Resistance Responses of 35 Watermelon Genotypes to Three Isolates of *Fusarium oxysporum* f. sp. *niveum*  
(Respons Ketahanan 35 Genotipe Semangka terhadap Tiga Isolat *Fusarium oxysporum* f. sp. *niveum*)

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**ABSTRAK**

Layu Fusarium yang disebabkan oleh cendawan *Fusarium oxysporum* f. sp. *niveum* (For) merupakan salah satu penyakit penting tanaman semangka. Studi yang mengevaluasi ketahanan genotipe semangka terhadap lebih dari satu isolat *Fon* masih sangat terbatas di Indonesia. Penelitian ini bertujuan menguji ketahanan genotipe semangka terhadap tiga isolat *Fon* dari tiga lokasi berbeda di Indonesia. Penelitian menggunakan 35 genotipe semangka dan tiga isolat *Fon* asal Karawang (FK), Lampung (FL), dan Purwakarta (FP). Penelitian menggunakan Rancangan Acak Lengkap dengan dua ulangan. Data indeks penyakit memperlihatkan sebanyak enam genotipe, yaitu New Hope, Sky Mountain, Southern Light, Super Sweet 66, Uranus, dan Yellow Baby, memiliki fenotipe ketahanan moderat sampai dengan tahan terhadap keliga isolat *Fon* yang diuji. Data masa inkubasi dan persentase tanaman bergejala juga menunjukkan respons yang berbeda antargenotipe, baik terhadap isolat yang sama maupun isolat yang berbeda. Genotipe New Orchid, sebagai contoh, menunjukkan sebanyak 57,14% tanaman uji bergejala dalam waktu kurang dari 10 hari setelah inokulasi (HIS) ketika diuji dengan isolat FL. Di pihak lain, genotipe New Dragon yang diinokulasi dengan isolat yang sama menunjukkan hanya 6,67% tanaman uji yang bergejala pada masa inkubasi lebih dari 23 HIS. Hasil ini mengindikasikan bahwa genotipe semangka yang tahan terhadap semua isolat dapat digunakan pada program pemuliaan untuk merakit galur semangka dengan spektrum ketahanan yang lebih luas terhadap berbagai isolat *Fon*. Genotipe tahan terpilih harus juga memiliki keragaan agronomi yang bagus dan produktivitas tinggi untuk dipertimbangkan sebagai varietas baru semangka.

**Kata kunci:** Semangka, layu Fusarium, genotipe, ketahanan, gejala penyakit.

**ABSTRACT**

Fusarium wilt caused by *Fusarium oxysporum* f. sp. *niveum* (*Fon*) is one of main diseases of watermelon. There have been very limited studies that tested watermelon genotypes to more than one isolates of *Fon* in Indonesia. This research aimed to determine the resistance of 35 watermelon genotypes to three *Fon* isolates taken from three different areas in Indonesia. Incubation period (IP) and disease index (DI) of the 35 watermelon genotypes were determined against three *Fon* isolates collected from Karawang (FK), Lampung (FL), and Purwakarta (FP). The experiment was arranged using a Completely Randomized Design with two replications. DI showed that six watermelon genotypes, i.e. New Hope, Sky Mountain, Southern Light, Super Sweet 66, Uranus, and Yellow Baby demonstrated moderate resistance to resistance phenotypes to all tested *Fon* isolates. IP and percentage of symptomatic plants (PSP) showed different responses among genotypes either to the same or to different isolates. Genotype New Orchid, for example, showed 57.14% symptomatic plants in less than 10 days after inoculation (DAI) when tested with FL isolate. Meanwhile, when tested with the same isolate, genotype New Dragon showed only 6.67% symptomatic plants in more than 23 DAI. The result of this study indicated that watermelon genotypes showing resistant to all tested isolates should be useful for breeding program to develop watermelon lines with broader resistance spectrum against *Fon* pathogen. The resistance genotypes selected should also demonstrate good agronomic performances and high yield to be considered as a new watermelon variety.

**Keywords:** Watermelon, Fusarium wilt, genotype, resistance, disease symptom.
INTRODUCTION

Watermelon (Citrullus lanatus var. lanatus [Thunb.] Matsum & Nakai) is one of highly consumed fresh fruit with cultivation area as much 6.8% of worldwide cultivation area (Gusmini and Wehner 2005). Watermelon is also among most annual fruit crops cultivated in Indonesia reaching an export value up to 111,275 USD in 2018. However, watermelon production in 2018 decreased by as much as 3.54% compared to that of 2017 (Statistics Indonesia 2018).

One problem of watermelon production worldwide is insect and disease attacks. Fusarium wilt caused by Fusarium oxysporum f. sp. niveum (Fon) is one of the most destructive diseases which lead to great loss in watermelon production around the world including Indonesia (Egel and Hoke 2007; Dau et al. 2009; Zhou et al. 2010; Budiastuti et al. 2012; Tran-Nguyen et al. 2013; Martyn 2014). This pathogen infects all stages of plants causing damping-off in seedlings or wilt and smaller fruit size in mature plants which eventually causing the plant collapse and die. Fusarium wilt disease is characterized by the brown to reddish discoloration in dissected root crown of the attacked plants (Egel and Martyn 2007; Roberts et al. 2019).

Fon is categorized as a soil-borne disease that is not easily managed (Lü et al. 2014) since it forms infectious chlamydospore to survive for a very long period in the soil (Wechter et al. 2012). Hazardous methyl bromide is often used for watermelon land preparation to anticipate this problem (Everts and Himmelstein 2015). Considering the facts, the best management practice to control this disease is by utilizing resistant cultivars for planting materials (Meru and McGregor 2016).

Fusarium wilt disease development of watermelon has not much been reported in Indonesia. Only few studies have been done related to Fon disease development such as that reported by Budiastuti et al. (2012). Identification of Fon race has not been reported and there is no study has yet been reported using differential varieties to test watermelon genotypes against Fusarium wilt pathogen in Indonesia. There have been only limited studies related to watermelon breeding that have been reported in Indonesia. These included study on watermelon agronomic characterization (Yasinda et al. 2015; Makful et al. 2019), character heritability prediction (Abdurrahman et al. 2018), and yield potential analysis (Pamuji et al. 2017).

On the other hand, there are various introduced and local watermelon varieties that have been cultivated by Indonesian farmers. Each of the genotypes has different superior characters which make the genotypes are potentially used as parents in watermelon breeding programs. Breeding toward developing watermelon varieties resistance to Fusarium wilt is of great interest to control the disease in cheap and environmentally friendly manners. The objectives of this study were to determine the resistance of 35 watermelon genotypes against three Fon isolates taken from three different areas in Indonesia.

MATERIALS AND METHODS

This study was done in Faculty of Agriculture, IPB University, Dramaga District, Bogor, West Java from December 2008 to September 2009. Isolation, purification, identification, and preparation of inoculum substrates for Fon isolates were carried out at the Mycology Laboratory of the Department of Plant Protection. The sterilization of the growing media was carried out at the Soil Biology Laboratory of the Department of Soil Science. Evaluation of resistance to the three Fon isolates was carried out in the Leuwikopo Greenhouse of the Department of Agronomy and Horticulture.

Plant Materials

Genetic materials used were 35 watermelon genotypes consisted of 31 genotypes that were introduced plants originated from abroad and 4 genotypes were local varieties (Table 1).

Fon Isolation

Plant materials having true Fusarium wilt disease symptoms were sampled from watermelon cultivation fields (Figure 1) in three watermelon production areas, i.e. Central Lampung Regency, Lampung Province (FL isolate), Karawang Regency, West Java Province (FK isolate), and Purwakarta Regency, West Java Province (FP isolate). The symptomatic crowns (lowest part of main stem nearest to the root) having brown circle on its xylem were dissected into tiny cuts (approx. 5 mm × 5 mm). The explants were then rewarshed with sterilized water, dried with tissue paper, and subsequently plated onto potato dextrose agar (PDA) media. The isolate cultures were then purified and maintained on PDA until the cultures in Petri dishes demonstrated homogeneity in physical appearance, i.e. colony color, colony form, etc., to obtain pure...
cultures in the sense that such fungal pathogen cultures do not have any bacterial and other fungi contaminations. The pure cultures were then used for \textit{Fon} identification and inoculation studies.

\textbf{Fon Identification}

Fusarium wilt cultures were transferred into carnation leaf agar (CLA) for 3 weeks. Olympus Binocular™ Microscope was used to identify each of the isolated cultures. The identification of macroconidia and microconidia was done by referring to that of the \textit{The Fusarium Laboratory Manual} (Leslie and Summerell 2006). The identified cultures were then isolated and transferred into slanted media for extended use and time.

\textbf{Fon Inoculation}

\textbf{Plant preparation for Fon inoculation}

Seeds of each watermelon genotypes were planted in seedlings in trays containing sterilized media consisted of soil and dung manure (1:1). The young seedlings were carefully uprooted and transplanted to pots containing sterilized growth media to obtain a 14-day-old healthy watermelon seedling. Polybags of 15 cm \times 15 cm were filled with sterilized media with the same composition one day before transplantation and \textit{Fon} inoculation. The plant preparations were done in the Leuwikopo Greenhouse. Soil sterilization was carried out by autoclaving the soil media at 121°C for 30 min.

\textbf{Fon isolate preparation for inoculation}

Rice grains were rinsed with running tap water, air-dried, then sterilized at 121°C. Cultivation of \textit{Fon} isolates was initially run inside the laminar air flow cabinet by transferring the \textit{Fon} isolate culture into each of sterilized rice grain substrate and the rice grains containing the \textit{Fon} isolates were then maintained at room temperature until used for inoculation.

### Table 1. Watermelon genotypes used in this study.

| No. | Genotype               | Genetic background*               |
|-----|------------------------|-----------------------------------|
| 1   | 6372                   | Local variety (IPB University collection) |
| 2   | Amor                   | \(F_1\) hybrid (PT East West Indonesia) |
| 3   | Bangkok Flower         | \(F_1\) hybrid (Chia Thai, Thailand) |
| 4   | Black Jumbo            | Introduction line (Syngenta Seeds, USA) |
| 5   | Charleston Gray        | Introduction line (USDA, USA) |
| 6   | Diana Bangkok Dragon   | \(F_1\) hybrid (Chia Thai, Thailand) |
| 7   | Dragon Giant 145       | Introduction line |
| 8   | Falcon                 | \(F_1\) hybrid (Chia Thai, Thailand) |
| 9   | Full Orchid            | Introduction line (Chung Shin Seed, Taiwan) |
| 10  | Golden Bright          | Introduction line (Chung Shin Seed, Taiwan) |
| 11  | Grace                  | Introduction line (Widegrow, Taiwan) |
| 12  | Hitam Manis            | \(F_1\) hybrid 134-6 (F) \times 386-2 (M) (Known You Seed, Taiwan) |
| 13  | Jalur Madu             | \(F_1\) hybrid (Known You Seed, Taiwan) |
| 14  | King Dragon            | Introduction line (Takii Seed, Japan) |
| 15  | Little Boy             | Introduction line (Known You Seed, Taiwan) |
| 16  | Mas Kuning             | Introduction line (Known You Seed, Taiwan) |
| 17  | Milano                 | \(F_1\) hybrid WM 2015 \times WM 2012 (PT Benih Citra Asia) |
| 18  | New Dragon             | \(F_1\) hybrid F28-1-2 (F) \times F613 (M) (Known You Seed, Taiwan) |
| 19  | New Hope               | \(F_2\) hybrid yellow diploid INR045 (F) from INRA, France \times diploid YX0789 (M) from Green Seeds Co. Ltd. (Technisem Asia Co. Ltd., Vietnam) |
| 20  | New Orchid             | Introduction line (Known You Seed, Taiwan) |
| 21  | Nina                   | \(F_1\) hybrid WH 92-357-65 (F) \times WH 92-1468-81 (M) (Nunhems Zaden BV, Netherlands) |
| 22  | Sky Mountain           | Introduction line (Known You Seed, Taiwan) |
| 23  | Southern Light         | Introduction line (Known You Seed, Taiwan) |
| 24  | Sugar Baby-Chunshin    | Introduction line (Chung Shin Seed, Taiwan) |
| 25  | Sugar Baby-Yates       | Introduction line (Yates Seed Co., USA) |
| 26  | Sunflower              | Introduction line (Chung Shin Seed, Taiwan) |
| 27  | Super Sweet 66         | Introduction line (Spring Plough Agriculture, Hong Kong) |
| 28  | SW 144                 | Introduction line (Chung Shin Seed, Taiwan) |
| 29  | Ten-Bow                | Introduction line (Chung Shin Seed, Taiwan) |
| 30  | TM Dragon              | Introduction line (Takii Seed, Japan) |
| 31  | TM Lion                | Introduction line (Takii Seed, Japan) |
| 32  | Torino                 | \(F_1\) hybrid WM 1800 \times WM 1531 (PT Benih Citra Asia) |
| 33  | Uranus                 | \(F_1\) hybrid yellow diploid INR045 (F) from INRA, France \times yellow diploid VB947 (M) from Technisem France (Technisem Asia Co. Ltd., Vietnam) |
| 34  | Yellow Baby            | Introduction line (Chung Shin Seed, Taiwan) |
| 35  | Yun An Flower          | \(F_1\) hybrid WM 25.7.10.4.11.21.8 (F) \times WM 7.6.12.23.5.9.20 (M) (Acegreen Seed Co. Ltd., Taiwan) |
Inoculation of watermelon seedlings with Fon isolates

Fon inoculation was carried out at the Leuwikopo Greenhouse. Inoculum density of each Fon isolate was calculated weekly using a haemocytometer until cultures reached the targeted density of 10^5 cfu/g. Inoculation was applied by mixing inoculated substrate with sterile growing media (1:10) into 15 cm x 15 cm polybags containing sterilized growth media. The 14-day-old plant seedlings were then transferred from sterile seedling media into Fon infested growing media in polybags. A Completely Randomized Design was applied for each Fon isolate. The experiment was repeated twice with 15 plants from each combination. Plants were maintained in the greenhouse for incubation period (IP) and disease index (DI) observations.

IP and DI Observations

IP and DI were observed by using modified score from Chikh-Rouh et al. (2008) with criteria: 0 = no symptom; 1 = beginning of wilting yet leaves were still green; 2 = almost total of leaves wilted; 3 = all leaves wilted with the green stem; 4 = plant died with necrosis on main stem and crown. IP was observed once in 2 days for 4 weeks to determine the number of days an isolate needs to cause symptomatic plants. DI was observed once a week for 1 month. DI was calculated by referring to Golenia in Swiad et al. (2002) formula as shown below:

$$ DI = \frac{\sum (n \times v)}{N \times V} \times 100 $$

with n = disease score (0–4), v = number of plants from nth score, N = total observation per replication, and V = highest score (4).

DI was then used to define resistance category by following Martyn and McLaughlin (1983) method: 0–20% = strongly resistant; 21–50% = moderate resistant; 51–80% = slightly resistant; 81–100% = susceptible. Re-isolation of Fon was carried out to verify Fon infection by culturing the crown of scored symptomatic plants resulted from inoculation results of each Fon isolate tested in this study.

Data Analysis

IP data were recapitulated and averaged using Microsoft Office Excel 2003 for Windows. Meanwhile, DI data on the 4th week after inoculation was computed separately for each isolate using SAS software to generate analysis of variance (ANOVA) and continued with Duncan’s Multiple Range Test (DMRT) using SAS ver. 9.1.

RESULTS AND DISCUSSION

Characteristics of Fon Isolates

Cultures of three Fon isolates from symptomatic plant samples demonstrated different colony colors of FL and FP isolates compared to that of the previous isolated FK isolate. FK isolate formed a dark
purple colony, slightly differed from that of FP isolate that formed reddish dark purple colony, and FL isolate which showed dark, cream colony (Figure 2).

Species of the genus *Fusarium* were highly diverse since the genetic make-up and environmental variations created their morphological variations (Seo and Kim 2017). Microscopic identification based on *The Fusarium Laboratory Manual* (Leslie and Summerell 2006) and CLA media (Summerell et al. 2003) showed that FL isolate (Figure 3) and FP isolate (Figure 4) were different.

**Figure 2.** Growth characteristics of *Fusarium oxysporum* f. sp. *niveum* isolates derived from symptomatic watermelon plants collected from Karawang (FK), Lampung (FL), and Purwakarta (FP) on PDA media. (A) Underside part of the plated cultures. (B) Upper side parts of the plated cultures.

**Figure 3.** Identification of *Fusarium oxysporum* f. sp. *niveum* isolate FL derived from symptomatic watermelon plants collected from Lampung. (A) Chlamydospore and microconidia. (B, C) False head on microconidia. (D) Macroconidia with hooked apical cell on PDA media. (E) Macroconidia with monophialide on CLA media.
from *F. oxysporum*, based on observations of the structure of microconidia, false head on short monophialide, as well as chlamydospores.

Responses of Watermelon Genotypes to Three *Fon* Isolates

The *Fon* inoculation was carried out on 14-day-old plants (when the first leaves perfectly opened). Symptomatic plants as shown in Figure 5 had slightly wilted green leaves which turned to yellowish color followed by the weakened stem, stem (crown) necrosis, and finally collapsed. This phase of Fusarium wilt symptom was similar to the previous studies reported by Kurt et al. (2008) and Wechter et al. (2012). *Fon* can affect every stage of plant growth either in the seedling phase in the greenhouse or in older plants in the field. The infected seedlings showed stunted growth and wilted appearance followed by damping-off (Kleczewski and Egel 2011). *Fon* infection was initiated by the colonization of the root cortex to the xylem which blocks nutrition and water uptakes. At the end of the infection stages, *Fon* released lytic enzymes and toxin causing disease symptoms, such as necrotic, chlorosis, wilt, and plant
The scoring system, which was adapted from *Fusarium oxysporum* f. sp. *melonis* (Chikh-Rouhou et al. 2008) based on leaves and stem appearances, proved the ability to distinguish the changes of *Fon* infection symptoms of watermelon plants. Almost all of the observed plants expressed the changing stages of symptoms following the respective scores of 0, 1, 2, 3, and 4.

**Incubation Period (IP)**

IP data (Table 2) showed that no genotype seemed to escape the infection of any given *Fon* isolate despite of its resistance category. *Fon* is highly effective in colonizing and penetrating the crown of both resistant and susceptible watermelon plants (Zhou and Everts 2004). The IP also reflected the different reactions among genotypes against *Fon* isolates. Most of tested genotypes showed the longest IP of more than 3 weeks or 23 days after inoculation (DAI) when the genotypes were inoculated with FL isolate. This means that FL isolate required a longer period for causing symptoms on given tested watermelon genotypes. Meanwhile, FP isolate recorded the shortest IP (mostly 11–16 DAI) which indicated that this isolate elicited symptoms on plants faster than other tested isolates, FL and FK. This result also suggested different virulence ability among the three isolates to infect one genotype and vice versa. They differed in the genotypic reaction against one isolate, in terms of how long one genotype can endure for encountering the infection before expressing disease symptom.

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Figure 5. Inoculated watermelon plants showing *Fusarium oxysporum* f. sp. *niveum* infections. (A) No symptom appeared (score 0). (B) Plant was still vigorous with green and slightly wilted leaf (score 1). (C) The leaf wilted (score 2). (D) Plant started to collapse (score 3). (E) Plant collapsed with necrosis in stem (score 4).
Table 2. Average IP and PSP of watermelon genotypes infected with three *Fusarium oxysporum* f. sp. *niveum* isolates collected from Karawang (FK), Lampung (FL), and Purwakarta (FP).

| No. | Genotype          | FK IP (DAI) | FP IP (DAI) | FL IP (DAI) | FK PSP (%) | FL PSP (%) | FP PSP (%) |
|-----|------------------|-------------|-------------|-------------|------------|------------|------------|
| 1.  | 6372             | >23         | >23         | >23         | 60.00      | 26.67      | 11–16      | 35.00      |
| 2.  | Amor             | 17–22       | 17–22       | 23          | 60.00      | 6.67       | 11–16      | 53.34      |
| 3.  | Bangkok Flower   | 17–22       | 17–22       | 23          | 86.67      | 73.33      | 11–16      | 63.33      |
| 4.  | Black Jumbo      | >23         | >23         | >23         | 56.67      | 63.33      | 11–16      | 55.00      |
| 5.  | Charleston Gray  | >23         | >23         | >23         | 50.00      | 40.00      | 11–16      | 70.00      |
| 6.  | Diana Bangkok    | >23         | 11–16       | 11–16       | 73.33      | 10.00      | 11–16      | 56.66      |
| 7.  | Dragon Giant 145 | 17–22       | >23         | >23         | 63.33      | 70.00      | 11–16      | 80.00      |
| 8.  | Falcon           | 17–22       | 11–16       | 11–16       | 66.66      | 35.00      | 11–16      | 60.00      |
| 9.  | Full Orchid      | 17–22       | 11–16       | 11–16       | 45.44      | 10.00      | 17–22      | 50.00      |
| 10. | Golden Bright    | 17–22       | 17–22       | 17–22       | 73.33      | 76.67      | 17–22      | 43.33      |
| 11. | Grace            | >23         | >23         | >23         | 43.33      | 43.33      | 11–16      | 90.00      |
| 12. | Hitam Manis      | 11–16       | >23         | >23         | 49.99      | 45.83      | <10        | 50.00      |
| 13. | Jalur Madu       | 17–22       | 17–22       | 17–22       | 66.67      | 61.53      | 11–16      | 66.67      |
| 14. | King Dragon      | 17–22       | >23         | >23         | 66.67      | 63.33      | 11–16      | 80.00      |
| 15. | Little Boy       | 11–16       | 17–22       | 17–22       | 80.00      | 33.33      | 11–16      | 66.67      |
| 16. | Mas Kuning       | 17–22       | >23         | >23         | 86.67      | 83.33      | 11–16      | 13.33      |
| 17. | Milano           | >23         | >23         | >23         | 40.00      | 10.00      | 17–22      | 56.67      |
| 18. | New Dragon       | >23         | >23         | >23         | 46.67      | 6.67       | 11–16      | 50.00      |
| 19. | New Hope         | >23         | >23         | >23         | 63.33      | 36.67      | 11–16      | 80.00      |
| 20. | New Orchid       | 11–16       | <10         | >23         | 50.00      | 57.14      | 11–16      | 60.00      |
| 21. | Nina             | 11–16       | 11–16       | 11–16       | 46.66      | 30.00      | 11–16      | 53.33      |
| 22. | Sky Mountain     | 17–22       | 17–22       | 17–22       | 76.66      | 100.00     | 17–22      | 93.34      |
| 23. | Southern Light   | 11–16       | >23         | >23         | 31.25      | 46.67      | >23        | 43.33      |
| 24. | Sugar Baby-Chunshin | 11–16     | >23         | >23         | 73.34      | 63.33      | >23        | 86.36      |
| 25. | Sugar Baby-Yates | >23         | >23         | >23         | 100.00     | 93.00      | 11–16      | 43.33      |
| 26. | Sunflower        | 11–16       | 11–16       | 11–16       | 53.33      | 30.00      | 11–16      | 66.67      |
| 27. | Super Sweet 66   | 17–22       | >23         | >23         | 60.00      | 50.00      | 17–22      | 36.67      |
| 28. | SW 144           | 17–22       | 17–22       | 17–22       | 83.33      | 20.00      | 11–16      | 80.00      |
| 29. | Ten Bow          | 11–16       | >23         | >23         | 50.00      | 13.33      | 17–22      | 63.34      |
| 30. | TM Dragon        | 11–16       | >23         | >23         | 56.67      | 39.28      | 11–16      | 63.33      |
| 31. | TM Lion          | >23         | >23         | >23         | 38.46      | 16.67      | 11–16      | 53.33      |
| 32. | Torino           | 17–22       | >23         | >23         | 60.00      | 33.33      | 17–22      | 100.00     |
| 33. | Uranus           | >23         | 17–22       | 17–22       | 36.67      | 6.67       | 11–16      | 40.00      |
| 34. | Yellow Baby      | 11–16       | >23         | >23         | 46.67      | 18.18      | 11–16      | 53.33      |
| 35. | Yunan Flower     | 17–22       | >23         | >23         | 45.44      | 16.67      | 17–22      | 50.00      |

IP = incubation period, PSP = percentage of symptomatic plants, DAI = days after inoculation.

When tested with FL isolate, of all 35 genotypes, New Dragon variety showed the longest IP (>23 DAI) with the least number of infected plants (6.67%), whereas New Orchid recorded the shortest IP with 57.14% of its population showing disease symptoms in less than 10 DAI. On the other hand, when tested against FP isolate, Southern Light recorded the longest IP (>23 DAI) with 43.33% of its population were infected, whereas Hitam Manis showed the shortest IP (<10 DAI) with 50% plants of this genotype were infected and showing disease symptoms. This different reaction was possibly caused by the genetic potential of each genotype to inhibit the pathogen colonization rates. Hudec and Muchová (2010) reported that there were different levels of pathogen aggressiveness among *F. oxysporum* isolates that were collected from different locations.

**Disease Index (DI)**

The calculation of DI showed variation of genotypic resistance responses against *Fon* isolates. The data was divided into four groups (Table 3) for easier interpretation. The first group (Group I) consisted of six genotypes that showed fairly good resistance against all tested *Fon* isolates, i.e. New Hope, Southern Light, Sky Mountain, Super Sweet 66, Uranus, and Yellow Baby. Group II consisted of seven genotypes that showed resistance only to both FK and FL isolates, i.e. Bangkok Flower, Charleston Gray, Full Orchid, Grace, Mas Kuning, New Dragon, and TM Lion. Group III consisted of 19 genotypes that showed resistance against only one of the *Fon* isolates. The last group (Group IV) consisted of three genotypes which appeared to be susceptible to all tested *Fon* isolates, i.e. New Orchid, Hitam Manis, and TM Dragon.
Table 3. Fusarium wilt DI (%) and resistance categories of 35 watermelon genotypes infested with three *Fusarium oxysporum* f. sp. *niveum* isolates collected from Karawang (FK), Lampung (FL), and Purwakarta (FP).

| No. | Genotype          | FK          | FL          | FP          |
|-----|-------------------|-------------|-------------|-------------|
|     |                   | 75.84<sup>b</sup> | 40.84<sup>b</sup> | 75.84<sup>b</sup> | SR          |
| 1.  | New Hope          | 66.67<sup>a</sup> | 25.84<sup>b</sup> | 75.83<sup>a</sup> | SR          |
| 2.  | Sky Mountain      | 50.28<sup>a</sup> | 31.67<sup>b</sup> | 73.30<sup>a</sup> | SR          |
| 3.  | Southern Light    | 72.50<sup>a</sup> | 43.33<sup>a</sup> | 67.50<sup>a</sup> | SR          |
| 4.  | Super Sweet 66    | 78.34<sup>a</sup> | 10.00<sup>a</sup> | 75.67<sup>a</sup> | SR          |
| 5.  | Uranus            | 78.33<sup>a</sup> | 18.18<sup>a</sup> | 74.15<sup>a</sup> | SR          |
| 6.  | Yellow Baby       | 79.17<sup>a</sup> | 73.34<sup>a</sup> | 81.26<sup>a</sup> | S           |
| 7.  | Bangkok Flower    | 67.38<sup>a</sup> | 30.00<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 8.  | Full Orchid       | 73.86<sup>a</sup> | 23.34<sup>a</sup> | 95.85<sup>a</sup> | S           |
| 9.  | Grace             | 73.34<sup>a</sup> | 34.17<sup>a</sup> | 93.30<sup>a</sup> | S           |
| 10. | Mas Kuning        | 69.17<sup>a</sup> | 10.00<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 11. | New Dragon        | 80.84<sup>a</sup> | 16.67<sup>a</sup> | 96.65<sup>a</sup> | S           |
| 12. | TM Lion           | 60.58<sup>a</sup> | 16.65<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 13. |                   | 83.33<sup>a</sup> | 31.67<sup>a</sup> | 96.65<sup>a</sup> | S           |
| 14. | Amor              | 94.17<sup>a</sup> | 20.00<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 15. | Black Jumbo       | 100.00<sup>a</sup> | 22.50<sup>a</sup> | 93.30<sup>a</sup> | S           |
| 16. | Diana Bangkok     | 100.00<sup>a</sup> | 13.32<sup>a</sup> | 93.30<sup>a</sup> | S           |
| 17. | Dragon Giant 145  | 93.33<sup>a</sup> | 42.50<sup>a</sup> | 85.85<sup>a</sup> | S           |
| 18. | Falcon            | 84.15<sup>a</sup> | 12.50<sup>a</sup> | 96.65<sup>a</sup> | S           |
| 19. | Golden Bright     | 81.67<sup>a</sup> | 37.50<sup>a</sup> | 93.30<sup>a</sup> | S           |
| 20. | Jalur Madu        | 100.00<sup>a</sup> | 27.08<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 21. | King Dragon       | 95.00<sup>a</sup> | 40.38<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 22. | Little Boy        | 94.64<sup>a</sup> | 24.17<sup>a</sup> | 95.00<sup>a</sup> | S           |
| 23. | Milano            | 93.34<sup>a</sup> | 13.32<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 24. | Nina              | 100.00<sup>a</sup> | 56.67<sup>a</sup> | 92.50<sup>a</sup> | S           |
| 25. | Sugar Baby Chunshin| 90.00<sup>a</sup> | 30.00<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 26. | Sugar Baby-Yates  | 85.42<sup>a</sup> | 65.00<sup>a</sup> | 93.35<sup>a</sup> | S           |
| 27. | Sunflower         | 90.84<sup>a</sup> | 53.34<sup>a</sup> | 96.65<sup>a</sup> | S           |
| 28. | SW 144            | 100.00<sup>a</sup> | 41.67<sup>a</sup> | 96.65<sup>a</sup> | S           |
| 29. | Bowman            | 86.67<sup>a</sup> | 19.17<sup>a</sup> | 81.73<sup>a</sup> | S           |
| 30. | Torino            | 90.00<sup>a</sup> | 42.50<sup>a</sup> | 86.67<sup>a</sup> | S           |
| 31. | Yunan Flower      | 82.95<sup>a</sup> | 40.00<sup>a</sup> | 90.00<sup>a</sup> | S           |
| 32. |                   | 100.00<sup>a</sup> | 92.86<sup>a</sup> | 93.30<sup>a</sup> | S           |
| 33. | New Orchid        | 85.84<sup>a</sup> | 90.18<sup>a</sup> | 100.00<sup>a</sup> | S           |
| 34. | TM Dragon         | 100.00<sup>a</sup> | 81.25<sup>a</sup> | 93.75<sup>a</sup> | S           |
| 35. | Hitam Manis       | 100.00<sup>a</sup> | 92.86<sup>a</sup> | 93.30<sup>a</sup> | S           |

Numbers followed by the same letters in the same column are not significantly different according to DMRT α = 5%. Resistance category: R = resistant (0–20%), MR = moderate resistant (21–50%), SR = slightly resistant (51–80%), S = susceptible (81–100%).

Evaluation of genotypic reaction against different pathogenic isolates can be used to determine whether it is specific disease resistance or not (Liu and Anderson 2003). Thus, the genotype which proved to be resistant against isolate from one location can be susceptible if tested with other isolates from different areas (Latin 1993). Genotypes Sugar Baby and Charleston Gray showed the range of resistance category from moderate resistant, slightly resistant to susceptible when tested to each of *Fon* isolates. This result was similar to the previous study testing with the same genotypes (Tran-Nguyen and McMaster 2017). Unlike other *F. oxysporum* race which usually expressed resistance in discrete values, *Fon* frequently showed continued virulence (Zhou et al. 2010). Therefore, plants may expose a range of resistance categories, i.e. from highly resistant to susceptible (Leach et al. 2014). Our study also conformed to Patton (1955) who studied that the pathogen expressed a range of virulence level to resistance gene in the host plant. The external factors that potentially affect disease incident include the quantity of *Fon* inoculum infested in the soil (Kurt et al. 2008), sterility of growing media (Alves et al. 2008), inoculum substrate (Zhou et al. 2010), glucose and carbon contents of the inoculum (Srivastava et al. 2011), and temperature (Chen et al. 2013).
CONCLUSION

Different responses among 35 watermelon genotypes to three *Fon* isolates were demonstrated in this study as revealed by IP and DI. Most genotypes were slightly resistant to resistant against one *Fon* isolate but they were susceptible against other *Fon* isolates. Six watermelon genotypes that consistently showed resistance phenotypes against the three *Fon* isolates were New Hope, Sky Mountain, Southern Light, Super Sweet 66, Uranus, and Yellow Baby. These resistance genotypes are potentially used as parents in watermelon breeding programs for developing watermelon variety resistant to Fusarium wilt disease.

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AUTHOR CONTRIBUTIONS

NA is the main contributor who designed and performed the whole experiment and wrote the manuscript. SW and S are the member contributors who supervised, gave advice and guidance on the research design, and helped correction for the thesis from which this manuscript was written.

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