002) and Mohanty (2002). Sujin *et al.* (2017) reported significant positive correlation in brinjal cultivars between fruit weight, fruit girth and number of fruits per plant. Khatun, (2011) reported significant positive correlation in brinjal genotypes between plant height, number of primary branches, Days to 50% flowering, days to first harvest, number of fruits per plant, fruit diameter and yield per plant.

SUMMARY

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6. SUMMARY

Brinjal (*Solanum melongena* L.) is a versatile crop adapted to different agro-climatic regions. It is one of the most common tropical vegetables grown throughout the year in India. Brinjal is grown for its immature fruits which are used in a variety of ways like roasted, fried, stuffed, cooked as a curry, pickles and it has attained a considerable position in Indian culinary in the form of *Bharta*. It has much potential as a raw material for pickle preparation and dehydration industries (Goiterogenic principle).

Although not a widely grown crop in Kerala, the area under this crop is expanding day by day due to its increasing popularity. There are many high yielding varieties and hybrids, both from public and private sector, released for commercial cultivation but in Kerala, all of them are highly prone to the bacterial wilt disease. Hence, identification of genotypes having desirable qualitative and quantitative characters, with good yield potential along with resistance to bacterial wilt is very essential for successful cultivation of brinjal in the state. Grafting is widely practiced in Solanaceous vegetables (Tomato, Brinjal, Chilli and Capsicum) all over the world and the vegetable growing farmers in Kerala who are growing hybrids especially under precision farming system of cultivation are commercially utilising grafted seedlings. Grafted plants on resistant rootstocks of Solanaceous vegetables were highly resistant to bacterial wilt and high yielding (Narayanankutty *et al.*, 2015).

Hence considering the importance of eggplant cultivation in the state as well as the occurrence of severe incidence of bacterial wilt in the crop, the present investigation entitled as "Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)" was undertaken at Agricultural Research Station, Mannuthy and Centre for Hi-Tech Horticulture and Precision Farming, Vellanikkara, Thrissur during the year 2018-2019. Ten available rootstocks comprising of *Solanum torvum* (2 collections- a local KAU collection and a collection from TNAU), *Solanum sisymbrifolium* (one collection) and *Solanum melongena* (7 Collections-Surya, Haritha, SM1, SM2, SM3, SM116 and SM398) were used with the objective of evaluation of rootstocks for resistance to bacterial wilt and to study the field performance of grafted brinjal plants on resistant rootstocks. The results of the investigation carried out in three experiments namely field

evaluation of rootstocks, artificial inoculation and field evaluation of grafts are summarized below here.

1. Field evaluation of rootstocks

Genotypes such as Surya, Haritha, SM3 and SM116 did not show any wilt incidence even when spot planted with susceptible check genotype Pusa Ruby which showed 100 percent wilt incidence and these genotypes were categorised as highly resistant to bacterial wilt. SM398 (40 % PDI), SM2 (40 % PDI), SM1 (23.3 % PDI), *Solanum torvum* KAU1(16.6 % PDI) and *Solanum torvum* TNAU 1 (20 % PDI) were found moderately resistant to bacterial wilt. *Solanum sisymbrifolium* was highly susceptible to bacterial wilt with 96.6% wilt incidence. The Percentage Disease Incidence (PDI) in check genotype Pusa Ruby was ranged from 86.67 percent to 100 percent.

Highly susceptible genotype *Solanum sisymbrifolium* spot planted with Pusa Ruby took minimum number of days to wilt incidence (23.40 days) whereas SM398 took maximum days to wilt (32.3 days) followed by SM1 (30.3 days), *Solanum torvum* TNAU 1 (29.0 days), SM2 (28.7 days) and *Solanum torvum* KAU1(26.8 days).

2. Artificial inoculation

The genotype *Solanum sisymbrifolium* exhibited 73.33 per cent wilt incidence along with the susceptible check Pusa Ruby which exhibited 86.6 per cent wilt incidence were classified as susceptible to bacterial wilt.

All other genotypes *viz.,* Surya, Haritha, SM1, SM2, SM3, SM116, SM398, *Solanum torvum* KAU1and *Solanum torvum*TNAU1 did not show any wilt incidence under artificial inoculation and these were classified as resistant to bacterial wilt. *Solanum sisymbrifolium* took more number of days to wilt (16.81 days) when compared to the susceptible check Pusa Ruby (9.77 days).

There was significant difference among the three inoculation methods (root dip, stem inoculation and media drenching) in inducing bacterial wilt in the genotypes with respect to number of days to wilt incidence and percent disease incidence (PDI). The root dip method recorded highest per cent of disease incidence (16.97 per cent) when compared to media drenching (14.55 per cent) and stem injection (12.12 per cent)

methods. The number of days to wilt incidence was also the lowest in root dip method (1.71days) followed by stem inoculation (2.10 days) and media drenching (3.43 days) methods.

From above studies it could be summarised that genotypes Surya, Haritha, SM3 and SM116 are resistant to bacterial wilt while *Solanum sisymbrifolium* along with susceptible check Pusa Ruby was susceptible to bacterial wilt.

3. Field evaluation of grafts

Significant differences were observed with respect to plant height, plant spread, stem girth and number of primary branches among all the rootstocks used when compared to non-grafted control. Irrespective of the rootstocks used all the grafted plants produced significantly higher plant height, plant spread, stem girth and number of primary branches than control plants at 30, 60, 90 and 120 DAT. Maximum plant height was recorded in SM116 rootstock followed by Haritha. Maximum plant spread, stem girth and number of primary branches were recorded in Haritha rootstock. Lowest performance of all the above parameters were recorded in non-grafted control plants.

Irrespective of the rootstocks used, all the grafted plants showed significant difference with respect to days to first flowering, fruits per plant, fruit length, fruit girth, average fruit weight, yield per plant, total phenolic, dry matter, number of wilted plants, root length and root spread among all the rootstocks used when compared to control plants. The highest number of fruits per plant (94.80), yield per plant (6.69 kg), fruit length (22.22 cm), root length (63.65 cm) and root spread (87.05 cm) was recorded when cultivar Haritha was used as a rootstock. SM116 rootstock recorded the highest fruit girth (10.97 cm) and average fruit weight (78.00 g). The total phenolic content was the highest when SM3 (113.30 mg) was used as rootstock. Highest dry matter content was found in fruits of SM398 (11.12 per cent) rootstock which was closely followed by *Solanum torvum* TNAU1(11.12 per cent) rootstock. Maximum number of wilted plants were observed in non-grafted control (5.75) plants. The performance of non-grafted control plants was poor for all the fruits per plant, fruit length, fruit girth, average fruit weight, yield per plant, total phenolic, root length and root spread characters studied except for days to first flowering and total dry matter content of fruits.

Grafting did not prolong the duration of the crop or increased the number of harvests and total soluble solids. It had no significant effect on incidence of other pests and other diseases on the crop except for bacterial wilt.

From above studies it could be summarised that rootstock Haritha was found to be best, which recorded the highest plant spread, stem girth, number of primary branches, fruits per plant, yield per plant, fruit length, root length and root spread followed by SM116 rootstock which recorded the highest plant height, fruit girth and average fruit weight.

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Appendix I. Weather data during experiment period

Sl. No.	Month	Temperature						RH (%)			Rainfall (mm)			Sunshine hours		
		Min (°C)			Max (°C)											
		2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019	2017	2018	2019
1	January	22.9	20.9	20.4	34.1	33.5	32.9	53	55	55	0	0	0	7.6	8.2	8.4
2	February	23.3	23.2	23.4	36	35.7	35.3	51	58	59	0	0	0	8.7	9.5	8.7
3	March	24.7	24	24.8	36.1	36.7	36.7	67	66	65	13.2	5.2	0	7.4	8.4	8.6
4	April	26	24.8	25.5	35.7	36.1	36.2	70	69	70	19.1	28.9	76.4	6.5	7.3	8
5	May	24.9	22.6	25.3	34.6	33.2	36.4	72	79	72	167.5	483.6	70.1	5.5	4.8	8.2
6	June	23.5	23.2		30.4	29.8		87	89		630.2	730		2	1.7	
7	July	22.8	22.5		30.8	29.6		85	88		385.5	793.2		2.9	1.9	
8	August	23.3	22.5		30.1	29.2		87	87		470	928		3.1	2.2	
9	September	22.9	22.5		31.5	32.2		84	75		413.9	290		4.2	7.2	
10	October	22.3	22.9		31.7	32.8		81	76		183.4	393		4.9	5.7	
11	November	21.8	23.3		33	32.7		73	68		58.3	66.6		6.4	6.9	
12	December	21.1	22.5		32.4	33		63	63		11.5	0		7.3	7	

Rootstock evaluation and grafting studies in brinjal (*Solanum melongena* L.)

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ABSTRACT OF THE THESIS

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ABSTRACT

The present investigation was conducted at Agricultural Research Station, Mannuthy and Centre for Hi-Tech Horticulture and Precision Farming, Vellanikkara, Thrissur during the year 2018-2019 with the objective to evaluate ten available rootstocks comprising of Surya, Haritha, SM1, SM2, SM3, SM116, SM398, *Solanum sisymbrifolium, Solanum torvum* KAU1, *Solanum torvum* TNAU1 for resistance to bacterial wilt in both field evaluation and artificial inoculation and to study the field performance of grafted brinjal plants on bacterial wilt resistant rootstocks.

In the field trials *Solanum sisymbrifolium* was highly susceptible to bacterial wilt with 96.6% wilt incidence whereas SM398 (40% PDI), SM2 (40% PDI), SM1 (23.3% PDI), *Solanum torvum* KAU1 (16.6% PDI) and *Solanum torvum* TNAU1 (20% PDI) were found moderately resistant to bacterial wilt. Genotypes such as Surya, Haritha, SM3 and SM116 found highly resistant to bacterial wilt even when spot planted with susceptible check genotype Pusa Ruby which showed 100 percent wilt incidence. The PDI in check genotype Pusa Ruby ranged from 86.67 per cent to 100 per cent. *Solanum sisymbrifolium* spot planted with Pusa Ruby took minimum number of days to wilt incidence (23.40 days) whereas SM398 took maximum days to wilt (32.3 days).

Under artificial inoculation the genotype *Solanum sisymbrifolium* exhibited 73.33 per cent wilt incidence along with the susceptible check Pusa Ruby which exhibited 86.6 per cent wilt incidence and both the genotypes were classified as susceptible to bacterial wilt. All other genotypes *viz.,* Surya, Haritha, SM1, SM2, SM3, SM116, SM398, *Solanum torvum* KAU1 and *Solanum torvum* TNAU1 did not show any wilt incidence under artificial inoculation and were resistant to bacterial wilt. *Solanum sisymbrifolium* took more number of days to wilt (16.81 days) when compared to the susceptible check Pusa Ruby (9.77 days). The root dip method recorded highest PDI in both susceptible genotype *Solanum sisymbrifolium* (86.67%) and the susceptible check Pusa Ruby (100%) when compared to media drenching and stem injection methods and the number of days to wilt incidence was also the lowest in root dip method (11.70 days) followed by stem inoculation (12.25 days) and media drenching (26.50 days).

Significant differences were observed with respect to plant height, plant spread, stem girth, number of primary branches, fruits per plant, fruit length, fruit girth, average fruit weight, yield per plant, total phenolic, dry matter, number of wilted plants, root length and root spread

among all the rootstocks used when compared to non-grafted control and all the grafted plants produced significantly better performance for all the above parameters irrespective of the rootstocks used. Maximum yield per plant (6.69 kg), number of fruits per plant (94.80), plant spread, stem girth, number of primary branches, fruit length (22.22 cm), root length (63.65 cm) and root spread (87.05 cm) were recorded when cultivar Haritha was used as a rootstock. The highest plant height, fruit girth (10.97 cm) and average fruit weight (78.00 g) were recorded on SM116 rootstock. Highest dry matter content was found in fruits of grafted plants of SM398 (11.12%) and the total phenolic content was the highest when SM3 (113.30 mg/100g) was used as rootstock. Maximum numbers of wilted plants were observed in non-grafted control. The performance of non-grafted control plants was poor for all the above characters studied. Grafting did not significantly influence earliness, duration of the crop or number of harvests or total soluble solids content of fruits in brinjal. It had no significant effect on incidence of other pests on the crop except for bacterial wilt.

From above studies it could be summarised that spot planting could be used as an effective tool for screening brinjal genotypes against bacterial wilt. Grafting technology could be successfully utilised in brinjal not only for bacterial wilt resistance but also for obtaining higher productivity. Haritha was found to be best rootstock for grafting in brinjal as it recorded significantly higher yield per plant, number of fruits per plant, plant spread, stem girth, number of primary branches, fruit length, root length and root spread followed by SM116 rootstock which recorded the highest plant height, fruit girth and average fruit weight.