# Evaluation of rocket resistance to *Fusarium* wilt

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**Abstract**: In north-western Italy serious losses were observed in cultivated (*Eruca vesicaria*) and wild (*Diplotaxis* spp.) rocket varieties infected by *Fusarium oxysporum*, as one of important diseases in horticultural production. For the evaluation of varietal resistance of rocket to *Fusarium* wilt, forty-four varieties of rocket, belonging to cultivated and wild rockets, respectively, were chosen for resistance test carried out in glasshouse from June to November, 2004. Roots of 30 day old plants were artificially inoculated by dipping in a spore suspension ($1 \times 10^6$ cfu/mL) of the pathogen. The trials were independently conducted, with three replicates, using, as inoculum, a mixture of thirty-two strains (MIX) isolated from different varieties of cultivated and wild rockets, and other two strains, Fus. Ruc. 9A/02 and Fus. Ruc. 13/03, respectively, gotten from two different varieties of wild rocket. The trials were repeated twice. Two indicators were used to evaluate the different resistance, one of which was percentage of dead plants, the other disease index (DI). Significant correlation ($P < 0.01$) was found between these two indicators, which showed that both methods were feasible for the evaluation of rocket's resistance to *Fusarium* wilt. The majority of rocket varieties showed a resistance to strain Fus. Ruc. 13/03, while the majority of them showed a susceptibility to mixtured strains MIX and strain Fus. Ruc. 9A/02. MIX and strain Fus. Ruc. 9A/02 behaved similarly on the tested varieties and were more virulent than strain Fus. Ruc. 13/03. The varieties 12/03 and 20/03 showed a high resistance to MIX, the varieties 6/03 and 7/04 showed a high resistance to strain Fus. Ruc. 9A/02, and the varieties 9/02, 2/03, 5/03, 6/03, 7/03, 9/03, 11/03, 12/03, 20/03, 21/03, 24/03, 3/04, 6/04, 7/04 and 11/04 showed a high resistance to strain Fus. Ruc. 13/03.

**Key words**: *Fusarium* wilt; resistance; rocket

## 芝麻菜品种对尖镰孢菌枯萎病的抗性评价

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**摘要**: 尖镰孢菌枯萎病是意大利西北部芝麻菜栽培品种(*Eruca vesicaria*)和野生品种(*Diplotaxis* spp.)上的重要病害之一,常引起严重的损失。为评价芝麻菜品种对尖镰孢菌枯萎病的抗性,2004年6 ~11 月,选用了44 个栽培及野生品种资源在玻璃温室进行抗性试验,使用浓度为 $1 \times 10^6$ cfu/mL 的孢子悬浮液蘸根法人工接种30 天苗龄的芝麻菜幼苗,以分离自芝麻菜两个不同野生品种的菌株 Fus. Ruc. 9A/02 和 Fus. Ruc. 13/03,以及分离自栽培和野生品种的32 个菌株混合(MIX),分别作为抗病试验接种体,每次接种试验设 A、B、C 三个重复。整个试验重复进行2 次。调查病害引

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起的死苗率(%)和病情指数(DI),作为评价芝麻菜品种抗性差异的两项指标。研究结果显示,这两项指标间的相关性极显著($P<0.01$),即表明可采用其中一项指标评价芝麻菜品种对尖镰孢菌枯萎病的抗性。供试的44个栽培及野生芝麻菜品种中,多数品种抗尖镰孢菌菌株 Fus. Ruc. 13/03,而对菌株 Fus. Ruc. 9A/02 及菌株混合 MIX 表现为易感性,而且这些易感品种在菌株 Fus. Ruc. 9A/02 及菌株混合 MIX 两试验中的抗性表现较为一致,Fus. Ruc. 9A/02 和 MIX 的毒性也更强于 Fus. Ruc. 13/03 菌株。芝麻菜品种 12/03 和品种 20/03 高抗菌株混合 MIX,品种 6/03 和品种 7/04 高抗菌株 Fus. Ruc. 9A/02,而品种 9/02、2/03、5/03、6/03、7/03、9/03、11/03、12/03、20/03、21/03、24/03、3/04、6/04、7/04 和 11/04 高抗菌株 Fus. Ruc. 13/03。

**关键词**:尖镰孢菌枯萎病;抗病性;芝麻菜

Rocket is a vegetable variety increasingly used in the Mediterranean cuisine as salad and or to decorate dishes. Two types of rockets are available on the market in Italy. One is *Eruca vesicaria* (synonym *E. sativa*) known as ruchetta or cultivated garden rocket, and the other are several species of *Diplotaxis* (*Diplotaxis erucoides*, *D. muralis*, and *D. tenuifolia*), which are wild plants now widely cultivated. *Fusarium* wilt caused by *Fusarium oxysporum* was reported previously on cultivated rocket (*Eruca sativa*) in India[1] and also in Italy[2]. On wild rocket (*Diplotaxis* spp.), until 2003, *Fusarium* wilt was not reported world-wide[2]. In spring 2002, plants of the cultivated and wild rockets showing symptoms of a wilt disease were observed in several commercial plastic greenhouses near Bergamo in northern Italy[2]. Diseased plants were stunted and chlorotic with brown or black streaks in the vascular system. *Fusarium oxysporum* was consistently and readily isolated from symptomatic vascular tissues when plated on a *Fusarium*-selective medium[3]. When the temperature ranged between 26℃ and 35℃ in plastic greenhouses, rocket plants got severely infected. When artificial inoculation with a spore suspension ($1\times10^6$ cfu/mL) of *Fusarium oxysporum* was conducted at 25℃ to 28℃ in growth chamber, wilt symptom developed on all rocket plants 20 days after inoculation[4].

So far it was not known the presence of significant difference in varieties' resistance of cultivated and wild rockets to *Fusarium* wilt. The trials reported in this paper were designed to identify and evaluate the resistance of several varieties of rocket, which were conducted in the automatic greenhouses. Understanding of the varieties' resistance will contribute to direct the production of rocket and the breeding of resistant varieties. Two evaluational methods adopted in the study were compared at the same time so that the evaluation criterion could be referred in future practice for taking advantage of rocket resistance.

# 1 Materials and Methods

## 1.1 Isolates used

Thirty-two strains of *Fusarium oxysporum* were obtained in 2002 – 2004 from infected rocket plants collected in northern Italy (Lumbardy and Piedmont). The different strains of *F. oxysporum* were maintained on PDA at 8℃ in the preservation chamber.

## 1.2 Production of inoculums

The mixture of thirty-two strains (MIX; Table 2), strain Fus. Ruc. 9A/02 isolated from one variety of wild rocket (*Diplotaxis tenuifolia*) and strain Fus. Ruc. 13/03 obtained from another variety of wild rocket (*Diplotaxis* sp.) were grown in liquid medium (CH) of casein hydrolisate (0.2%) at 25℃ with 12 h of fluorescent light per day, with agitating, for 10 days. The concentration of spore and mycelium fragments was determined by hemacytometer and adjusted with deionized water to a concentration of $1\times10^6$ cfu (colony forming units)/mL, which was adopted throughout the trials.

## 1.3 Susceptibility test

Forty-four rocket varieties obtained from different seed companies in Italy, belonging to cultivated and wild rockets, were tested (Table 1). Seeds were sown in a steamed soil mixture (peat, compost broad bark and sand, respectively, 60∶20∶20 vol/vol) in plug trays and maintained at 25℃. Roots of 30 day old plants were trimmed to a length of 5 cm, and dipped for 10 min in the pathogen spore suspension prepared as described above. Inoculated seedlings were transplanted in

baskets (10 litres) containing steamed soil (30 min at 80℃). Control plants were prepared similarly but soaked in plain deionized water. Ten seedlings per basket were transplanted in each trial. Each basket was considered as a replicate. Three replicates were used in each trial. Plants were maintained in a greenhouse at a temperature ranging from 20℃ (min.) to 41℃ (max.), controlled by an automatic mechanical system. Symptom started to be visible 7 – 10 days after artificial inoculation. Plants were evaluated weekly for disease development and wilted plants were counted. The data was expressed as a percent of dead plants and disease index (DI). The disease rating reached the top value in 4 to 6 weeks after inoculation.

**Table 1 List of different varieties of rocket tested**

| Code of the variety | Species | Type | Seed company |
|---|---|---|---|
| 7/02 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 8/02 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI MILANO |
| 9/02 | *Eruca sativa* | Cultivated | OROSEM |
| 10/02 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI |
| 1/03 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI (LODI) |
| 2/03 | *Diplotaxis tenuifolia* | Wild | FRANCHI |
| 3/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 4/03 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI (LODI) |
| 5/03 | *Diplotaxis tenuifolia* | Wild | FRANCHI |
| 6/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 7/03 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI (LODI) |
| 9/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 10/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 11/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 12/03 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI (LODI) |
| 13/03 | *Diplotaxis tenuifolia* | Wild | ISI SEMENTI S. P. A |
| 14/03 | *Diplotaxis tenuifolia* | Wild | MAZZOCCHI (LODI) |
| 15/03 | *Diplotaxis tenuifolia* | Wild | FRANCHI |
| 16/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 17/03 | *Diplotaxis tenuifolia* | Wild | OROSEM |
| 18/03 | *Diplotaxis tenuifolia* | Wild | SAIS |
| 19/03 | *Eruca sativa* | Cultivated | SAIS |
| 20/03 | *Diplotaxis tenuifolia* | Wild | SAIS |
| 21/03 | *Eruca sativa* | Cultivated | SAIS |
| 22/03 | *Eruca sativa* | Cultivated | SAIS |
| 23/03 | *Diplotaxis tenuifolia* | Wild | SAIS |
| 24/03 | *Diplotaxis tenuifolia* | Wild | SAIS |
| 25/03 | *Eruca sativa* | Cultivated | SAIS |
| 26/03 | *Eruca sativa* | Cultivated | SAIS |
| 1/04 | *Eruca sativa* | Cultivated | SAIS |
| 2/04 | *Diplotaxis tenuifolia* | Wild | AGRISEM |
| 3/04 | *Eruca sativa* | Cultivated | AGRISEM |
| 4/04 | *Diplotaxis tenuifolia* | Wild | ISI SEMENTI |
| 5/04 | *Diplotaxis tenuifolia* | Wild | ISI SEMENTI |
| 6/04 | *Diplotaxis tenuifolia* | Wild | ISI SEMENTI |
| 7/04 | *Diplotaxis tenuifolia* | Wild | ISI SEMENTI |
| 8/04 | *Eruca sativa* | Cultivated | ISI SEMENTI |
| 9/04 | *Diplotaxis tenuifolia* | Wild | LA SEMIORTO SEMENTI |
| 10/04 | *Eruca sativa* | Cultivated | LA SEMIORTO SEMENTI |
| 11/04 | *Eruca sativa* | Cultivated | GALASSI SEMENTI |
| 12/04 | *Eruca sativa* | Cultivated | SAIS |
| 13/04 | *Eruca sativa* | Cultivated | SAIS |
| 14/04 | *Eruca sativa* | Cultivated | SAIS |
| 15/04 | *Eruca sativa* | Cultivated | SAIS |

The first trial started on July 19th 2004 and finished on September 1st 2004. The inoculum consisted of the mixture of thirty-two strains of *Fusarium oxysporum* (Table 2). The second trial started on July 29th 2004 and completed on September 1st 2004. The inoculum Fus. Ruc. 9A/02 was prepared by using isolate obtained from one variety of wild rocket. The third trial started on August 13th 2004 and ended on September 13th 2004. The isolate Fus. Ruc. 13/03 for inoculation was one of *Fusarium oxysporum* strains isolated from another variety of wild rocket. These three trials were conducted for a second time on September 13th to October 21st, on September 9th to October 27th, on September 24th to November 10th, respectively. The maximum, minimum, and average temperature were 41.0℃, 20.0℃, and 29.7℃ in trial 1, 41.0℃, 20.0℃, and 29.7℃ in trial 2, 41.0℃, 21.0℃, and 31.1℃ in trial 3, 35.5℃, 29.6℃, and 30.0℃ in the repeated trial 1, 38.5℃, 20.0℃, and 29.9°C in the repeated trial 2, 37.0℃, 20.0℃, and 27.8℃ in the repeated trial 3, respectively.

**Table 2 List of different strains of *F. oxysporum* isolated in infected plants of rocket in Bergamo field**

| Code of the strains | Host plant | Source farm of the strains |
|---|---|---|
| Fus. Ruc. 2/02 | *Diplotaxis tenuifolia* | Az. Agr. Consoli Innocente e Figli |
| Fus. Ruc. 3/02 | *Diplotaxis tenuifolia* | Orticoltura G. N. R. di Ghilardi Donatella & C. S. S. |
| Fus. Ruc. 4/02 | *Diplotaxis tenuifolia* | Belussi 2 |
| Fus. Ruc. 6/02 | *Eruca sativa* | Cunj - Ersi Moris |
| Fus. Ruc. 7/02 | *Diplotaxis tenuifolia* | Orticoltura Sonzogni Giuliano |
| Fus. Ruc. 8A/02 | *Diplotaxis tenuifolia* | GIULIANO |
| Fus. Ruc. 10B/02 | *Diplotaxis tenuifolia* | BELUSSI |
| Fus. Ruc. 12A/02 | *Diplotaxis tenuifolia* | Bizioli Roberto |
| Fus. Ruc. 9A/02 | *Diplotaxis tenuifolia* | Az. Agr. Mangili Francesco Mario |
| Fus. Ruc. 13D/02 | *Diplotaxis tenuifolia* | Bonacina Maria |
| Fus. Ruc. 15B/02 | *Diplotaxis tenuifolia* | Az. Agr. Quarantini Luigi |
| Fus. Ruc. 14B/02 | *Diplotaxis tenuifolia* | Baroni Maria |
| Fus. Ruc. 16A/02 | *Diplotaxis tenuifolia* | Az. Agr. Esposito Giovanni |
| Fus. Ruc. 17A/02 | *Diplotaxis tenuifolia* | Az. Locatelli |
| Fus. Ruc. 1/03 | *Diplotaxis tenuifolia* | Bellina C. |
| Fus. Ruc. 3/03 | *Diplotaxis tenuifolia* | Merlie Sanzoni |
| Fus. Ruc. 4/03 | *Diplotaxis tenuifolia* | Mangili F. |
| Fus. Ruc. 6/03 | *Diplotaxis tenuifolia* | Mogli Fausto |
| Fus. Ruc. 8/03 | *Diplotaxis tenuifolia* | Belossi Nuovo |
| Fus. Ruc. 13/03 | *Diplotaxis tenuifolia* | Lonni B. |
| Fus. Ruc. 16/03 | *Diplotaxis tenuifolia* | Chiodini |
| Fus. Ruc. 17/03 | *Diplotaxis tenuifolia* | Chiodini |
| Fus. Ruc. 21/03 | *Diplotaxis tenuifolia* | Chiodini |
| Fus. Ruc. 22/03 | *Diplotaxis tenuifolia* | Gremorre |
| Fus. Ruc. 24/03 | *Diplotaxis tenuifolia* | Oberti |
| Fus. Ruc. 26/03 | *Eruca sativa* | Berruto |
| Fus. Ruc. 28/03 | *Eruca sativa* | Berruto |
| Fus. Ruc. 30/03 | *Eruca sativa* | Berruto |
| Fus. Ruc. 33/03 | *Eruca sativa* | Berruto |
| Fus. Ruc. 34/03 | *Eruca sativa* | Berruto |
| Fus. Ruc. 1/04 | *Diplotaxis tenuifolia* | Bioagro |
| Fus. Ruc. 2/04 | *Diplotaxis tenuifolia* | Lucignolo |

### 1.4 Rate of dead plant and disease index

Two indictors were applied to evaluate the resistance of rocket varieties, one of which was the percentage of dead plants (%) and the other was disease index (DI 0 - 4). Four levels of dead rate were applied to classify the resistance or susceptibility of rocket tested, which was as follows: resistance (R, 0 - 10% of dead plants), partial resistance (PR, 11% - 30%), moderate susceptibility (MS, 31% - 60%), susceptibility (S, 61% - 100%).

### 1.5 Statistics method

EXCEL 2000 was used for the general statistic work. The software SPSS 11.0 version was applied to Pearson correlation analysis, and mutiply variants analysis for example Tukey's test.

## 2 Results and Analysis

The method of artificial inoculation adopted in the study resulted in good level of disease incidence in all the trials, providing effective screening for *Fusarium* wilt resistance (Tables 3 – 4).

**Table 3 Death rate of rocket varieties after inoculation** (%)

| Code of the varieties | Strains MIX | | | | Strain Fus. Ruc. 9A/02 | | | | Strain Fus. Ruc. 13/03 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | |
| 7/02 | 13.3 | ab | 23.3 | abc | 23.3 | a-d | 26.7 | abc | 20.0 | abc | 26.7 | a-d |
| 8/02 | 43.3 | a-e | 46.7 | a-d | 50.0 | a-j | 30.0 | a-d | 23.3 | abc | 20.0 | a-d |
| 9/02 | 36.7 | a-d | 26.7 | abc | 36.7 | a-g | 23.3 | abc | 26.7 | abc | 10.0 | ab |
| 10/02 | 20.0 | ab | 26.7 | abc | 26.7 | a-e | 30.0 | a-d | 13.3 | abc | 20.0 | a-d |
| 1/03 | 20.0 | ab | 36.7 | a-d | 13.3 | ab | 23.3 | abc | 13.3 | abc | 40.0 | a-f |
| 2/03 | 23.3 | abc | 20.0 | ab | 13.3 | ab | 30.0 | a-d | 6.7 | ab | 13.3 | abc |
| 3/03 | 10.0 | ab | 46.7 | a-d | 26.7 | a-e | 46.7 | a-f | 6.7 | ab | 33.3 | a-e |
| 4/03 | 33.3 | a-d | 20.0 | ab | 30.0 | a-f | 40.0 | a-e | 13.3 | abc | 33.3 | a-e |
| 5/03 | 26.7 | a-d | 43.3 | a-d | 13.3 | ab | 20.0 | ab | 10.0 | abc | 16.7 | a-d |
| 6/03 | 23.3 | abc | 23.3 | abc | 30.0 | a-f | 10.0 | a | 13.3 | abc | 0.0 | a |
| 7/03 | 33.3 | a-d | 26.7 | abc | 26.7 | a-e | 16.7 | a | 13.3 | abc | 10.0 | ab |
| 9/03 | 50.0 | a-f | 46.7 | a-d | 23.3 | a-d | 26.7 | abc | 3.3 | a | 6.7 | ab |
| 10/03 | 36.7 | a-d | 33.3 | abc | 96.7 | j | 20.0 | ab | 46.7 | cde | 10.0 | ab |
| 11/03 | 23.3 | abc | 46.7 | a-d | 33.3 | a-g | 23.3 | abc | 6.7 | ab | 16.7 | a-d |
| 12/03 | 6.7 | a | 10.0 | a | 16.7 | abc | 36.7 | a-e | 6.7 | ab | 6.7 | ab |
| 13/03 | 36.7 | a-d | 30.0 | abc | 30.0 | a-f | 16.7 | a | 6.7 | ab | 46.7 | a-f |
| 14/03 | 46.7 | a-e | 40.0 | a-d | 70.0 | d-j | 20.0 | ab | 30.0 | a-d | 43.3 | a-f |
| 15/03 | 50.0 | a-f | 40.0 | a-d | 80.0 | f-j | 43.3 | a-ef | 0.0 | a-e | 53.3 | b-f |
| 16/03 | 53.3 | a-f | 33.3 | abc | 63.3 | b-j | 20.0 | ab | 26.7 | abc | 20.0 | a-d |
| 17/03 | 56.7 | a-f | 33.3 | abc | 70.0 | d-j | 33.3 | a-d | 66.7 | def | 76.7 | ef |
| 18/03 | 36.7 | a-d | 33.3 | abc | 40.0 | a-h | 36.7 | a-e | 13.3 | abc | 46.7 | a-f |
| 19/03 | 73.3 | c-f | 56.7 | a-e | 90.0 | hij | 63.3 | a-ef | 43.3 | b-e | 16.7 | a-d |
| 20/03 | 10.0 | ab | 26.7 | abc | 33.3 | a-g | 16.7 | a | 10.0 | abc | 10.0 | ab |
| 21/03 | 46.7 | a-e | 63.3 | b-e | 76.7 | e-j | 63.3 | a-f | 23.3 | abc | 10.0 | ab |
| 22/03 | 33.3 | a-d | 53.3 | a-e | 90.0 | hij | 53.3 | a-f | 30.0 | a-d | 13.3 | abc |
| 23/03 | 76.7 | def | 16.7 | ab | 93.3 | ij | 76.7 | b-f | 0.0 | a-e | 40.0 | a-f |
| 24/03 | 33.3 | a-d | 33.3 | abc | 23.3 | a-d | 16.7 | a | 10.0 | abc | 3.3 | a |
| 25/03 | 60.0 | b-f | 70.0 | cde | 90.0 | hij | 50.0 | a-f | 43.3 | b-e | 13.3 | abc |
| 26/03 | 73.3 | c-f | 63.3 | b-e | 66.7 | c-j | 43.3 | a-f | 36.7 | a-e | 20.0 | a-d |
| 1/04 | 46.7 | a-e | 50.0 | a-d | 73.3 | d-j | 36.7 | a-e | 20.0 | abc | 13.3 | abc |
| 2/04 | 26.7 | a-d | 0.0 | abc | 26.7 | a-e | 0.0 | abc | 26.7 | abc | 0.0 | a-d |
| 3/04 | 46.7 | a-e | 36.7 | a-d | 76.7 | e-j | 33.3 | a-d | 10.0 | abc | 13.3 | abc |
| 4/04 | 100.0 | f | 100.0 | e | 100.0 | j | 100.0 | f | 90.0 | f | 63.3 | def |
| 5/04 | 76.7 | def | 83.3 | de | 76.7 | e-j | 86.7 | def | 33.3 | a-d | 83.3 | f |
| 6/04 | 20.0 | ab | 33.3 | abc | 26.7 | a-e | 33.3 | a-d | 3.3 | a | 6.7 | ab |
| 7/04 | 13.3 | ab | 20.0 | ab | 10.0 | a | 16.7 | a | 10.0 | abc | 36.7 | a-f |
| 8/04 | 56.7 | a-f | 40.0 | a-d | 83.3 | g-j | 80.0 | c-f | 33.3 | a-e | 23.3 | a-d |
| 9/04 | 36.7 | a-d | 50.0 | a-d | 60.0 | a-j | 36.7 | a-e | 30.0 | a-d | 36.7 | a-f |
| 10/04 | 90.0 | ef | 83.3 | de | 100.0 | j | 93.3 | ef | 70.0 | ef | 60.0 | c-f |
| 11/04 | 26.7 | a-d | 43.3 | a-d | 33.3 | a-g | 43.3 | a-f | 6.7 | ab | 10.0 | ab |
| 12/04 | 56.7 | a-f | 40.0 | abcd | 70.0 | d-j | 33.3 | a-d | 0.0 | a-e | 63.3 | def |
| 13/04 | 30.0 | a-d | 33.3 | abc | 43.3 | a-i | 16.7 | a | 20.0 | abc | 13.3 | abc |
| 14/04 | 36.7 | a-d | 50.0 | a-d | 73.3 | d-j | 26.7 | abc | 33.3 | a-e | 20.0 | a-d |
| 15/04 | 73.3 | c-f | 50.0 | a-d | 93.3 | ij | 60.0 | a-f | 26.7 | abc | 26.7 | a-d |

Note: Means of the same column, followed by the same letter, do not significantly differ following Tukey's test ($P=0.05$).

**Table 4 Disease index of rocket varieties after inoculation** (DI 0 – 4)

| Code of the varieties | Strains MIX | | | | Strain Fus. Ruc. 9A/02 | | | | Strain Fus. Ruc. 13/03 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | | Trial 1 | | Trial 2 | |
| 7/02 | 1.00 | ab | 1.33 | a-d | 1.67 | a-f | 1.48 | abc | 1.20 | abc | 1.27 | a-f |
| 8/02 | 2.02 | a-h | 2.23 | a-f | 2.50 | a-l | 1.57 | abc | 1.40 | a-e | 1.00 | a-e |
| 9/02 | 1.83 | a-g | 1.48 | a-d | 2.15 | a-k | 1.33 | abc | 1.67 | a-e | 0.78 | a-d |
| 10/02 | 1.23 | abc | 1.50 | a-d | 1.73 | a-g | 1.52 | abc | 0.93 | abc | 1.25 | a-f |
| 1/03 | 1.20 | abc | 1.93 | a-e | 1.17 | abc | 1.38 | abc | 0.92 | abc | 2.03 | a-g |
| 2/03 | 1.40 | a-e | 1.25 | abc | 1.12 | ab | 1.62 | a-d | 0.65 | ab | 0.84 | a-e |
| 3/03 | 0.85 | a | 2.45 | b-f | 1.72 | a-g | 2.42 | a-f | 0.72 | ab | 2.00 | a-g |
| 4/03 | 1.68 | a-g | 1.38 | a-d | 1.73 | a-g | 1.88 | a-e | 0.92 | abc | 1.80 | a-g |
| 5/03 | 1.20 | abc | 2.25 | a-f | 1.05 | ab | 1.10 | a | 0.77 | ab | 1.10 | a-f |
| 6/03 | 1.33 | a-d | 1.27 | a-d | 1.73 | a-g | 0.88 | a | 0.98 | abc | 0.38 | a |
| 7/03 | 1.65 | a-g | 1.52 | a-d | 1.72 | a-g | 0.97 | a | 1.08 | abc | 0.60 | ab |
| 9/03 | 2.25 | a-h | 2.20 | a-f | 1.50 | a-d | 1.50 | abc | 0.57 | a | 0.57 | ab |
| 10/03 | 1.78 | a-g | 1.90 | a-e | 3.97 | l | 1.15 | a | 2.30 | b-e | 0.68 | ab |
| 11/03 | 1.33 | a-d | 2.40 | a-f | 1.80 | a-h | 1.40 | abc | 0.65 | ab | 1.05 | a-f |
| 12/03 | 0.82 | a | 0.60 | a | 1.30 | abc | 1.62 | abc | 0.63 | ab | 0.75 | a-d |
| 13/03 | 1.82 | a-g | 1.58 | a-d | 1.75 | a-g | 1.17 | ab | 0.63 | ab | 2.33 | b-g |
| 14/03 | 2.27 | a-i | 2.03 | a-e | 3.33 | f-l | 1.20 | ab | 1.72 | a-e | 2.10 | a-g |
| 15/03 | 2.38 | a-i | 2.12 | a-e | 3.53 | h-l | 2.13 | a-f | 2.03 | a-e | 2.63 | d-g |
| 16/03 | 2.37 | a-i | 1.77 | a-e | 2.87 | c-l | 1.17 | ab | 1.72 | a-e | 1.22 | a-f |
| 17/03 | 3.03 | d-i | 1.68 | a-e | 3.18 | d-l | 1.83 | a-e | 3.00 | de | 3.38 | g |
| 18/03 | 1.80 | a-g | 1.63 | a-d | 1.97 | a-j | 1.83 | a-e | 0.98 | abc | 2.08 | a-g |
| 19/03 | 3.13 | e-i | 2.50 | b-f | 3.67 | jkl | 2.73 | a-f | 1.97 | a-e | 0.98 | a-e |
| 20/03 | 0.85 | a | 1.52 | a-d | 2.02 | a-j | 1.03 | a | 0.87 | ab | 0.70 | abc |
| 21/03 | 2.13 | a-h | 3.07 | def | 3.25 | e-l | 2.72 | a-f | 1.30 | a-d | 0.78 | a-d |
| 22/03 | 1.72 | a-g | 2.95 | c-f | 3.65 | i-l | 2.43 | a-f | 1.50 | a-e | 0.98 | a-e |
| 23/03 | 3.30 | ghi | 1.05 | ab | 3.87 | kl | 3.23 | b-f | 1.97 | a-e | 2.03 | a-g |
| 24/03 | 1.70 | a-g | 1.80 | a-e | 1.92 | a-i | 1.05 | a | 0.97 | abc | 0.38 | a |
| 25/03 | 2.65 | b-i | 2.97 | c-f | 3.70 | jkl | 2.30 | a-f | 2.05 | a-e | 0.97 | a-e |
| 26/03 | 3.08 | e-i | 3.03 | c-f | 3.23 | d-l | 2.03 | a-f | 1.93 | a-e | 1.12 | a-f |
| 1/04 | 2.22 | a-h | 2.25 | a-f | 3.07 | d-l | 1.77 | a-d | 1.20 | abc | 0.88 | a-e |
| 2/04 | 1.63 | a-g | 1.62 | a-d | 1.53 | a-e | 1.63 | a-d | 1.52 | a-e | 1.40 | a-f |
| 3/04 | 2.22 | a-h | 1.77 | a-e | 3.22 | d-l | 1.68 | a-d | 0.90 | abc | 0.90 | a-e |
| 4/04 | 4.00 | i | 4.00 | f | 4.00 | l | 4.00 | f | 2.60 | cde | 2.72 | efg |
| 5/04 | 3.20 | f-i | 3.45 | ef | 3.25 | e-l | 3.70 | def | 1.85 | a-e | 3.45 | g |
| 6/04 | 1.28 | abc | 1.60 | a-d | 1.63 | a-f | 1.72 | a-d | 0.53 | a | 0.42 | a |
| 7/04 | 1.05 | abc | 1.03 | ab | 0.88 | a | 1.03 | a | 0.75 | ab | 2.02 | a-g |
| 8/04 | 2.53 | a-i | 1.95 | a-e | 3.42 | g-l | 3.40 | c-f | 1.72 | a-e | 1.25 | a-f |
| 9/04 | 1.82 | a-g | 2.40 | a-f | 2.77 | b-l | 1.97 | a-f | 1.60 | a-e | 1.78 | a-g |
| 10/04 | 3.65 | hi | 3.47 | ef | 4.00 | l | 3.87 | ef | 3.02 | e | 2.60 | c-g |
| 11/04 | 1.47 | a-f | 2.32 | a-f | 1.82 | a-h | 2.17 | a-f | 0.73 | ab | 0.68 | ab |
| 12/04 | 2.78 | c-i | 2.10 | a-e | 3.28 | f-l | 1.82 | a-e | 1.67 | a-e | 2.95 | fg |
| 13/04 | 1.62 | a-g | 1.82 | a-e | 2.38 | a-l | 1.05 | a | 1.37 | a-e | 0.97 | a-e |
| 14/04 | 2.03 | a-h | 2.48 | b-f | 3.28 | f-l | 1.43 | abc | 1.67 | a-e | 1.17 | a-f |
| 15/04 | 3.17 | f-i | 2.28 | a-f | 3.85 | kl | 2.67 | a-f | 1.45 | a-e | 1.42 | a-f |

Note: Means of the same column, followed by the same letter, do not significantly differ following Tukey's test ($P = 0.05$).

Wilt symptoms started to be visible at 7 – 10 days after artificial inoculation, and the percentage of dead plants reached maximum 4 – 6 weeks after the inoculation. In the case of highly susceptible varieties, wilt symptom developed very quickly, particularly in summer when the maximum temperature reached 35 – 41℃ in the greenhouse.

It was found the correlation co-efficiency of dead plants percentage of all the varieties tested between two trials was much significant (Table 5). The similar results

occurred in the correlation co-efficiency of disease index (DI 0 – 4) of all the varieties tested between the two trials (Table 6). Significant correlation ($P < 0.01$) was also found between the percentage of dead plants and disease index (Table 7), which showed both of two methods used in the study were valid and feasible for the evaluation of rocket resistance to *Fusarium* wilt.

**Table 5 Correlation co-efficiency of the percentage of dead plants of all the varieties tested between two trials**

| Trial | Strains MIX | | Strain Fus. Ruc. 9A/02 | | Strain Fus. Ruc. 13/03 | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| MIX-1 | 1.00 | | | | | |
| MIX-2 | 0.70** | 1.00 | | | | |
| Fus. Ruc. 9A-1 | 0.80** | 0.61** | 1.00 | | | |
| Fus. Ruc. 9A-2 | 0.74** | 0.68** | 0.66** | 1.00 | | |
| Fus. Ruc. 13/03-1 | 0.77** | 0.61** | 0.77** | 0.62** | 1.00 | |
| Fus. Ruc. 13/03-2 | 0.49** | 0.36* | 0.33* | 0.45** | 0.55** | 1.00 |

Note: Pearson's correlation co-efficiency by the method of Bivariate correlations (2-tailed); ** Means correlation is significant at the 0.01 level ($P < 0.01$); * Means correlation is significant at the 0.05 level ($P < 0.05$). The same as follows.

**Table 6 Correlation co-efficiency of the disease index (DI 0 – 4) of all the varieties tested between two trials**

| Trial | Strains MIX | | Strain Fus. Ruc. 9A/02 | | Strain Fus. Ruc. 13/03 | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| MIX-1 | 1.00 | | | | | |
| MIX-2 | 0.59** | 1.00 | | | | |
| Fus. Ruc. 9A-1 | 0.81** | 0.58** | 1.00 | | | |
| Fus. Ruc. 9A-2 | 0.74** | 0.64** | 0.62** | 1.00 | | |
| Fus. Ruc. 13/03-1 | 0.78** | 0.49** | 0.81** | 0.53** | 1.00 | |
| Fus. Ruc. 13/03-2 | 0.48** | 0.27 | 0.30* | 0.45** | 0.49** | 1.00 |

**Table 7 Correlation co-efficiency between the disease index (DI 0 – 4) and the percentage of dead plants of all the varieties tested in the same trial**

| Item | Strains MIX | | Strain Fus. Ruc. 9A/02 | | Strain Fus. Ruc. 13/03 | |
|---|---|---|---|---|---|---|
| | Trial 1 | Trial 2 | Trial 1 | Trial 2 | Trial 1 | Trial 2 |
| R value | 0.99** | 0.98** | 0.99** | 0.99** | 0.96** | 0.99** |

The majority of rocket varieties, however, showed a resistance to strain Fus. Ruc. 13/03, while the majority of rocket varieties showed a susceptibility to mixture strains MIX and strain Fus. Ruc. 9A/02. Strains MIX and strain Fus. Ruc. 9A/02 behaved similarly on the tested varieties and was more virulent than strain Fus. Ruc. 13/03 (Table 8).

Particularly, strain Fus. Ruc. 9A/02, the inoculum of second trial carried out in the hot summer from July 29th to September 1st, indicated a high pathogenicity to nearly half of the total forty-four varieties. What's more, nearly all the forty-four varieties of rocket were infected by strain Fus. Ruc. 9A/02 in the trials and had a loss in different degrees, and no rocket variety, apart from 6/03 and 7/04, showed high resistance to strain Fus. Ruc. 9A/02 (Table 8).

In summary, varieties 12/03 and 20/03 showed a high resistance to strain MIX, varieties 6/03 and 7/04 showed a high resistance to strain Fus. Ruc. 9A/02, and varieties 9/02, 2/03, 5/03, 6/03, 7/03, 9/03, 11/03, 12/03, 20/03, 21/03, 24/03, 3/04, 6/04, 7/04 and 11/04 showed a high resistance to strain Fus. Ruc. 13/03 (Table 8).

Adversely, varieties 19/03, 21/03, 25/03, 26/03, 4/04, 5/04, 10/04, and 15/04 showed a high susceptibility to strain MIX, varieties 15/03, 17/03, 19/03, 21/03, 22/03, 23/03, 25/03, 26/03, 1/04, 3/04, 4/04, 5/04, 8/04, 10/04, 12/04, and 15/04

**Table 8 Resistance sequence by % of dead plants among different varieties of rocket tested**

| Sequence | Code of varieties | Strains MIX Trial 1 | Code of varieties | Strains MIX Trial 2 | Code of varieties | Fus. Ruc. 9A/02 Trial 1 | Code of varieties | Fus. Ruc. 9A/02 Trial 2 | Code of varieties | Fus. Ruc. 13/03 Trial 1 | Code of varieties | Fus. Ruc. 13/03 Trial 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12/03 | R | 12/03 | R | 7/04 | R | 6/03 | R | 6/04 | R | 6/03 | R |
| 2 | 20/03 | R | 23/03 | PR | 1/03 | PR | 13/03 | PR | 9/03 | R | 24/03 | R |
| 3 | 3/03 | R | 2/03 | PR | 2/03 | PR | 13/04 | PR | 11/03 | R | 12/03 | R |
| 4 | 7/02 | PR | 4/03 | PR | 5/03 | PR | 20/03 | PR | 11/04 | R | 6/04 | R |
| 5 | 7/04 | PR | 7/04 | PR | 12/03 | PR | 24/03 | PR | 12/03 | R | 9/03 | R |
| 6 | 1/03 | PR | 6/03 | PR | 24/03 | PR | 7/03 | PR | 13/03 | R | 10/03 | R |
| 7 | 10/02 | PR | 7/02 | PR | 7/02 | PR | 7/04 | PR | 2/03 | R | 11/04 | R |
| 8 | 6/04 | PR | 10/02 | PR | 9/03 | PR | 10/03 | PR | 3/03 | R | 20/03 | R |
| 9 | 11/03 | PR | 20/03 | PR | 10/02 | PR | 14/03 | PR | 20/03 | R | 21/03 | R |
| 10 | 2/03 | PR | 7/03 | PR | 2/04 | PR | 16/03 | PR | 24/03 | R | 7/03 | R |
| 11 | 6/03 | PR | 9/02 | PR | 3/03 | PR | 5/03 | PR | 3/04 | R | 9/02 | R |
| 12 | 11/04 | PR | 13/03 | PR | 6/04 | PR | 1/03 | PR | 5/03 | R | 1/04 | PR |
| 13 | 2/04 | PR | 2/04 | PR | 7/03 | PR | 11/03 | PR | 7/04 | R | 13/04 | PR |
| 14 | 5/03 | PR | 10/03 | MS | 13/03 | PR | 9/02 | PR | 1/03 | PR | 2/03 | PR |
| 15 | 13/04 | PR | 13/04 | MS | 4/03 | PR | 14/04 | PR | 10/02 | PR | 22/03 | PR |
| 16 | 22/03 | MS | 16/03 | MS | 6/03 | PR | 7/02 | PR | 18/03 | PR | 25/03 | PR |
| 17 | 24/03 | MS | 17/03 | MS | 11/03 | MS | 9/03 | PR | 4/03 | PR | 3/04 | PR |
| 18 | 4/03 | MS | 18/03 | MS | 11/04 | MS | 2/04 | PR | 6/03 | PR | 11/03 | PR |
| 19 | 7/03 | MS | 24/03 | MS | 20/03 | MS | 10/02 | PR | 7/03 | PR | 19/03 | PR |
| 20 | 10/03 | MS | 6/04 | MS | 9/02 | MS | 2/03 | PR | 1/04 | PR | 5/03 | PR |
| 21 | 13/03 | MS | 1/03 | MS | 18/03 | MS | 8/02 | PR | 13/04 | PR | 10/02 | PR |
| 22 | 14/04 | MS | 3/04 | MS | 13/04 | MS | 12/04 | MS | 7/02 | PR | 14/04 | PR |
| 23 | 18/03 | MS | 12/04 | MS | 8/02 | MS | 17/03 | MS | 21/03 | PR | 16/03 | PR |
| 24 | 9/02 | MS | 14/03 | MS | 9/04 | MS | 3/04 | MS | 8/02 | PR | 26/03 | PR |
| 25 | 9/04 | MS | 15/03 | MS | 16/03 | S | 6/04 | MS | 15/04 | PR | 8/02 | PR |
| 26 | 8/02 | MS | 8/04 | MS | 26/03 | S | 1/04 | MS | 16/03 | PR | 2/04 | PR |
| 27 | 1/04 | MS | 11/04 | MS | 12/04 | S | 12/03 | MS | 2/04 | PR | 8/04 | PR |
| 28 | 14/03 | MS | 5/03 | MS | 14/03 | S | 18/03 | MS | 9/02 | PR | 15/04 | PR |
| 29 | 21/03 | MS | 11/03 | MS | 17/03 | S | 9/04 | MS | 14/03 | PR | 7/02 | PR |
| 30 | 3/04 | MS | 3/03 | MS | 1/04 | S | 4/03 | MS | 22/03 | PR | 3/03 | MS |
| 31 | 15/03 | MS | 8/02 | MS | 14/04 | S | 11/04 | MS | 9/04 | PR | 4/03 | MS |
| 32 | 9/03 | MS | 9/03 | MS | 21/03 | S | 15/03 | MS | 12/04 | MS | 7/04 | MS |
| 33 | 16/03 | MS | 1/04 | MS | 3/04 | S | 26/03 | MS | 14/04 | MS | 9/04 | MS |
| 34 | 12/04 | MS | 14/04 | MS | 5/04 | S | 3/03 | MS | 5/04 | MS | 1/03 | MS |
| 35 | 17/03 | MS | 15/04 | MS | 15/03 | S | 25/03 | MS | 8/04 | MS | 23/03 | MS |
| 36 | 8/04 | MS | 9/04 | MS | 8/04 | S | 22/03 | MS | 26/03 | MS | 14/03 | MS |
| 37 | 25/03 | MS | 22/03 | MS | 19/03 | S | 15/04 | MS | 23/03 | MS | 13/03 | MS |
| 38 | 15/04 | S | 19/03 | MS | 22/03 | S | 19/03 | S | 15/03 | MS | 18/03 | MS |
| 39 | 19/03 | S | 21/03 | S | 25/03 | S | 21/03 | S | 19/03 | MS | 15/03 | MS |
| 40 | 26/03 | S | 26/03 | S | 15/04 | S | 23/03 | S | 25/03 | MS | 10/04 | MS |
| 41 | 23/03 | S | 25/03 | S | 23/03 | S | 8/04 | S | 10/03 | MS | 12/04 | S |
| 42 | 5/04 | S | 10/04 | S | 10/03 | S | 5/04 | S | 17/03 | S | 4/04 | S |
| 43 | 10/04 | S | 5/04 | S | 10/04 | S | 10/04 | S | 10/04 | S | 17/03 | S |
| 44 | 4/04 | S | 4/04 | S | 4/04 | S | 4/04 | S | 4/04 | S | 5/04 | S |

Note: R means resistance with range of 0 – 10% of dead plants; PR means partial resistance with range of 11% – 30% of dead plants; MS means moderate susceptibility with range of 31% – 60% of dead plants; S means susceptibility with range of 61% – 100% of dead plants.

showed a high susceptibility to strain Fus. Ruc. 9A/02, and varieties 17/03, 4/04, 5/04, 10/04, and 12/04 showed a high susceptibility to strain Fus. Ruc. 13/03 (Table 8).

## 3 Discussion

The resistance inconsistency of some rocket varieties observed in different trials was principally caused

by the infectious difference of the pathogen in the three inoculum trials. Based on the investigation data in the study, compared to strain Fus. Ruc. 13/03, strain Fus. Ruc. 9A/02 and the mixed strain MIX were observed to have a higher pathogenicity to cultivated and wild rockets tested in the trials, although both strains Fus. Ruc. 13/03 and Fus. Ruc. 9A/02 were obtained from infected plants of wild rocket. It was probably caused just by the higher pathogenicity of strain Fus. Ruc. 9A/02, or other strain(s) with higher virulence. Further research, hence, is necessary to understand the reason behind the pathogenic characteristics.

The three trials were repeated twice. Significant correlation was found between these two trials both in dead plants percentage and disease index of all the varieties tested. It indicated that the data of the two trials was completely believed without environmental disturbance. Moreover, significant correlation was also found between the percentage of dead plants and disease index, which suggested both of these two methods used in the study were feasible for the evaluation of rocket's resistance to *Fusarium* wilt disease.

Understanding of the varieties' resistance in the study will contribute to guide the horticultural production of rocket in a correct way. Besides, *Fusarium* wilt caused other ornament crops, such as carnation[5], to be diseased in horticultural production. It also infected many kinds of vegetables, for instance melon[6]. So the resistance evaluation work showed its importance in varieties identificaion and breeding.

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