



RESEARCH ARTICLE

Effect of *Fusarium* spp. resistance rootstocks on yield and quality parameters of *Cucumis melo* L. in greenhouse conditions

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Abstract

Fusarium spp. are major soil-borne pathogens causing severe wilt disease in melon, leading to significant reductions in yield and fruit quality. This study aimed to evaluate the resistance of selected cucurbit species to fusarium wilt and to assess the yield and fruit quality of *Cucumis melo* L. var. *makuwa* grafted onto cucurbit rootstocks under *Fusarium incarnatum* infection. The experiment was conducted using a completely randomised two-factorial design. The results demonstrated that *F. incarnatum* induced more severe disease symptoms than *F. equiseti*. Among the cucurbit species evaluated, *Benincasa hispida* and *C. melo* var. *conomon* exhibited higher resistance to fusarium wilt compared with *Luffa aegyptiaca* and *C. melo* var. *makuwa*. When used as rootstocks for grafting *C. melo* var. *makuwa*, these resistant species significantly improved plant performance under pathogen pressure. Melons grafted onto *C. melo* var. *conomon* achieved the highest marketable yield (23.1 t ha⁻¹) and fruit soluble solids content (14.7 °Brix), whereas ungrafted plants recorded the lowest values (18.6 t ha⁻¹ and 13.5 °Brix, respectively). These findings suggest that *C. melo* var. *conomon* is a promising rootstock for mitigating fusarium wilt and enhancing melon productivity and fruit quality and its use is therefore recommended for sustainable melon production in *Fusarium*-infested soils.

Keywords: *Cucumis melo*; fungal diseases; grafting; rootstock; yield

Introduction

Cucumis melo L. is an economically important fruit crop, valued for its pleasant flavour, rich nutritional composition and widespread consumption as a fresh fruit. Owing to high consumer demand, melons are often cultivated continuously for several harvests each year. Continuous cropping, however, has led to the increasing occurrence of pests and soil-borne diseases, particularly *Fusarium* wilt caused by *Fusarium* spp., which severely affects crop productivity. Infected plants initially exhibit symptoms of water loss and wilting from the apical parts downward, accompanied by cracking at the base of the stem. Seedlings often die in patches, while mature plants are severely affected during the flowering and fruiting stages, with branch wilting followed by sudden wilting and death of the entire plant (1).

Grafting is a technique that combines different plant individuals to form a grafted plant system (2). Graft compatibility refers not only to the successful formation of the graft union but also to the long-term survival and normal development of the grafted plants. The survival of grafted plants is a complex process involving multiple physiological and cellular mechanisms, including wound response, cell wall modification, cell division and tissue reconnection (3). Previous researchers demonstrated that grafting is one of the

most effective and economical approaches for continuous melon production over multiple cropping cycles without severe infection by *Fusarium* (4). In addition, grafted plants retain the desirable characteristics of the scion cultivar, enhance water and nutrient uptake, shorten breeding and selection time and improve tolerance to adverse environmental conditions (5).

Importantly, the resistance of grafted plants to soil-borne diseases is largely determined by the characteristics of the rootstock. Disease-resistant rootstocks can effectively limit the invasion and colonisation of *Fusarium* spp. in the root system, restrict pathogen movement into vascular tissues and enhance plant tolerance to fusarium wilt (6). In Cucurbitaceae, vigorous and resistant rootstocks have been reported to improve root architecture, strengthen defence responses and maintain vascular function under pathogen pressure, thereby reducing yield losses caused by fusarium wilt (7). Moreover, grafted plants with strong root systems not only exhibit enhanced disease resistance and increased yield but also contribute to reduced reliance on chemical control measures (8).

Therefore, the identification and evaluation of Cucurbitaceae rootstocks with resistance to fusarium wilt caused by *Fusarium* spp. represent a safe and effective technical strategy to improve the growth, yield and quality of melon crops under greenhouse conditions.

Materials and Methods

Materials

The Cucurbitaceae species used as rootstocks were *Benincasa hispida*, *Luffa aegyptiaca*, *Cucumis melo* var. *conomon* and *C. melo* var. *makuwa*, supplied by Nong Huu Seed Company (Vietnam). These varieties are characterised by rapid growth, strong, deep and well-developed root systems and good resistance to soil-borne pathogens. In addition, *Cucumis melo* L. var. *makuwa* was used as both the scion and rootstock.

The *Fusarium* A1 strain was isolated from a diseased melon sample in Rach Gia ward, An Giang province (Vietnam). The initial symptoms appeared at the fruiting stage. Normally, the growing plants began to develop small brown spots at the base, which then spread along the stem. The lower leaves gradually withered and yellowed and finally the entire plant wilted and died. Mycelium appeared at the site of the diseased area at the base of the plant. The samples were collected, isolated and purified. The *Fusarium* A1 had a fungal colony diameter of 63.78 mm after 7 days of culture. The colony grew unevenly; the mycelium grew thin and slightly cottony; the centre was burnt yellow, while the outer region was opaque white (Fig. 1). The identification of the species through gene sequencing showed that *Fusarium* A1 was 99.44 % like *Fusarium equiseti*.

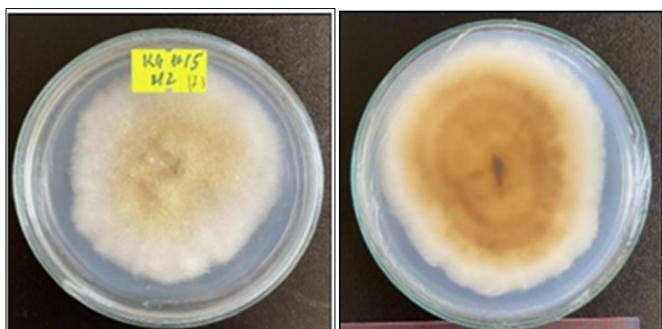


Fig. 1. *Fusarium equiseti*.

Similarly, the *Fusarium* A2 strain was isolated in Binh Minh commune, Vinh Long province (Vietnam). After 7 days of culture, *Fusarium* A2 produced a white colony with a diameter of 72.78 mm and thin mycelium. The centre of the colony was raised and light yellow in colour (Fig. 2). Based on gene sequencing analysis, *Fusarium* A2 was identified as *Fusarium incarnatum* with 100 % sequence similarity.

Experimental design

Experiment 1: Investigation of resistance to *Fusarium* wilt in cucurbit plants

The experiment was arranged in a completely randomized 2-factorial design. The factor A included 3 types of rootstock plants and a control (melon) and factor B included 2 strains of *F. equiseti*, *F. incarnatum* and a control (water). The experiment was laid out with 5 replications and each replication had 10 pots with 1 plant per pot (Table 1).

Table 1. Experimental treatments for evaluating resistance to *Fusarium* spp. in cucurbit plants under greenhouse condition at of An Giang University, Vietnam

Types of rootstock (B)	Fusarium strain (A)		
	<i>F. equiseti</i> (A1)	<i>F. incarnatum</i> (A2)	Control (A0) (water)
<i>Benincasa hispida</i> (B1)	B1-A1	B1-A2	B1-A0
<i>Cucumis melo</i> var. <i>conomon</i> (B2)	B2-A1	B2-A2	B2-A0
<i>Luffa aegyptiaca</i> (B3)	B3-A1	B3-A2	B3-A0
<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	B4-A1	B4-A2	B4-A0



Fig. 2. *Fusarium incarnatum*.

Preparation of substrate: Coconut fibre was soaked in water for 7 days, in lime for 48 hr and then rinsed thoroughly. The substrate was mixed from humus and coconut fibre in a 1:1 ratio and sterilised at 100 °C for 11 hr. Then, the substrate was added to a pot with dimension of 28 x 24 cm.

Preparation of the rootstocks and control: The seeds of *B. hispida*, *L. aegyptiaca*, *C. melo* var. *conomon* and *C. melo* var. *makuwa* were soaked and incubated until they germinated. The germinated seeds were then sown in plastic cups. The seedlings were transplanted to the pots at 10 days after sowing.

Artificial infection: Ten days after transplanting, artificial inoculation was carried out by applying 10 mL of *Fusarium* spp. spore suspension (5×10^6 spores mL⁻¹) to the base of each plant. Inoculation was carried out in the afternoon at a moderate temperature (25–27 °C) and watering was withheld for 24 hr to avoid the inoculum from being washed away.

Fertilisation: Organic fertiliser was applied at a rate of 20 g/pot before planting. The slow-release NPK 20–15–15 fertiliser was applied at a rate of 20 g/pot after 3 days of planting.

Watering: The drip irrigation system combined with automatic timer watered every 30–60 min with 100–200 mL/pot.

Experiment 2: Investigation of the growth, yield and quality of *Cucumis melo* L. var. *makuwa* grafted on cucurbit rootstocks infected with *Fusarium incarnatum*

The experiment was arranged in a 2-factor completely randomised block design, with 4 replications. Each replication had 9 pots and each pot had one plant. The factor C included one fungal strain (*F. incarnatum*) selected from experiment 1 and a control (water); the factor D included 3 grafted melon and one control (no grafting) (Table 2).

Preparation of the rootstocks and control: The seeds of *B. hispida*, *L. aegyptiaca*, *C. melo* var. *conomon* and *C. melo* var. *makuwa* were soaked and incubated until they germinated. The germinated seeds were then sown in plastic cups. The seedlings can be used as rootstocks at 16 days after sowing for *B. hispida*, 14 days for *C. melo* var. *conomon* and *L. aegyptiaca* and 10 days for *C. melo* var. *makuwa* (Fig. 3).

Table 2. Experimental treatments for evaluating growth, yield and quality of *Cucumis melo* var. *makuwa* grafted onto cucurbit rootstocks under *Fusarium incarnatum* infection

Types of rootstock (D)	Infection (C)	
	Infection (C1)	Control (C0)
<i>Benincasa hispida</i> (D1)	D1-C1	D1-C0
<i>Cucumis melo</i> var. <i>conomon</i> (D2)	D2-C1	D2-C0
<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	D3-C1	D3-C0
<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	D4-C1	D4-C0

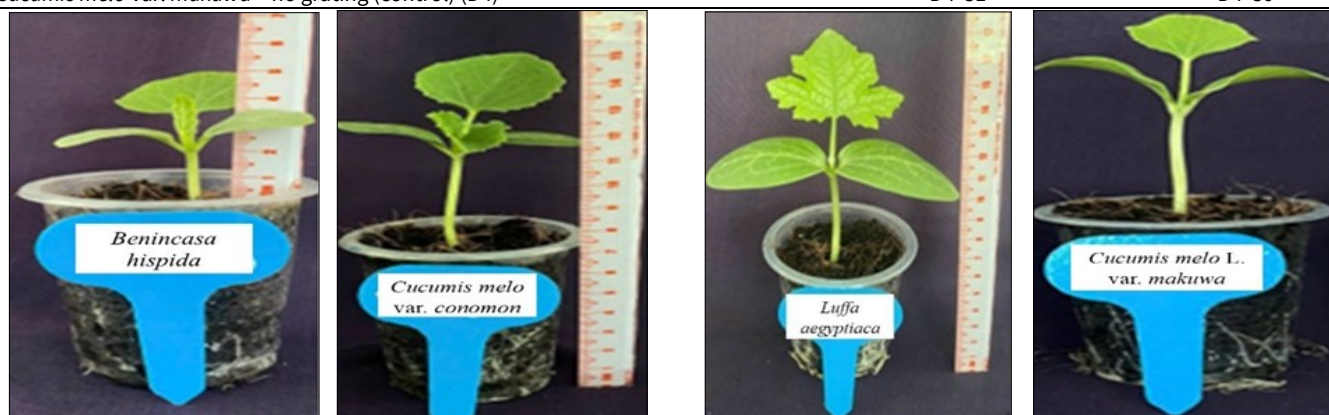


Fig. 3. Cucurbitaceae rootstocks. a: *Benincasa hispida*; b: *Cucumis melo* var. *conomon*; c: *Luffa aegyptiaca*; d: *Cucumis melo* var. *makuwa*.

Preparation of the grafted shoots: *C. melo* var. *makuwa* were sown directly into the nursery tray with sterilised coconut fibre. The seeds were sown for 6 days to be used as grafted scion.

Preparation of the recovery room: Light intensity was reduced and grafted plants were shielded from wind exposure. Water was supplied to the trays to maintain high humidity, regular misting was conducted to regulate humidity and temperature and seedlings were placed 10 cm above the ground.

Grafting: Approach grafting is applied for all types of rootstocks (9).

Planting: The plants were transplanted into substrate-filled pots 10 days after grafting. The pots then were placed on cement floor under greenhouse conditions.

Preparation of substrate, artificial infection, fertilisation and watering were carried out similar to the experiment 1.

Data collection

Rate and index of the disease

Rate and index of the disease were calculated using equations 1 and 2 (10).

$$\text{Rate of disease (\%)} = \frac{N_0}{N} \times 100 \quad \text{Eqn. 1}$$

Where, N_0 is the total number of trees infected with *Fusarium* and N is the total number of trees in the treatment

$$\text{Disease index} = \frac{(N_1 \times 1) + (N_2 \times 2) + (N_3 \times 3) + (N_4 \times 4)}{N \times 4}$$

Eqn. 2

Where, N_1 is the total number of trees infected with *Fusarium* at level 1

N_2 is the total number of trees infected with *Fusarium* at level 2

N_3 is the total number of trees infected with *Fusarium* at level 3

N_4 is the total number of infected with *Fusarium* at level 4

N is the total number of trees in the treatment

4 is the highest disease level on the scale.

Growth index

The length of the stem (cm) was measured from the grafted position to the growing tip of the main stem using a tape measure.

Number of leaves on the stem (leaf) were counted all the true leaves on the main stem and the length of the leaf blade > 2 cm.

The diameter of the rootstock (cm) was measured twice perpendicular to each other at a position 1 cm below the cotyledon with a calliper.

The grafting ratio was determined as the ratio of the rootstock diameter/graft tip diameter.

Total yield ($t\ ha^{-1}$): The total weight of all fruits harvested from each plot was recorded and subsequently converted to yield per hectare.

Marketable yield ($t\ ha^{-1}$): Marketable fruits were selected based on conformity to varietal characteristics in terms of shape and colour, absence of pest and disease damage and lack of mechanical injury. The total weight of marketable fruits was recorded and converted to marketable yield per hectare.

Fruit quality parameters

Flesh thickness (cm): Fruits were longitudinally sectioned and flesh thickness was measured using a digital calliper at three positions: the upper, middle and lower portions of the fruit. The upper and lower measurement points were located 2 cm from the fruit apex and base, respectively. Mean values were calculated from measurements taken on 5 fruits per treatment.

Total soluble solids ($^{\circ}\text{Brix}$, %): Total soluble solids content was determined using an Atago refractometer. Fruit juice was directly applied to the prism of the refractometer and $^{\circ}\text{Brix}$ values were recorded. Measurements were conducted on three fruits per plot at three positions (upper, middle and lower portions of the fruit) and the mean value was calculated. All measurements were performed one day after harvest.

Storage periods: The melons were stored at room temperature ($25 \pm 2\ ^{\circ}\text{C}$) and relative humidity of $70 \pm 2\ \%$. The storage time was determined by the number of days from harvest until the fruit showed signs of wilting and began to rot.

Data analysis methods

Data were analysed using two-way analysis of variance (ANOVA) to evaluate the effects of factor A, factor B and their interaction. When significant differences were detected ($p < 0.05$), Duncan's multiple range test was applied for mean comparisons. Statistical analyses were performed using SPSS, version 22.

Results and Discussion

Resistance of cucurbitaceous plants to wilt disease caused by *Fusarium* spp.

Two-way ANOVA revealed a highly significant interaction between *Fusarium* species and rootstock types at all observation times ($p < 0.01$). Disease severity varied depending on the combination of fungal species and rootstock. Both *F. equiseti* and *F. incarnatum* caused the highest disease incidence on *C. melo* L. var. *makuwa*, whereas low disease levels were observed on *B. hispida* and *C. melo* var. *conomon*, indicating a strong host–pathogen interaction.

The rate of disease was statistically different between Cucurbitaceous plants. The *B. hispida* (B1 treatment) and *C. melo* var. *conomon* (B2 treatment) showed better resistance than the *C. melo* var. *makuwa* (control, B4 treatment) at all the times surveyed. After 7 and 10 days of infection, the lowest disease rate was recorded in the and B2 treatments (4 %) (no statistically significant difference between the two rootstocks). After 13 and 16 days of infection, B4 treatment had a disease rate of 36.7 %, while others ranged from 4.0–10.7 %. The results also showed that the disease rate was seriously affected by *Fusarium* strain. Specifically, 7 days after infection with *F. equiseti*, the disease rate was 32 % in the control treatment and 56 % at 13 and 16 days after infection. The rate of disease caused by *F. incarnatum* was lower at 7 days after infection, only 14 %; however, the disease rate increased rapidly and reached 54 % at 13 and 16 days after infection. The B1 treatment had the lowest disease rate when infected with *F. equiseti* and *F. incarnatum* (4 % and 8 %, respectively); followed by the B2 treatment (10 % and 8 %, respectively). This suggested that the cucurbitaceous plants were more resistant to the disease than the control treatment (*C. melo* var. *makuwa*) (Table 3).

Similarly, the disease index results also showed differences (Table 4). The B1 and B2 treatments were always more resistant to

Fusarium wilt disease surveyed, compared to the B4 treatment. After 7 days of infection, the B1 and B2 treatments had the lowest disease index (2 % for *F. equiseti* and 4 % for *F. incarnatum*), while the B4 treatment (control) showed 16 % and 7 % for *F. equiseti* and *F. incarnatum*, respectively. In addition, the B4 treatment had a rapidly increasing disease index and at 16 days after infection, the disease index was 29 % with *F. equiseti* and *F. incarnatum* infection. Meanwhile, the disease index of the B1 and B2 treatments only increased slightly and had a value of 2–5 % after 16 days of *F. equiseti* and *F. incarnatum* infection. Once again, it was confirmed that cucurbitaceous roots were more resistant to disease than the control treatment (*C. melo* var. *makuwa*). Grafting is the most effective and economical method to grow melons continuously for many years without the seedlings being attacked by *Fusarium* spp. (4). Previous researchers reported that *F. oxysporum* caused wilt on zucchini in Korea (11). On melons, *F. oxysporum* was pathogenic to cantaloupe, cucumber and watermelon, although the pathogenicity varied significantly among the 13 strains (12). According to another study, the use of *C. melo* var. *conomon* as rootstocks could resist *Fusarium* wilt disease (13).

The results also showed that *F. incarnatum* had a higher rate and index of disease than *F. equiseti* on the B1 and B2 treatments (Table 3 and 4). *F. incarnatum* has been identified as the causal agent of cantaloupe fruit disease (14, 15). Therefore, fungus *F. incarnatum*, cucurbits *B. hispida* and *C. melo* var. *conomon* were selected for further experiment.

The growth, yield and quality of *Cucumis melo* var. *makuwa* grafted on cucurbit rootstock infected with *Fusarium incarnatum*

The growth of *C. melo* var. *makuwa* grafted on cucurbit rootstocks (through height of the stem, number of true leaves on the stem, the diameter of the rootstock and the grafting ratio) infected with *F. incarnatum* after 55 days of planting in the greenhouse was presented in Table 5.

The results showed that the artificial infection did not significantly affect the growth of melon. The length of the stem ranged from 211 to 214 cm, the number of true leaves was from 28.8 to 30.1 leaves, the root diameter ranged from 12.7 to 12.8 mm and the grafting ratio ranged from 1.1 to 1.2. These results suggest that artificial inoculation had no measurable impact on the growth of grafted melon plants. The finding of previous researchers showed that some rootstocks of cucurbitaceous plants have good resistance to wilt

Table 3. The disease rate (%) caused by *Fusarium* strains on cucurbitaceous plants

<i>Fusarium</i> strains (A)	Types of rootstock (B)	Disease severity (%) at different observation times			
		Days after infection (days)			
		7	10	13	16
<i>F. equiseti</i> (A1)	<i>Benincasa hispida</i> (B1)	4.0 ^{bc}	4.0 ^{bc}	4.0 ^d	4.0 ^d
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	4.0 ^{bc}	4.0 ^{bc}	10.0 ^{bcd}	10.0 ^{bcd}
	<i>Luffa aegyptiaca</i> (B3)	8.0 ^{bc}	10.0 ^{bc}	14.0 ^{bc}	14.0 ^{bc}
	<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	32.0 ^a	32.0 ^a	56.0 ^a	56.0 ^a
<i>F. incarnatum</i> (A2)	<i>Benincasa hispida</i> (B1)	8.0 ^{bc}	8.0 ^{bc}	8.0 ^{cd}	8.0 ^{cd}
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	8.0 ^{bc}	8.0 ^{bc}	8.0 ^{cd}	8.0 ^{cd}
	<i>Luffa aegyptiaca</i> (B3)	14.0 ^c	14.0 ^c	18.0 ^b	18.0 ^b
	<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	14.0 ^c	26.0 ^a	54.0 ^a	54.0 ^a
Control (A0) (Water)	<i>Benincasa hispida</i> (B1)	0.0	0.0	0.0	0.0
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	0.0	0.0	0.0	0.0
	<i>Luffa aegyptiaca</i> (B3)	0.0	0.0	0.0	0.0
	<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	0.0	0.0	0.0	0.0
F(A)		**	**	**	**
F(B)		**	**	**	**
F(A) × F(B)		**	**	**	**
CV (%)		66.2	61.2	3.81	52.2

Numbers in the same column followed by the same letter or no letter were not significantly different; **: significant at the 1 % level.

Table 4. The disease index caused by *Fusarium* strains on cucurbitaceous plants

Inoculation (A)	Rootstock (B)	Disease incidence (%) at different observation times			
		Days after infection (days)			
		7	10	13	16
<i>Fusarium equiseti</i> (A1)	<i>Benincasa hispida</i> (B1)	2.0 ^c	2.0 ^{cd}	2.0 ^{de}	2.0 ^{de}
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	2.0 ^c	2.0 ^{cd}	5.0 ^{cd}	5.0 ^{bcd}
	<i>Luffa aegyptiaca</i> (B3)	4.0 ^{bc}	5.0 ^{bc}	7.0 ^{bc}	7.0 ^{bc}
	<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	16.0 ^a	16.0 ^a	28.0 ^a	29.0 ^a
<i>Fusarium incarnatum</i> (A2)	<i>Benincasa hispida</i> (B1)	4.0 ^{bc}	4.0 ^{bcd}	4.0 ^{cde}	4.0 ^{cde}
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	4.0 ^{bc}	4.0 ^{bcd}	4.0 ^{cde}	4.0 ^{cde}
	<i>Luffa aegyptiaca</i> (B3)	7.0 ^b	7.0 ^b	9.0 ^b	9.0 ^b
	<i>Cucumis melo</i> L. var. <i>makuwa</i> (B4)	7.0 ^b	13.0 ^a	28.5 ^a	29.0 ^a
Control (A0) (Water)	<i>Benincasa hispida</i> (B1)	0.0	0.0	0.0	0.0
	<i>Cucumis melo</i> var. <i>conomon</i> (B2)	0.0	0.0	0.0	0.0
	<i>Luffa aegyptiaca</i> (B3)	0.0	0.0	0.0	0.0
F(A)	<i>Cucumis melo</i> var. <i>makuwa</i> (B4)	0.0	0.0	0.0	0.0
		**	**	**	**
		**	**	**	**
F(B)		**	**	**	**
		**	**	**	**
		**	**	**	**
F(A) x F(B)		**	**	**	**
		**	**	**	**
		**	**	**	**
CV (%)		50.1	47.6	40.5	40.9
		50.1	47.6	40.5	40.9
		50.1	47.6	40.5	40.9

Numbers in the same column followed by the same letter or no letter were not significantly different; **: significant at the 1 % level.

Table 5. The growth of *Cucumis melo* var. *makuwa* grafted on cucurbit rootstock infected with *Fusarium incarnatum* after 55 days of cultivation in the greenhouse condition

Infection treatment (C)	Rootstock (D)	Length of the stem (cm)	Number of true leaves (leaf)	The diameter of the rootstock (mm)	The grafting ratio
Infection with <i>Fusarium incarnatum</i> (C1)	<i>Benincasa hispida</i> (D1)	212 ± 12	28.8 ± 1.2	16.8 ± 1.0	1.32 ± 0.1
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	217 ± 10	30.1 ± 1.8	11.3 ± 1.1	1.08 ± 0.1
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	216 ± 11	29.4 ± 1.8	10.8 ± 1.1	1.02 ± 0.1
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	213 ± 13	28.3 ± 2.1	11.8 ± 1.3	1.00 ± 0.1
Control (Uninfection) (C0)	<i>Benincasa hispida</i> (D1)	207 ± 10	28.8 ± 1.6	16.8 ± 1.3	1.32 ± 0.1
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	214 ± 11	30.2 ± 1.8	11.1 ± 1.2	1.09 ± 0.1
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	214 ± 18	29.2 ± 1.6	11.4 ± 1.2	1.06 ± 0.1
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	210 ± 15	28.3 ± 1.9	11.8 ± 1.3	1.00 ± 0.1
Mean (D)	<i>Benincasa hispida</i> (D1)	209.5 ^{BC}	28.8 ^{BC}	16.8 ^A	1.32 ^A
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	215.5 ^A	30.15 ^A	11.2 ^B	1.08 ^B
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	215 ^A	29.3 ^B	11.1 ^B	1.04 ^{BC}
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	211.5 ^B	28.3 ^C	11.8 ^B	1.00 ^C
F(C)		ns	ns	ns	ns
F(D)		ns	**	***	***
F(C) x F(D)		ns	ns	ns	ns
CV (%)		3.27	3.42	2.67	3.99

Numbers in the same column followed by the same letter or no letter were not significantly different; ***: significant at the 1 % level; **: significant at the 5 % level; ns: not statistically significant difference.

disease and effectively support the growth of the grafted plants (16).

The results also showed that the melon growth was affected by the rootstock, except for the length of the stem. In the control treatment, the number of true leaves and the grafting ratio were the lowest (28.3 leaves and 1.00, respectively) in both infection and no infection. At the rootstock of *B. hispida* (D1 treatment), the diameter of the rootstock and the grafting ratio were the highest (16.8 cm and 1.32, respectively), indicating the vigorous growth of the rootstock. The grafting ratio was approximately 1 (ranging from 1.02 to 1.08) for both *C. melo* var. *conomon* (D2 treatment) and *C. melo* L. var. *makuwa* (D3 treatment). The diameter of rootstock is an important index to evaluate the growth of plants because the rootstock is the place to transport water and minerals from the soil to the organs of plants (17). The rootstock diameter determines the ability to absorb nutrients well due to an extensive, healthy root system and thereby giving better productivity. In addition, the ratio of grafting shows the compatibility between the root and tip of the grafted melon (18). According to previous study, the grafting ratio is similar about 1.00, the grafted melon can grow normally; if this ratio

is greater than 1, the grafted melon is stunted and slow to grow (19). Although *B. hispida* (D1) showed a larger rootstock diameter and good resistance, *C. melo* var. *conomon* (D2) produced superior yield and fruit quality, likely due to better graft compatibility with the scion. As D2 belongs to the same species, closer genetic affinity may have promoted more effective vascular connections and assimilate transport at the graft union, enhancing fruit development (20). These results suggest that rootstock vigour or resistance alone does not ensure high yield and quality and that graft compatibility is a key factor determining grafting success.

The results of the Table 6 showed that no significant interaction between infection treatment and rootstock type was detected for any of the measured traits ($p > 0.05$), indicating that the response of yield and fruit characteristics to rootstock selection was consistent under both infected and non-infected conditions. The results in Tab. 6 also indicated that infection with *F. incarnatum* had no significant effect ($p > 0.05$) on fruit weight (1.35–1.68 kg), fruit height (14.4–16.3 cm) or fruit circumference (43.2–45.4 cm); total yield (18.5–23.3 t ha⁻¹), commercial yield (17.7–23.3 t ha⁻¹);

Table 6. Yield components of *Cucumis melo* L. var. *makuwa* grafted on cucurbit rootstock infected with *Fusarium incarnatum* in the greenhouse condition

Infection treatment (C)	Rootstock (D)	Fruit weight (kg)	Fruit height (cm)	Fruit circumference (cm)	Total yield (t ha ⁻¹)	Commercial yield (t ha ⁻¹)	commercial yield/total yield (%)
Infection with <i>Fusarium incarnatum</i> (C1)	<i>Benincasa hispida</i> (D1)	1.57 ± 0.1	15.2 ± 1.1	44.5 ± 2.6	21.6 ± 1.6	20.6 ± 1.5	95.5 ± 3.6
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	1.68 ± 0.1	16.2 ± 1.3	45.4 ± 3.1	23.3 ± 1.5	23.3 ± 1.6	100 ± 0.0
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	1.45 ± 0.1	14.7 ± 1.2	43.5 ± 3.6	20.1 ± 1.5	19.1 ± 1.6	95.0 ± 3.1
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	1.35 ± 0.1	14.4 ± 1.2	43.2 ± 3.9	18.7 ± 1.5	17.8 ± 1.5	95.3 ± 3.2
Control (Uninfection) (C0)	<i>Benincasa hispida</i> (D1)	1.55 ± 0.1	15.4 ± 1.2	44.9 ± 3.8	21.3 ± 1.6	20.4 ± 1.9	95.9 ± 3.5
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	1.59 ± 0.1	16.3 ± 1.2	45.3 ± 3.7	23.0 ± 1.7	23.0 ± 1.8	100 ± 0.0
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	1.45 ± 0.1	14.8 ± 1.1	43.4 ± 3.8	20.4 ± 1.9	19.7 ± 1.6	96.2 ± 3.1
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	1.38 ± 0.1	14.5 ± 1.2	43.2 ± 3.8	18.5 ± 1.05	17.7 ± 1.6	95.9 ± 3.2
MEAN (D)	<i>Benincasa hispida</i> (D1)	1.56 ^A	15.3 ^B	44.7 ^B	21.4 ^B	20.5 ^B	
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	1.63 ^A	16.2 ^A	45.4 ^A	23.1 ^A	23.1 ^A	
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	1.45 ^B	14.8 ^C	43.5 ^C	20.3 ^C	19.4 ^{BC}	
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	1.36 ^B	14.4 ^D	43.2 ^C	18.6 ^D	17.8 ^D	
F(C)		ns	ns	ns	ns	ns	ns
F(D)		**	**	**	**	**	ns
	F(C) × F(D)	ns	ns	ns	ns	ns	ns
CV (%)		4.21	1.52	0.66	2.40	8.53	7.78

Numbers in the same column followed by the same letter or no letter were not significantly different; **: significant at the 1 % level.

commercial yield/actual yield ratio (95.0–100 %). In contrast, rootstock type significantly affected all fruit growth and yield parameters ($p < 0.01$). The results also showed that the D1 and D2 treatments gave the highest fruit weight (1.63 and 1.56 kg, respectively). In addition, the D2 treatment was superior in terms of fruit height (16.2 cm), fruit circumference (45.4 cm), commercial yield (23.1 t ha⁻¹) and the commercial yield/actual yield ratio reached nearly 100 %. This result was consistent with another study, the fruit height and fruit circumference of the melon grafted on the cantaloupe rootstock are the highest compared to the remaining rootstock (21). These yield components have the same trend as the growth indicators proven above. Moreover, earlier reports also showed that the yield of grafted plants increased (25–55 %) compared to ungrafted melon (22). Grafting plants onto vigorous rootstocks enhances their ability to absorb water and minerals and improves the efficiency of nutrient transport to the fruit, thereby contributing to increased yield, as reported previously (23, 24). Previous studies emphasised the effectiveness of certain rootstocks in enhancing fruit growth (25). Similar observations suggest that selecting an appropriate rootstock is a key factor in maintaining productivity under adverse conditions (3).

The results presented in Table 7 show that artificial infection did not significantly affect the Brix level (13.1–14.7 °Brix) the thickness of fruit flesh (3.00 to 3.48 cm) and the storage time (15.8–21.0 days). However, rootstock significantly influenced fruit quality parameters. Among the treatments, D2 resulted in the highest fruit soluble solids content (14.65 °Brix) and the greatest flesh thickness (3.52 cm), indicating that rootstock selection plays a crucial role in regulating assimilate accumulation in melon fruit. Although several studies have reported a reduction in fruit sweetness when melons are

grafted onto cucurbit rootstocks (26, 27), the present study demonstrated an increase in sweetness in plants grafted onto *C. melo* var. *conomon* compared with the ungrafted control. This result is consistent with previous reports showing that compatible rootstocks can enhance soluble solid accumulation and improve fruit quality (25, 28). In addition, another study showed a tendency to store more dry matter in the stem and leaves as a resistance response mechanism in disease-infected plants (29). The ability to accumulate sugars was higher, consistent with previous studies highlighting the role of rootstock in carbohydrate transport (25). Previous studies showed that melon rootstocks can prolong fruit storage duration by reducing the rates of transpiration and oxidation (30).

Conclusion

This study provides new evidence that *Benincasa hispida* and *Cucumis melo* var. *conomon* exhibit higher resistance to *Fusarium incarnatum* than *Cucumis melo* var. *makuwa*. Notably, grafting *C. melo* var. *makuwa* onto *C. melo* var. *conomon* not only enhanced disease tolerance but also resulted in the highest yield, improved fruit quality and extended storage life. These findings highlight *C. melo* var. *conomon* as a promising rootstock for sustainable melon production in areas affected by *F. incarnatum*.

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Table 7. Quality of *Cucumis melo* var. *makuwa* grafted on cucurbit rootstock infected with *Fusarium incarnatum* in the greenhouse condition

Infection treatment (C)	Rootstock (D)	°Brix	Thickness of flesh (cm)	Storage time (days)
Infection with <i>Fusarium incarnatum</i> (C1)	<i>Benincasa hispida</i> (D1)	13.3 ± 0.1	3.14 ± 0.3	19.5 ± 1.0
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	14.6 ± 0.3	3.48 ± 0.3	21.0 ± 1.0
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	13.5 ± 0.1	3.00 ± 0.2	21.0 ± 1.0
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	13.4 ± 0.0	3.07 ± 0.2	19.5 ± 1.0
Control (Uninfection) (C0)	<i>Benincasa hispida</i> (D1)	13.1 ± 0.0	3.29 ± 0.2	19.5 ± 1.0
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	14.7 ± 0.1	3.54 ± 0.1	20.3 ± 1.0
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	13.6 ± 0.0	3.15 ± 0.1	19.8 ± 1.0
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	13.5 ± 0.1	3.02 ± 0.1	19.5 ± 1.0
MEAN (D)	<i>Benincasa hispida</i> (D1)	13.20 ^B	3.22 ^B	
	<i>Cucumis melo</i> var. <i>conomon</i> (D2)	14.65 ^A	3.52 ^A	
	<i>Cucumis melo</i> var. <i>makuwa</i> (D3)	13.55 ^B	3.08 ^{BC}	
	<i>Cucumis melo</i> var. <i>makuwa</i> – no grating (control) (D4)	13.45 ^B	3.05 ^C	
F(C)		ns	ns	ns
F(D)		**	**	ns
	F(C) x F(D)	ns	ns	ns
CV (%)		4.45	3.41	12.8

Numbers in the same column followed by the same letter or no letter were not significantly different; **: significant at the 1 % level.

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Authors' contributions

TVK designed the study, carried out the experiment, analysed the data and wrote, reviewed and edited the manuscript. NMH, VTBT, NTTX and NTNG carried out the experiment and analysed the data. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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