**Varietal Response of Tomato Cultivars to *Meloidogyne incognita* and *Fusarium oxysporum* a Disease Complex in China**

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**Abstract:** *Meloidogyne incognita* (*Mi*)and *Fusarium oxysporum**(Fo)*are major pest of vegetables all over the world especially tropical and sub-tropical areas. All commercial tomato cultivars showed variation response to *Mi* and *Fo.* The objective of this study to find out resistant cultivars in order to facilitate growers and breeders for cultivation and gene manipulation. A greenhouse study was directed to evaluate twenty commercial tomato cultivars against *Mi* (1500 J2) and *Fo* (105cfu/mL). Three cultivars (Sun8062, Cherry tomatoes and Moangal T-11) had significantly fewer roots galls, number of eggs and females without any reduction in biomass and chlorophyll contents in single *Mi* and with *Fo* inoculation. These cultivars may improve tomato production in *Mi* and *Fo* infested field. Three cultivars Zn17, Zn48 and Zhongza 09 were moderately resistant with disease severity (8%) and Pf/Pi (0-0.2) with minimum reduction in biomass. During our study, maximum tested cultivars were highly susceptible to *Mi* and *Fo* co-inoculation according to disease severity (80-100%) and Pf/Pi (5-7) and they were declared as suitable host for these soil borne pathogens with maximum reduction in biomass and chlorophyll contents and carotenoids. The statistical analysis revealed that *Mi* population decreased in the presence of *Fo* infestation. All cultivars response minimum disease severity in single inoculation of *Fo* on foliar part of plant.

**Introduction:** Tomato (*Solanum lycopersicum*) belongs to the solanaceous family, is cultivated as vegetable and fruit worldwide. It grows not only in fields (Knapp and Peralta 2016) but also in the greenhouse (Seid *et al.* 2015) and has a somewhat short growth cycle than any other genus of this family (Acosta-Quezada *et al.* 2016). Tomato fruit is a rich dietary source of antioxidants which have been linked to many health benefits including reduced risk of heart and cancer. It is also good source of potassium, folate, vitamin C & K. Tomato cultivated on more than 4.6 million hectares and produced more than 163.4 million tons tomato fruit worldwide FAO. China is the chief tomato producer, consisting of about 109,866 ha of tomato cultivated area and 5.25 tons/ha tomato yield (Heuvelink 2018). In the last few years, the consumption and production of tomato have rapidly been alleviated in China due to biotic and abiotic factors (Yan *et al.* 2013). Tomato plant have to deal with various types of interactions of several pathogens involving fungi, bacteria and nematodes, limited its production by disrupting the physiological and metabolic mechanisms (Bennett and Wallsgrove 1994). Among all the factors root knot nematode and *Fusarium oxysporum* are silent threat to many economical crops, because they are distributed all over the world. Tomato vascular wilt and root rot disease caused by *Fusarium oxysporum* f.sp*. lycopersici* caused economical losses on many vegetable and crops in field as well as in green house across the globe (Singh *et al.* 2017). The FOL invade into the epidermis of root cells, later extents through vascular tissues, resulting in clogging of xylem vessels in form of tylosis and impediment the movement of water and nutrients as a result plant showed wilting (Abdallah *et al.* 2010). The chlamydospores of FOL survive long time in soil in the absence of host plant (Akhter *et al.* 2016). The development of plant vascular disease infection by Fusarium oxysporum is a complex phenomenon, and the progressive steps involved in the infection process are as follows: (i) recognition of roots through host-pathogen signals, (ii) attachment of aspersorium to root hairs and hyphal propagation, (3) invasion of the root cortex, and vascular tissue and differentiation within xylem vessels, (4) finally oozing of toxins (enzymes) and virulence factors. The colonization of the fungus mycelium in vessels leads to disease progression and the characteristic yellowing and wilting of the host plant (Lichius and Lord 2014).

The root knot nematode *Meloidogne incognita* is a plant parasitic nematode that caused significant yield losses of many fruits and vegetables worldwide (Anwar and McKenry 2012). It infected at least 1700 different plant species (Hamza *et al.* 2017). So, it is one of the major threat to vegetable and fruit production in many countries (Hussain *et al.* 2017). *M. incognita* is an obligate endoparasite (Phani and Rao 2018). The second stage juvenile (J2) enter into root cells and secretes several metabolites and enzymes through oesophageal glands that suppress the immune system of host plant (Favery *et al.* 2016). Root-knot nematodes can parasitize a wide range of vascular plants and migrate intracellularly through the root tips to reach the vascular bundles in the elongation zone and develop a feeding sites (Escobar *et al.* 2015). These feeding sites of root-knot nematodes consist of multinucleate giant cells that are induced from a distinct initial cell (Bartlem *et al.* 2014). The life cycle of root knot nematode completed within 35-40 days (Ashraf and Khan 2005; Bartlem *et al.* 2014). Root not nematode interacts with several soil borne fungi and bacteria to create disease complex (Rizvi and Mahmood 2017) and cause break down of resistance in plants against many pathogens which ultimately reduces the level of tolerance against environmental stresses (biotic & abiotic) (Taylor *et al.* 1990) continues farming of same crop in a yield increase the risk of infestation. Different strategies are used to control soil borne diseases such as genetic resistance in host plant, cultural practices and soil treatment with solarization and chemicals. In this regard genetic resistance offer a long term strategy to control soil borne diseases. Currently many commercial hybrid cultivars have been available in market with resistance characters. The objective of this study was to assess the resistance of tomato varieties to *Fusarium oxysporum* and *Meloidogyne incognita* single and in combination*.*

**Material and Method**

**Collection of Tomato germplasm**

Seed of twenty tomato cultivars Zhongza 201, Zhongza 109, Zhongza 09, Ji shi, Gailing maofen 802, Zhongyan, Touch healthy, Red fruit 808, Naite 3 F1, Cherry tomatoes, Maofen 202 and Xin bite 2 F1 were collected from Chinese Academy of Agricultural Sciences (CAAS), China Vegetable Seed Technology Co., Ltd. Beijing, China. Seven cultivars were purchased from Vegetable Seed market Nanning China. These cultivars are widely grown in all over China.

**Fungal Culture**

The *Fusarium oxysporum* culture under (accession number MN240928) were taken from Guangxi Key Laboratory of Agric‐Environment and Agric‐products Safety, Agricultural College Nanning China. The mycelial culture was multiplied on potato dextrose agar medium (PDA) medium for 7 days. The chlamydospores were collected by abrading the fungal culture on PDA medium and cleaned with distilled water to make suspension. The number of conidia was counted on a hemocytometer (Yancheng Cordial Medlab. Co., Ltd Jiangsu, China) under stereomicroscope. The constant number of conidia 1 × 105 CFU mL−1 was used in whole experiment.

**Nematode Culture**

The root knot nematode *Meloidogyne incognita* (Mi) was cultured in Guangxi Key Laboratory of Agric‐Environment and Agric‐products Safety, Agricultural College Nanning China on tomato roots of susceptible cultivar (Money maker) from single egg mass in an incubator at 28 oC +.2 for 35 days. After 35 days nematode infected tomato roots were uprooted, rinsed with tap water and cut into small pieces. The egg masses were collected in a beaker contained sodium hypochlorite (NaOCl) solution (Hussey and Barker, 1973). The egg masses were allowed to hatch in a petriplates containing double distilled water. These plates were incubated for 3 days at 28 oC + 2. The freshly hatched second stage juveniles were used in this experiment.

**Experimental set up**

The pot experiment was carried out in green house of Guangxi University Nanning, China during October to January 2018-2019 in a complete randomized design (CRD). Twenty cultivars were screened to single and co-inoculationof *Fusarium oxysporum* and *Meloidogyne incognita*. The seeds of twenty cultivars were surface sterilized with 10 % bleach for 2 minutes and washed five times with distilled water. These seeds were sown in plastic trays contained autoclaved peat moss. Thirty days old seedlings of each cultivar were transplanted into pots (21 cm diameter, 15 cm height) and each pot contained 1 kg autoclaved peat moss. The experiment consisted of four treatments: 1) CK (without inoculated plants); 2) Mi (plants inoculated with *Meloidogyne incognita*); (3) Fo (plants inoculated with *Fusarium oxysporum*; and (4) Fo + Mi (plants co‐inoculated with *Fusarium oxysporum* and *Meloidogyne incognita*). A total of 1600 pots were prepared and each treatment has 20 replicates. Three holes were made around the rhizospheric area of each plant and 1500 J2 Mi and 1 × 105 CFU mL−1 Fo (suspension form in distilled water) either solely or in combination were pipetted in each pot. All pots were irrigated equally with same amount of water and interval. Chlorotic data after 21days while nematode reproduction parameters after 35 days were recorded.

**Disease assessment of foliar part**

Each plant was evaluated for disease scoring on the foliage part by using disease scale (0–4) for *Fusarium oxysporum* (Fo): 0 = asymptomatic (healthy plants); 1 = up to 25% of leaves were chlorotic and wilted; 2 = up to 50% leaves were chlorotic and wilted; 3 = up to 75% of leaves chlorotic and wilted; 4 = 100% of the plant chlorotic or wilted. The disease austerity was observed from 0 days. The disease severity index was calculated by following the formula given by

*Disease intensity* = (𝑁𝑢𝑚𝑏𝑒𝑟 𝑜𝑓 𝑝𝑙𝑎𝑛𝑡𝑠 𝑤𝑖𝑡ℎ 𝑖𝑡ℎ 𝑠𝑐𝑜𝑟𝑒) x (𝑉𝑎𝑙𝑢𝑒 𝑜𝑓 𝑖𝑡ℎ 𝑠𝑐𝑜𝑟𝑒) X 100

 (𝑇𝑜𝑡𝑎𝑙 𝑛𝑢𝑚𝑏𝑒𝑟 𝑜𝑓 𝑝𝑙𝑎𝑛𝑡𝑠) x (𝐻𝑖𝑔ℎ𝑒𝑠𝑡 𝑣𝑎𝑙𝑢𝑒 𝑡𝑜 𝑠𝑦𝑚𝑝𝑡𝑜𝑚𝑠)

**Disease assessment of root galls and nematode population**

After 35 days plants of all treatments were uprooted, washed with tap water and stained with 0.5 % NaOCl solution to calculate *M. incognita* population in soil (second stage juveniles/per 100cc of soil) and roots (number of eggs and females). To count the number of egg masses and females whole root system was stained with fuchsin acid solution (0.35 g of acid fuchsin, 25 mL of acetic acid, and 75 mL of distilled water) for 30 minutes. The females of *M. incognita* were handpicked from root system under stereomicroscope. The eggs were collected by using bleach (0.5 % NaOCl) solution passing through a sieve mesh with pore size 500, 200, 100 and 50 mm (Hussey and Barker 1973). The root system was rated on the basis of galling from 0 to 5 scale (Anwar et al 2007). 0 = no galls, 1 = 1-2 galls, 2 = 3-10 galls, 3 = 11-30 galls, 4 = 31-100 galls, 5 >100 galls. The second stage juveniles (J2) were extracted from soil (250 cm3) of each plant by centrifugation and floating method. The number of eggs and juveniles were counted on hemocytometer scale under stereomicroscope of 40X. The nematode population was assessed by calculated the reproduction rate as Pf/Pi whereas Pi = is initial population level, Pf = is final population level.

**Plant biomass accumulation**

For plant growth assessment, all plants were carefully uprooted at 35 DAI (days after inoculum added) for shoot and root growth assessment. The plants were carefully washed and air dried for assessment of plant fresh weight (gram) and length (cm) were measured using a digital weight balance and scale with 0.0001 g accuracy. The percent increase and decrease in the growth parameters over the control were calculated by using the formulae (Mukhtar et al 2014)

**Total chlorophyll and carotenoids contents**

Percent increase or decrease = Un-inoculated plants- Inoculated plants x 100

 Un-inoculated plants

For measurement of total chlorophyll contents and carotenoids tomato leaves (0.5 g) of each cultivar and treatment were taken and extract solution was primed in 80% ethanol to assess the total chlorophyll contents (a&b) and carotenoids (Minocha et al., 2009). The absorbance for chlorophyll a (645 nm), chlorophyll b (663 nm) and carotenoids (270 nm) were measured and calculated according to the formula given by Lichtenthaler and Wellburn (1983).

**Statistical analysis**

Twenty plants of each cultivar were assessed thrice. The significant difference was analyzed using Tukey’s test at p ≤0.05 using statistical software statistics 8.1. The data were analyzed using factorial analysis of variance (ANOVA).

**Results**

*.* The *M. incognita and Fusarium oxysporum* showed variable effect on reproduction of *Mi* and plant growth of tomato cultivars. The statistical analysis revealed that three tomato cultivars highly resistant to *M. incognita and Fusarium oxysporum* single and in combination. The cultivars of tomato divided into four groups highly resistant (HR), moderately resistant (MR), moderately susceptible (MS) and highly susceptible (HS) based on the galling number, disease intensity, Pf/Pi, egg masses and growth factors significant and non-significant (LSD, p ≤ 0.05) among and within the groups of tested cultivars (Table 1). On the basis of disease severity three tomato cultivars categorized into highly resistant group (HR), three cultivars in moderately resistant (MR), four in moderately susceptible (MS) and ten in highly susceptible (HS). The investigated traits are significantly different among the groups and almost non-significant within the groups. Three tomato cultivars Tomato Mongal T-11, Sun6082 and cherry tomatoes have minimum number of galls index disease severity and final population of second stage juveniles in all treatments as compare to control (Table 1). These three cultivars ranked as highly resistant without any reduction in growth (Table 2) and photosynthetic pigments (Table 3). The three cultivars Zn17, Zn48 and Zhongza 09 were categorized into moderately resistant group (MR) due to disease intensity (2 %) after combine inoculation of *Fo* and *Mi.* In single inoculation of *Fo* and *Mi* no disease symptoms appeared on leaves with 0 % disease severity. On the other hand, galling index number decreased in combine infection of *Fo* and *Mi* as compared to single *Mi* application. The disease severity ranged between 16-18 % in moderately susceptible group after combine inoculation of *Fo* and *Mi*. Likewise in highly susceptible group nineteen cultivars showed maximum disease intensity 78-100 %. The leaves showed yellowing symptoms with wilting and mortality of plants after 40 days in combine inoculation of *Fo* and *Mi*. Maximum disease intensity 23 % was recorded in G. maofen 802 cultivar after single *Mi* application. In contrast Hongguan cultivars showed maximum susceptibility 30 % after single *Fo* application.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr. No.** | **Cultivars/line** | **Group** |  **Disease intensity (%)** |  **Galling index (0-5)** |  **Pf/Pi** |
| ***Ck*** | ***Mi*** | ***Fo*** | ***Mi+Fo*** | ***Ck*** | ***Mi*** | ***Fo*** | ***Mi+Fo*** | **Ck** | **Mi** | **Fo** | **Mi+Fo** |
| 1 | Sun8062 | Highly resistant | 0 | 0 | 0 | 0 | 0 | 1±0.05 | 0 | 1±0.05 | 0 | 1.1±0.05 | 0 | 0.2±0.02 |
| 2 | Cherry tomatoes | Highly resistant | 0 | 0 | 0 | 0 | 0 | 1±0.05 | 0 | 1±0.05 | 0 | 1±0.05 | 0 | 0.1±0.02 |
| 3 | Tomato Mongal T-11 | Highly resistant | 0 | 0 | 0 | 0 | 0 | 1±0.05 | 0 | 1±0.05 | 0 | 1.2±0.05 | 0 | 0.1±0.05 |
| 4 | Zn17 | Moderately resistant | 0 | 0 | 0 | 8.2±0.7 | 0 | 2±0.07 | 0 | 2±0.07 | 0 | 2.3±0.07 | 0 | 1.7±0.02 |
| 5 | Zn48 | Moderately resistant | 0 | 0 | 0 | 7.5±0.4 | 0 | 2±0.07 | 0 | 2±0.07 | 0 | 2.3±0.07 | 0 | 1.9±0.07 |
| 6 | Zhongza 09 | Moderately resistant | 0 | 0 | 0 | 8±0.3 | 0 | 2±0.07 | 0 | 2±0.07 | 0 | 2.1±0.07 | 0 | 1.9±0.07 |
| 7 | Zhongza 201 | Moderately susceptible | 0 | 10±0.5 | 2±0.07 | 16±0.7 | 0 | 4±0.1 | 0 | 4±0.1 | 0 | 4.6±0.1 | 0 | 3.5±0.1 |
| 8 | LA0385 | Moderately susceptible | 0 | 8±0.3 | 4±0.1 | 17±0.7 | 0 | 4±0.1 | 0 | 3±0.1 | 0 | 4.7±0.1 | 0 | 3.6±0.1 |
| 9 | Ji shi | Moderately susceptible | 0 | 8±0.3 | 2±0.07 | 16±0.7 | 0 | 4±0.1 | 0 | 4±0.1 | 0 | 4.8±0.1 | 0 | 3.5±0.1 |
| 10 | Zhangyan | Moderately susceptible | 0 | 9±0.5 | 4±0.1 | 18±0.7 | 0 | 4±0.1 | 0 | 3±0.1 | 0 | 4.6±0.1 | 0 | 3.2±0.1 |
| 11 | Touch healthy | Highly susceptible | 0 | 16±0.7 | 14±0.6 | 80±2.3 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.3±0.3 | 0 | 5.4±0.2 |
| 12 | Red fruit 808 | Highly susceptible | 0 | 15±0.6 | 16±0.7 | 91±2.7 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 5.6±0.2 | 0 | 5.9±.2.0 |
| 13 | Naite 3 F1 | Highly susceptible | 0 | 20±1.2 | 19±0.8 | 94±2.7 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.4±0.3 | 0 | 5.7±0.2 |
| 14 | G.maofen 802 | Highly susceptible | 0 | 23±1.3 | 19±0.8 | 100±3.0 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 5.6±0.2 | 0 | 4.6±0.1 |
| 15 | G.maofen 202 | Highly susceptible | 0 | 21±1.3 | 21±1.3 | 82±2.5 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.6±0.3 | 0 | 5.1±0.2 |
| 16 | Xinbite2 F1 | Highly susceptible | 0 | 18±0.7 | 23±1.3 | 80±2.3 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 5.5±0.1 | 0 | 3.7±0.1 |
| 17 | Shoufeng | Highly susceptible | 0 | 18±0.7 | 21±1.3 | 78±2.3 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.3±0.3 | 0 | 5.6±0.2 |
| 18 | Baofeng | Highly susceptible | 0 | 19±0.8 | 24±1.4 | 84±2.6 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.2±0.3 | 0 | 5.4±0.2 |
| 19 | Tianlong | Highly susceptible | 0 | 21±1.3 | 28±1.6 | 83±2.5 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 6.4±0.3 | 0 | 6.1±0.3 |
| 20 | Hongguan | Highly susceptible | 0 | 18±0.7 | 30±1.7 | 84±2.6 | 0 | 5±0.1 | 0 | 5±0.1 | 0 | 7.6±0.4 | 0 | 6.5±0.3 |

**Table 1** Host response of twenty tomato cultivars to *Meloidogyne incognita* as measured by galling index and reproduction factor in green house after 40 days after inoculation with an initial population density (Pi) 1500 second stage juvenile

All of the twenty cultivars respond to *Mi* inoculation. None of the cultivar was immuned to *Mi*. Maximum number of eggs per gram of roots were measured in highly susceptible group ranged between 9832-13346. The Maximum number of eggs were reproduced on Hongguan cultivar in single *Mi* application. The number eggs, juvenile’s and females were decreased in combine application of *Mi* with *Fo* in all cultivars. Contrarily highly resistant group showed minimum number of eggs (10-14), number of females (6-7) per gram of roots with Pf/Pi (1.1-1.2). Tianlong and G. maofen 202 cultivars had maximum size of galls (3.8mm) while Tomato Mongal T-11 had

**Table 2.** Host response of tomato genotypes to *Meloidogyne incognita* population single and in combination with *Fusarium oxysporum*.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No.** | **Cultivars/line** | **No. of eggs/ gram of root** | **No. of females/ gram of roots** | **Size of galls (mm)** |
| ***Mi*** | ***Mi+Fo*** | ***Mi*** | ***Mi+Fo*** | ***Mi*** | ***Mi+Fo*** |
| 1 | Sun8062 | 10±0.5 | 7±0.2 | 2±0.07 | 2±0.07 | 0.54±0.02 | 0.45±0.05 |
| 2 | Cherry tomatoes | 13±0.5 | 6±0.2 | 1±0.05 | 1±0.05 | 0.32±0.01 | 0.23±0.05 |
| 3 | Tomato Mongal T-11 | 14±0.6 | 7±0.2 | 1±0.05 | 1±0.05 | 0.24±0.01 | 0.21±0.05 |
| 4 | Zn17 | 30±1.3 | 25±1.3 | 4±0.1 | 4±0.1 | 1.7±0.05 | 1.5±0.05 |
| 5 | Zn48 | 19±1.4 | 19±0.8 | 5±0.2 | 4±0.1 | 1.4±0.05 | 1.2±0.05 |
| 6 | Zhongza 09 | 26±2.0 | 20±1.0 | 4±0.1 | 4±0.1 | 1.2±0.05 | 1.2±0.05 |
| 7 | Zhongza 201 | 1476±10.5 | 345±5.0 | 30±1.7 | 27±1.5 | 2.2±0.07 | 1.9±0.07 |
| 8 | LA0385 | 1452±10.7 | 321±5.0 | 25±1.3 | 24±1.4 | 2.1±0.07 | 2±0.07 |
| 9 | Ji shi | 1510±10.8 | 379±5.0 | 20±1.0 | 20±1.0 | 2.1±0.07 | 1.9±0.07 |
| 10 | Zhangyan | 1543±11 | 401±5.7 | 26±1.3 | 23±1.4 | 2.4±0.07 | 2.1±0.07 |
| 11 | Touch healthy | 11807±18 | 1065±10 | 75±2.1 | 72±2.0 | 3.6±0.1 | 2.6±0.07 |
| 12 | Red fruit 808 | 12341±12 | 10270±10 | 80±2.3 | 78±2.3 | 2.8±0.07 | 2.1±0.07 |
| 13 | Naite 3 F1 | 11463±11 | 9181±9.0 | 83±2.3 | 80±2.3 | 3.7±0.1 | 3±0.1 |
| 14 | G.maofen 802 | 12311±12 | 10887±10 | 74±2.1 | 72±2.0 | 3.5±0.1 | 3.1±0.1 |
| 15 | G.maofen 202 | 10984±10 | 8762±8.0 | 80±2.3 | 78±2.3 | 3.8±0.1 | 3.1±0.1 |
| 16 | Xinbite2 F1 | 11653±11 | 9876±9.0 | 81±2.3 | 76±2.1 | 3.6±0.1 | 3.2±0.1 |
| 17 | Shoufeng | 11888±11 | 9843±9.0 | 75±2.1 | 74±2.1 | 3.6±0.1 | 3.2±0.1 |
| 18 | Baofeng | 9875±9.0 | 6547±6.0 | 78±2.2 | 75±2.1 | 3.4±0.1 | 3.3±0.1 |
| 19 | Tianlong | 9832±9 | 6543±6.0 | 81±2.3 | 79±2.2 | 3.8±0.1 | 3.4±0.1 |
| 20 | Hongguan | 13346±12 | 6549±6.0 | 87±2.4 | 85±2.3 | 3.7±0.1 | 3.2±0.1 |

minimum size of galls (0.2 mm). The plant growth parameters were significantly affected by *Fo, Mi* single and combine inoculation. The *Mi* population is highly correlated with growth traits of tomato cultivars. Maximum reproduction of *Mi* reduced length and weight of shoot as compared to control. There is no reduction in weight and length of shoot in highly resistant group even in combine inoculation. Maximum reduction in shoot length (40 %) and weight (60%) was measured in G. maofen 802 after combine inoculation (Table 3).

**Table 3.** Effect of *Meliodogyne incognita* and *Fusarium oxysporum* on growth parameters of different tomato cultivars

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No** | **Cultivars** | **% reduction in shoot weight** | **% reduction in shoot length** |
| ***Fo*** | ***Mi*** | ***Mi+Fo*** | ***Fo*** | ***Mi*** | ***Mi+Fo*** |
| **1** | Sun8062 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2** | Cherry tomatoes | 0 | 0 | 0 | 0 | 0 | 1.6±0.05 |
| **3** | Tomato Mongal T-11 | 0 | 0 | 0 | 0 | 0 | 2.3±0.07 |
| **4** | Zn17 | 4±0.1 | 15±0.8 | 16±0.6 | 3.6±0.07 | 3.4±0.09 | 10.3±0.5 |
| **5** | Zn48 | 4.5±0.1 | 10±0.5 | 20.2±1.0 | 6.7±0.3 | 3.7±0.09 | 10.7±0.5 |
| **6** | Zhongza 09  | 5.2±0.1 | 12.5±0.6 | 16.4±1.4 | 8±0.3 | 4.3±0.1 | 10.6±0.5 |
| **7** | Zhongza 201 | 10.8±0.5 | 20±1.0 | 28.6±1.2 | 12±0.8 | 5.6±0.1 | 16.5±0.6 |
| **8** | LA0385 | 14.2±0.8 | 21.7±1.0 | 29±1.2 | 12.4±0.8 | 5.1±0.1 | 16.8±0.6 |
| **9** | Ji shi | 13.9±0.8 | 20±.1.0 | 28±1.2 | 12.5±0.8 | 5.7±0.2 | 17.2±0.6 |
| **10** | Zhangyan | 12.5±0.8 | 22.2±1.0 | 35.4±1.3 | 13±0.8 | 5.8±0.2 | 16.8±0.6 |
| **11** | Touch healthy | 18.6±0.9 | 30.3±1.3 | 46.4±1.7 | 17±0.9 | 19±0.9 | 27.4±0.7 |
| **12** | Red fruit 808 | 17.7±0.8 | 29.5±1.4 | 45.2±1.7 | 17.5±0.9 | 20.4±1.0 | 27.9±0.7 |
| **13** | Naite 3 F1 | 17±0.8 | 30.3±1.3 | 54.6±1.7 | 18.3±0.6 | 23.5±1.0 | 30±1.3 |
| **14** | G.maofen 802 | 20.3±1.0 | 27.5±1.2 | 60.4±2.5 | 17±0.6 | 27.8±1.0 | 40.4±1.4 |
| **15** | G.maofen 202 | 37.3±1.5 | 26.7±1.2 | 45.3±1.7 | 18±0.6 | 25.6±1.0 | 38.7±1.4 |
| **16** | Xinbite2 F1 | 39±1.6 | 30.2±1.3 | 54±1.8 | 16.9±0.6 | 30.2±1.3 | 37.7±1.4 |
| **17** | Shoufeng | 20.5±1.0 | 32.1±.5 | 46±1.7 | 17.2±0.6 | 27.4±1.2 | 30±1.3 |
| **18** | Baofeng | 20.5±1.0 | 26.7±1.2 | 46.2±1.7 | 16.5±0.6 | 25.5±1.2 | 27±1.2 |
| **19** | Tianlong | 36.5±1.5 | 29.3±1.2 | 56.4±1.7 | 17.2±0.6 | 26±1.2 | 27.5±1.2 |
| **20** | Hongguan | 46.4±1.7 | 32±1.3 | 55±1.7 | 16±0.6 | 25.5±1.2 | 30±1.3 |

Total chlorophyll contents (a&b) and carotenoids were significantly different in Highly resistant, moderate resistant, moderate susceptible and highly susceptible groups. However, non-significant (p ≤ 0.01) reduction was measured in highly resistant group as compared to control in all treatments. Maximum reduction in chlorophyll contents were recorded in total chlorophyll content and carotenoids was recorded in highly susceptible group cultivars shoufang and G. maofen 802 (Table 4).

**Table 4.** Effect of *Meliodogyne incognita* and *Fusarium oxysporum* on chlorophyll contents and carotenoids of tomato cultivars

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No** | **Cultivars** |  **Chlorophyll contents (a&b)** |  **Carotenoids** |
| ***Ck*** | ***Mi*** | ***Fo*** | ***Mi+Fo*** | ***Ck*** | ***Fo*** | ***Mi*** | ***Mi+Fo*** |
| **1** | Sun8062 | 3.8±0.09 | 3.8±0.08 | 3.7±0.09 | 3.7±0.09 | 6.4±0.3 | 6.3±0.3 | 6.2±0.3 | 6.2±0.3 |
| **2** | Cherry tomatoes | 3.8±0.09 | 3.6±0.08 | 3.7±0.09 | 3.7±0.09 | 6.2±0.3 | 6±0.3 | 6±0.3 | 5.9±0.2 |
| **3** | Tomato Mongal T-11 | 4±0.1 | 3.9±0.09 | 4±0.1 | 3.9±0.09 | 5.9±0.2 | 5.8±0.2 | 5.7±0.2 | 5.6±0.2 |
| **4** | Zn17 | 3.9±0.09 | 3.7±0.08 | 3.8±0.09 | 3.6±0.09 | 6±0.3 | 5.7±0.2 | 5.7±0.2 | 5.6±0. 0.2 |
| **5** | Zn48 | 3.6±0.09 | 3.8±0.09 | 3.6±0.09 | 3.5±0.09 | 6.1±0.3 | 6±0.3 | 6±0.3 | 5.9±0.2 |
| **6** | Zhongza 09  | 3.5±0.09 | 2.9±0.08 | 3.5±0.09 | 3.5±0.09 | 5.8±0.2 | 5.7±0.2 | 5.3±0.1 | 5.3±0.1 |
| **7** | Zhongza 201 | 3.2±0.09 | 3.4±0.09 | 3±0.09 | 2.9±0.07 | 5.8±0.2 | 5.8±0.2 | 5.7±0.2 | 4.4±0.1 |
| **8** | LA0385 | 3.1±0.09 | 3.3±0.09 | 2.9±0.08 | 2.8±0.07 | 6.2±0.3 | 6±0.3 | 6±0.3 | 4.6±0.1 |
| **9** | Ji shi | 2.8±0.08 | 2.9±0.08 | 2.2±0.07 | 2.3±0.07 | 5.8±0.2 | 5.7±0.2 | 5.5±0.2 | 4.6±0.1 |
| **10** | Zhangyan | 2.9±0.08 | 3±0.09 | 2.6±0.07 | 2±0.07 | 5.6±0.2 | 5.7±0.2 | 5.6±0.2 | 4.4±0.1 |
| **11** | Touch healthy | 3±0.09 | 2.6±0.07 | 2.8±0.08 | 2.1±0.07 | 5.5±0.2 | 5.3±0.1 | 5.3±0.1 | 4±0.1 |
| **12** | Red fruit 808 | 2.9±0.08 | 2.6±0.07 | 2.9±0.08 | 2.2±0.07 | 5.3±0.1 | 5.1±0.1 | 5±0.1 | 4.4±0.1 |
| **13** | Naite 3 F1 | 2.8±0.08 | 2.7±0.08 | 2±0.07 | 2.3±0.07 | 5.5±0.1 | 5.3±0.1 | 5.3±0.1 | 4±0.1 |
| **14** | G.maofen 802 | 3.2±0.09 | 2.4±0.07 | 3.1±0.09 | 1.8±0.06 | 6.1±0.2 | 5.8±0.2 | 5.9±0.1 | 3.5±0.1 |
| **15** | G.maofen 202 | 2.8±0.07 | 2.1±0.07 | 2.6±0.07 | 2±0.07 | 5.8±0.2 | 5.8±0.2 | 5.3±0.1 | 5±0.1 |
| **16** | Xinbite2 F1 | 3.2±0.09 | 2.8±0.07 | 2.9±0.08 | 2.2±0.07 | 6±0.3 | 5.7±0.2 | 5.5±0.1 | 5±0.1 |
| **17** | Shoufeng | 3.7±0.09 | 2.8±0.07 | 3.2±0.09 | 2.1±0.07 | 6.2±0.3 | 6±0.3 | 5.9±0.2 | 3.6±0.2 |
| **18** | Baofeng | 2.7±0.07 | 2.1±0.07 | 2.7±0.08 | 1.3±0.05 | 5.5±0.3 | 5.5±0.2 | 5.3±0.1 | 4.6±0.1 |
| **19** | Tianlong | 2.8±0.07 | 2.4±0.07 | 2.6±0.07 | 1.6±0.05 | 5.3±0.3 | 5.3±0.1 | 5±0.1 | 4.4±0.1 |
| **20** | Hongguan | 2.8±0.07 | 2.3±0.07 | 2.1±0.07 | 1.2±0.05 | 5.1±0.3 | 5±0.1 | 4.9±0.1 | 4.4±0.1 |

**Discussion**

Under more intensified cropping conditions agriculture will face increasing incidences of soil-borne plant pests and pathogens, leading to increasingly higher yield losses world-wide. Soil-borne disease complexes, particularly in soil, are difficult to control. Identification and utilization of genetic source for resistance against *Fusarium oxysporum* and *Meloidogyne incognita* is the only way to reduce the yield losses of tomato production. Therefore, the present study was carried out to screen twenty commercial tomato cultivars against *Fo* and *Mi* with disease severity, substantial estimation of growth parameters like shoot length, weight and nematode reproduction factors in roots and soil. *Mi* and *Fo* co-inoculationcaused damage to maximum cultivars with different variability. Twenty cultivars were kept in four groups by using a scale Silme and Cagirgan, (2010). Three cultivars Sun8062, Cherry tomatoes, Tomato Mongal T-11 were kept in highly resistant group (HR), Zn 17, Zn48, Zhongza 09 were categorized in moderately resistant group (MR). Moderately susceptible group (MS) had four cultivars, Zhongza 201, LA0385, Ji shi and Zhangyan. The remaining ten cultivars were highly susceptible to co-infection of *Fo* and *Mi* as compared to single inoculation. Likewise, Akaez et al (2017) using the same rating scale of Silme and Cagirgan, (2010) and characterized the tomato genotypes from susceptible to resistant against the effect of *Fo*. Cai Cheng Huang and Pim (2010) screened seventeen accessions of tomato for resistance to the Fusarium wilt disease caused by *Fusarium oxysporum f.sp. lycopersici* (Fol) race 1 and race 2 and found that highly resistant accession belongs to wild type toamto. Bhar Morid et al (2012) tested that the accessions of wild species were highly resistant and may be utilized as sources for the development of recombinant inbred lines. RAPD and CAPS marker usage to screen tomato cultivars against *Fusarium oxysporum* is paramount methodAdhikari et al (2017). Furthermore, our results showed that disease severity increased in all cultivars of tomato in the presence of *Fo* while galling index and final *Mi* population decreased. This might be due to attributes of both pathogens penetration together. These results are strengthening by findings of Al-Hazmi and Al-Nadary (2015); whereby combine inoculation of *M. incognita* race 2 and *Rhizoctonia solani* increased the index of root rot and the number of root galls on green beans (*Phaseolus vulgaris L*.). Kassie et al (2020) results related to galling index and final nematode population increased in the presence of *F. oxysporum* are also contradicting with our findings. Our results showed that *Mi* population decreased in the presence of *Fo*. *Mi* penetration in roots of plantselevated major organic constituents of root exudates mostly, carbohydrates and nitrogenous compounds during the first fourteen Van Gundy et al. (1977); Mai and Abawi, (1987). These organic constituents are considered to be major nutrient consumptions for different fusarium wilt inciting fungal species like *F. oxysporum* that co-infect with *Mi* on the same host plant. *Mi* number of egg, females, juveniles reproduced more in number in single inoculation on all cultivars as compared to combine infection with *Fo.* These results were similar to Hussain et al (2017) *F. oxysporum* have low infection on *Mi* eggs and juveniles. These results depict the negative correlation of *Fo* inoculation on *Mi* population Kumar et al (2017) findings are in line with this result. This might be due to rottning on roots surface area attributed to reduced nutrients constitutes for *Mi* ultimately its population reduced. Probably *Fo* metabolites have inhibitory effect on *Mi* egg hatching are also reported by Zahid et al (2002).

The maximum reduction in biomass, chlorophyll contents and carotenoids were measured in highly susceptible group with co-inoculation of *Fo* and *Mi* can be imputed to sever root damage which resulted in impairment and blockage of xylem vessels. These blocked xylem vessels disrupt the water and nutrient absorption. As the infected plants challenged insufficient supply of photosynthates, water, nutrients therefore biomass chlorophyll contents were highly hampered khan et al (2019).

The variation in reproduction and multiplication of *Mi* reduction in biomass and chlorophyll contents on different tomato cultivars are owing to variation in their genetic makeup Mukhtar et al (2013). Highly resistant group of tomato cultivars have minimum rate of *Mi* multiplication, without reduction in biomass and chlorophyll must be exhibited some resistant genes. Not only combine inoculation of *Fo* and *Mi* but also single inoculation did not affect its growth. The resistant group contain a limited number of nematodes as compared to susceptible group. In case of susceptible group maximum number of second stage juveniles penetrate into roots and complete its life cycle with full potential in single *Mi* application ultimately foliar part of plant reduced its growth.

This study directs our attention to investigate the mechanism of hypersensitive reaction and biochemical and molecular changes involved in resistant and susceptible plants.

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