Tropical Life Sciences Research, 23(2), 1–15, 2012

Diversity of *Fusarium* Species from Highland Areas in Malaysia

Nurhazrati Manshor, Hafizi Rosli, Nor Azliza Ismail, Baharuddin Salleh and Latiffah Zakaria*

School of Biological Sciences, Universiti Sains Malaysia, 11800 USM Pulau Pinang, Malaysia

Abstrak: *Fusarium* merupakan genus kosmopolitan dan sangat pelbagai, terdiri daripada kulat yang saprofitik, fitopatogenik dan toxigenik. Walaupun demikian, kewujudan dan kepelbagaian beberapa spesies *Fusarium* terhad kepada beberapa kawasan tertentu dan keadaan iklim. Kajian ini dijalankan untuk menentukan kewujudan dan kepelbagaian spesies *Fusarium* dari kawasan tanah tinggi tropika di Malaysia, dan untuk membandingkannya dengan kawasan temperat dan sub-tropika. Persampelan berperingkat dilakukan secara rawak daripada pelbagai perumah dan substrat dari tahun 2005 hingga 2009 di beberapa kawasan tanah tinggi di Malaysia iaitu: Cameron Highlands, Bukit Fraser dan Genting Highlands di Pahang; Bukit Bendera di Pulau Pinang; Gunung Jerai di Kedah; Kundasang dan Taman Kinabalu di Sabah; Taman Negara Kubah dan Bukit Begunan di Sarawak. Pemencilan *Fusarium* dilakukan menggunakan media agar pentakloronitrobenzena (PCNB) dan sebanyak 1449 pencilan *Fusarium* telah berjaya diperolehi. Berdasarkan ciri-ciri morfologi, 20 spesies *Fusarium* telah dikenal pasti. Spesies yang paling banyak diperolehi di kawasan tanah tinggi tersebut adalah *F. solani* (66.1%) diikuti dengan *F. graminearum* (8.5%), *F. oxysporum* (7.8%), *F. semitectum* (5.7%), *F. subglutinans* (3.5%) dan *F. proliferatum* (3.4%). Spesies *Fusarium* yang lain iaitu *F. avenaceum, F. camptoceras, F. chlamydosporum, F. compactum, F. crookwellense, F. culmorum, F. decemcellulare, F. equiseti, F. nygamai, F. poae, F. proliferatum, F. sacchari, F. sporotrichioides, F. sterilihyphosum* dan *F. verticillioides,* masing-masing terdiri daripada 1% pencilan. Kajian ini merupakan kajian yang pertama melaporkan kewujudan spesies *Fusarium* di kawasan tanah tinggi di Malaysia.

Kata kunci: Kepelbagaian, *Fusarium*, Kawasan Tanah Tinggi, Malaysia

Abstract: *Fusarium* is a cosmopolitan and highly diversified genus of saprophytic, phytopathogenic and toxigenic fungi. However, the existence and diversity of a few species of *Fusarium* are restricted to a certain area or climatic condition. The present study was conducted to determine the occurrence and diversity of *Fusarium* species in tropical highland areas in Malaysia and to compare with those in temperate and subtropical regions. A series of sampling was carried out in 2005 to 2009 at several tropical highland areas in Malaysia that is: Cameron Highlands, Fraser Hills and Genting Highlands in Pahang; Penang Hill in Penang; Gunung Jerai in Kedah; Kundasang and Kinabalu Park in Sabah; Kubah National Park and Begunan Hill in Sarawak. Sampling was done randomly from various hosts and substrates. Isolation of *Fusarium* isolates was done by using pentachloronitrobenzene (PCNB) agar and 1449 isolates of *Fusarium* were successfully recovered. Based on morphological characteristics, 20 species of *Fusarium* were identified. The most prevalent species occurring on the highlands areas was *F. solani* (66.1%) followed by *F. graminearum* (8.5%), *F. oxysporum* (7.8%), *F. semitectum* (5.7%), *F. subglutinans* (3.5%) and *F. proliferatum* (3.4%). Other *Fusarium* species, namely *F. avenaceum, F. camptoceras, F. chlamydosporum, F. compactum, F. crookwellense, F. culmorum, F. decemcellulare, F. equiseti, F. nygamai, F. poae,*

*Corresponding author: Lfah@usm.my

F. proliferatum, F. sacchari, F. sporotrichioides, F. sterilihyphosum and *F. verticillioides* accounted for 1% recoveries. The present study was the first report on the occurrences of *Fusarium* species on highland areas in Malaysia.

Keywords: Diversity, *Fusarium*, Highland Areas, Malaysia

INTRODUCTION

The genus *Fusarium* is one of the most economically important group of fungi infecting some very important agricultural and horticultural crops worldwide. The fungus can be found in most bioclimatic regions of the world including tropical and temperate grasslands, shrub lands, forests as well as harsh desert and alpine environment, soils associated with plants, organic debris and any part of plants from deepest root to highest flowers (Leslie & Summerell 2006). Therefore, *Fusarium* occurs in almost all ecosystems worldwide (Young *et al.* 1978; Nelson *et al.* 1994; Arney *et al.* 1997).

Fusarium species have been reported as plant pathogenic fungus causing various plant diseases on a variety of tropical plant parts such as root, fruits, seeds, storage tissues, stem and stalk rots, vascular wilt, canker, die-back, gall and leaf diseases (Stover 1981; Leslie & Summerell 2006). Moreover, isolates of *Fusarium* can spread through air, soils and from infected plant debris (Summerell *et al.* 2010).

Climate is one of the important factors which can determine the occurrence of fungi on a broad, regional scale (Money 1972). Malaysia is located in the tropical region which has a hot wet equatorial climate. The mean daily temperature in lowlands throughout the year ranges from 21°C to 32°C whereas in the tropic highlands, the temperature is slightly cooler ranging from 16°C to 26°C.

The highland of Malaysia located in the centre of Peninsular Malaysia (at about 1200 m) consists of granite masses whereas at the interior of Sabah and Sarawak (at about 1200 m to 1800 m) it is densely forested mountainous area with alluvial and swampy coastal plains (Andrews & Freestone 1972; Ooi 1976). The vegetation at the highland areas is mainly oaks, laurels, conifers, myrtles and plants from the family Theaceae. Mount Kinabalu is the highest mountain in Malaysia with different kinds of vegetation. The forest of oaks and conifers at the middle level altitudes are not so tall and they become more dwarfed at higher level where there is an association of Himalayan and temperate region plants such as from the genus *Rhododendron* (Andrews & Freestone 1972).

Previous studies have shown that mycogeography of *Fusarium* species was influenced by climatic conditions (Burgess 1981; Burgess *et al.* 1988; Marasas *et al.* 1988; Burgess & Summerell 1992). The climatic factor which includes temperature, rainfall and season could influence the distribution of *Fusarium* species (Sangalang *et al.* 1995a). In temperate and tropical regions, *Fusarium* species are diverse in terms of the number of species, distribution, host range and virulence (Gordon 1960; Summerell *et al.* 2003; Leslie & Summerell 2006). There are some *Fusarium* species which appear to be limited in certain climatic region while some species were not influenced by climatic factor

(Burgess *et al.* 1988; Summerell *et al.* 1993). *F. compactum* had only been recovered in warmer areas while *F. solani* and *F. oxysporum* can be found in all climatic regions, and these two species are commonly found in the soil (Burgess *et al.* 1988; Kommedahl *et al.* 1988; Jeschke *et al.* 1990; Leslie *et al.* 1990). Sangalang *et al.* (1995b) also reported that climate contributes to the distribution of many *Fusarium* species but the mechanism is unknown.

Occurrence of *Fusarium* species in lowland areas in Malaysia have been conducted by Latiffah *et al.* (2007, 2009, 2010) however, there is no report on the occurrence of *Fusarium* species in tropical highland areas in Malaysia. Therefore, the present study was carried out to determine the occurrences and diversity of *Fusarium* species at several tropical highlands areas in Malaysia and to compare with those in temperate and subtropical regions.

MATERIALS AND METHODS

Sampling Site

The samples were collected from 19 sampling sites in the Malaysian tropical highland areas which were located between 400 to 2030 m above sea level from 2005 to 2009. The highland tropical areas were: Cameron Highlands, Fraser's Hill, Genting Highlands, Penang Hill and Gunung Jerai in Peninsular Malaysia; Kinabalu Park, Kundasang, Begunan Hill and Kubah National Park in Sabah and Sarawak (East Malaysia). Tropical highlands has a more parallel climate than the temperate region with a minimum average temperature of 16.5°C and a maximum average temperature of about 24.8°C (Table 1).

Isolation of *Fusarium* Isolates

Isolates of *Fusarium* were isolated from various hosts and substrate as shown in Table 2. Isolation of *Fusarium* was done by directly plating the plant parts, debris and other substrates onto a semi-selective media, pentachloronitrobenzene (PCNB) agar (Nash & Snyder 1962). For identification, four media were used, namely potato dextrose agar (PDA), potato sucrose agar (PSA), carnation leaf agar (CLA) and water agar (WA) as described in The *Fusarium* Laboratory Manual (Leslie & Summerell 2006). Microscopic and macroscopic characteristics as described in the manual were used for species identification. Species descriptions were based on Wollenweber and Reinking (1935), Booth (1971), Joffe (1974), Gerlach and Nirenberg (1982), Nelson *et al.* (1983), Burgess *et al.* (1994) and, Leslie and Summerell (2006).

Table 1: Location of sampling sites of tropical highland areas in Malaysia.

Site no.	Location	Altitude (m)	Rainfall[a] (mm)	Mean temperature[a] (°C)	
				Min	Max
C1	Pine forest reserve, Cameron Highlands	1829	2500	15.2	21.9
C2	Gunung Irau (mossy forest), Cameron Highlands	1828	2500	15.2	21.9
C3	Gunung Brinchang, Cameron Highlands	2031	2500	15.2	21.9
C4	Tringkap's forest reserve, Cameron Highlands	1545	2500	15.2	21.9
C5	Grass, Cameron Highlands	1545	2500	15.2	21.9
C6	Boh Tea Plantation, Cameron Highlands	1829	2500	15.2	21.9
C7	Ulu Bertam forest reserve, Cameron Highlands	1500	2500	15.2	21.9
C8	Waterfall, Cameron Highlands	1829	2500	15.2	21.9
C9	Asparagus farm, Cameron Highlands	1829	2500	15.2	21.9
C10	Sugarcane plantation, Cameron Highlands	1829	2500	15.2	21.9
C11	Soil, Cameron Highlands	1829	2500	15.2	21.9
C12	Genting Highlands	2000	2150	16.0	23.0
C13	Fraser's Hill	1200	2350	16.2	21.3
C14	Penang Hill	1805	2250	19.0	25.9
C15	Gunung Jerai	1217	2500	21.0	27.0
C16	Kundasang, Sabah	2000	2500	19.0	32.0
C17	Kinabalu Park, Sabah	1866	305	13.5	20.0
C18	Begunan's Hill, Sarawak	400	2100	18.5	24.5
C19	Kubah National Park, Sarawak	800	3000	12.0	32.0

Note: [a]Rainfall and temperature data were provided by the Malaysian Meteorological Department

Table 2: Various hosts and substrates for isolation of *Fusarium* isolates.

Hosts	Scientific name	Common name	Plant part
Plants	*Casinia* sp.	Shower tree	wood
	Pinus sylvistris	Pine	stem, stalk ,flower, cone, leaf,
	Pinus oocarpa	Pine	root, stigma, soil
	Phyllostachys sp.	Bamboo	leaf stalk
	Epipremnum aureum	*Pokok duit-duit*	leaf
	Musa sp.	Banana	root

(*continued on next page*)

Table 2: (*continued*)

Hosts	Scientific name	Common name	Plant part
Plants	*Saccharum* sp.	Sugarcane	leaf
	Asparagus officinalis	Asparagus	stem, root, old shoot, ripened seed
	Zingiber officinale	Ginger	flower,root
	Ashasma megalocheilos	Tepus	flower, root
	Camellia sinensis	Tea tree	leaf, flower
	Vitis sp.	Grape	fruit
	Cucurbita maxima	Pumpkin	leaf
	Zea mays	Corn	leaf
	Luffa sp.	Loofah (petola)	fruit
	Capsicum annuum	Pepper	soil, root, twig, tree bark, seed
	Centella asiatica	*Pegaga*	root
	Ipomoea batatas	Yam	tuber
	Solanum tuberosum	Potato	tuber
	Piper betle	*Sirih*	flower
	Anthurium sp.	Flamingo flower	flower
	Gladiolus sp.	Sword lily	bulb
	Dendrobium sp.	Orchid	root
	Datura suaveolens	Angel's trumpet	leaf, flower
	Carnegia sp.	Cactus	flower
	Begonia sp.	Begonia	flower
	Cleome hassleriana	Spider flower	flower
	Catharanthus roseus	*Kemunting Cina*	flower
	Cyperus sp.	Papyrus sedges	flower
	Gomphrena sp.	Globe amaranth	flower
	Hippeastrum sp.	Jersey lily	flower
	Lilium longiforum	Easter lily	flower
	Ipomoea purpurea	Morning glory	flower
	Tibouchina semidecandra	Glory flower	flower
	Impatients walleriana	Balsam	leaf, flower
	Calamus sp.	Rattan	leaf stalk
	Mimosa pudica	Herbs	root
	Imperata cylindrica	Weed	root, stalk, leaf
	xElyhordeum montanense	Grasses	leaf, stalk, flowers, root
	Paspalum conjugatum	*Rumput kerbau*	leaf, stalk, flowers, root

(*continued on next page*)

Table 2: (*continued*)

Hosts	Scientific name	Common name	Plant part
Plants	*Eragrostis* sp.	Lovegrass	leaf, stalk, flowers, root
	Nephrolepis sp.	Fern	leaf, root
	Athyrium filix-femina	Lady fern	leaf, root
	Selaginella sp.; *Polytrichum* sp.; *Lycopodium* sp.	Moss	leaf, root
	Parmotrema perlatum	Lichen	leaf
Fungi	*Agaricus* sp.	Mushroom	
Insect / Invertebrate	*Helix aspersa*	Snail	The whole body parts
	Hirudo medicinalis	Leeches	
	Isoptera sp.	Termites	
	Spodoptera litura	Leaf worm	
Others		Debris, humus, cow feces, air	

RESULTS AND DISCUSSION

A total of 1449 isolates of *Fusarium* were successfully isolated from 19 highland areas in Malaysia. Twenty species from seven sections were identified based on morphological characteristics. The species were from section Arthrosporiella (*F. camptoceras*, *F. decemcellulare* and *F. semitectum*), Discolor (*F. crookwellense*, *F. culmorum* and *F. graminearum*), Elegans (*F. oxysporum*), Gibbosum (*F. compactum* and *F. equiseti*), Liseola (*F. subglutinans*, *F. nygamai*, *F. proliferatum*, *F. sacchari*, *F. verticillioides* and *F. sterilihyphosum*), Martiella (*F. solani*), Roseum (*F. avenaceum*) and Sporotrichiella (*F. chlamydosporum* and *F. sporotrichioides*). Table 3 shows the number of *Fusarium* species and the location from where the species were isolated. From Table 4, the most common species of *Fusarium* isolated from the highland areas was *F. solani* (66.1%) followed by *F. graminearum* (8.5%), *F. oxysporum* (7.8%), *F. semitectum* (5.7%), *F. subglutinans* (3.5%), *F. proliferatum* (3.4%) and other *Fusarium* species which comprised 1% recoveries.

F. solani was recovered in all sampling sites, and was the most prevalent in Fraser's Hill (C13) with 251 isolates. *F. solani* was recovered from various hosts and substrates which included different types of plants such as pine, flower and grasses as well as from the insect (termites, snail and leeches) (Tables 3 and 4). *F. solani* was mostly isolated from the soils (239 isolates) followed by leaves from different species of plants. *F. solani* is a cosmopolitan species, widely distributed in tropical region especially at lowland areas and in the soils in different environments (Leslie & Summerell 2006). *F. solani* can easily be isolated from different types of soils and had been isolated in subtropical, semiarid and grassland soils (Burgess & Summerell 1992), cultivated soils (Latiffah *et al.* 2007), forested area (Latiffah *et al.* 2009), sandy soils (Sarquis &

Borba 1997) and from arid and saline environments (Sangalang *et al.* 1995b; Mandeel 2006).

Although *F. graminearum* is a well-known pathogen of cereal grains, causing scab or head blight, in the present study, 73 isolates of *F. graminearum* were isolated from grass (Family: Gramineae) especially from *xElyhordeum montanense,* which is a wild grass growing at the hillside of Cameron Highlands. *F. graminearum* has been isolated from wild grass such as *Agrostis stolonifera* L. (creeping bent grass), *Echinochloa crusgalli* (L.) Beauv. (barnyard grass), *Agropyron trachycaulum* (Link) Malte (slender wheat grass) and *Bromus ciliates* L. (fringed brome) as reported by Inch and Gilbert (2003) and, Goswami and Kistler (2004). Besides grasses, 50 isolates of *F. graminearum* was also recovered from flowers, stalk pine, leaves and mosses. Burgess *et al.* (1988) reported that *F. graminearum* has been isolated from non-agricultural host such as grasses in temperate region.

A total of 113 *F. oxysporum* isolates were recovered from 14 sampling sites (Table 1) and 31 isolates were isolated mainly from soils, and the other 82 isolates were isolated from asparagus, flowers, grasses, moss, pine, lichen and air sampling. Similar with *F. solani*, *F. oxysporum* is a cosmopolitan species and is widespread in different types of soil worldwide. *F. oxysporum* is also a well-known plant pathogen in tropical and temperate regions; causing wilt and root rot diseases in a variety of agricultural crops, and can be easily isolated from agricultural soils as well as non-agricultural soils (Ooi & Salleh 1999; Baayen *et al.* 2000; Flood 2006; Latiffah *et al.* 2010). Some isolates of *F. oxysporum* are saprophytes especially on plant debris (Moss & Smith 1984; Gordon & Martyn 1997). *F. oxysporum* also has been reported to be among the most frequently isolated fungus from arid and saline environments (Sangalang *et al.* 1995b; Mandeel 2006).

Five species of *Fusarium,* namely *F. culmorum, F. crookwellense, F. sporotrichioides, F. poae* and *F. avenaceum* were recovered from different substrates such as moss, grasses and pine (Table 4). The number of isolates recovered was between 1 to 13 isolates. The five species of *Fusarium* are commonly found in temperate region and are frequently associated with cereal crops or small grains such as barley and wheat. Friebe *et al.* (1998) reported that *F. culmorum* was isolated from grasses in temperate region causing root rot disease. Similar with *F. culmorum*, *F. sporotrichioides, F. crookwellense* and *F. poae* was also isolated from grasses and small grains (Perkowski *et al.* 2003; Inch & Gilbert 2003; Mielniczuk *et al.* 2004). *F. sporotrichioides* and *F. culmorum* have been isolated from pine seed (Douglas-fir) however these species are nonpathogenic towards conifer seedlings (Hoefnagels & Linderman 1999; James & Perez 1999). *F. avenaceum* was also reported to cause pre- and post-emergence damping-off diseases to conifer germinates (James 1993) and dry rot on potato tubers (Satyaprasad *et al.* 1997). It is not surprising that these common temperate species occur in highland areas in Malaysia as the highland areas have cooler temperatures ranging from 16°C to 23°C and wetter weathers compared with the lowland areas.

A total of 117 isolates of section Liseola comprising six species namely *F. proliferatum* (49)*, F. subglutinans* (50)*, F. nygamai* (8)*, F. verticillioides* (9),

F. sacchari (14) and *F. sterilihyphosum* (3) were recovered from different substrates such as asparagus, grasses, pine, soil, maize and others (Table 4). The six species are common plant pathogen, infecting various crops in tropical and temperate regions. *F. proliferatum*, *F. verticillioides* and *F. subglutinans* are common pathogen of ear-rot disease of maize (*Zea mays*) in both temperate and tropical regions (Magnoli *et al.*1999; Voss *et al.* 2007) *F. nygamai*, *F. proliferatum* and *F. subglutinans* has been recovered from soils in three different climate regions in Australia namely tropical, arid and Mediterranean (Sangalang *et al.* 1995b) and also from soils of tropical highlands. In addition, *F. sterilihyphosum* is commonly associated with malformation of inflorescence of mango (*Mangifera indica*) especially in Asia, Africa and the Americas (Britz *et al.* 2002; Iqbal *et al.* 2006; Marasas *et al.* 2006). However, from the present study, *F. sterilihyphosum* was isolated from flowers and fern. Further studies on *F. sterilihyphosum* from the two substrates need to be carried out as the morphological characteristics of *F. sterilihyphosum* are very similar with other species of *Fusarium* in the section Liseola.

Three species from section Arthrosporiella namely, *F. camptoceras, F. decemcellulare* and *F. semitectum* were isolated from pine, grasses, moss, weeds, mushroom, sugarcane, air, asparagus, and soils (Table 4). The three species especially *F. semitectum* are commonly isolated from various substrates such as soils and plant debris in the tropical region. *F. semitectum* in particular, has been isolated from different types of soil such as soil from arid regions (Sangalang *et al.* 1995b), tropical and temperate regions (Burgess *et al*. 1988). The species is probably found as soil inhabitants (Leslie *et al.* 1990). *F. camptoceras* was isolated from leaf and pine (Table 4) and this species is limited, found only in subtropical and tropical regions (Jimenez *et al.* 1997; Leslie & Summerell 2006). In the present study, *F. decemcellulare* was isolated from leaf, grass, pine, *Sellaginella*, seed, flower and weed (Table 4). *F. decemcellulare* is commonly found in tropical regions (Ploetz *et al.* 1996) and is often associated with canker of various tree species (Leslie & Summerell 2006).

Two species of *Fusarium*, *F. equiseti* and *F. compactum* from section Gibbosum were isolated from asparagus, grasses, soils and pine tree (Table 4). Both species are well-distributed in warm temperature and subtropical areas (Burgess *et al.* 1988; Burgess & Summerell 1992). The occurrence of *F. equiseti* was reported in many tropical, subtropical and temperate countries worldwide (Burgess 1981; Backhouse & Burgess 1995). Whereas, *F. compactum* is generally recovered in hot arid and semi-arid climates and commonly occurs as soil saprophyte and is rarely found in cooler areas (Backhouse & Burgess 2002). Sangalang *et al.* (1995b) reported that *F. compactum* is commonly recovered from a variety of soils.

F. chlamydosporum (section Sporotrichiella) was isolated from pine (Table 4). This species is a common saprophyte on a variety of substrates especially in soils of arid and semi-arid areas and has been reported to cause damping-off of rooibos tea plants (Engelbrecht *et al.* 1983) and stem canker of okra (Fugro 1999).

Table 3: Number of *Fusarium* isolates from various locations.

Fusarium species	*Location																		
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19
F. avenaceum	**–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. camptoceras	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. chlamydosporum	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. compactum	1	3	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–
F. crookwellense	–	1	–	–	–	–	–	–	–	–	–	–	6	–	–	–	–	–	–
F. culmorum	8	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. decemcellulare	1	–	2	–	1	–	–	–	–	–	–	–	3	–	–	–	1	–	–
F. equiseti	–	2	–	1	5	–	–	–	–	–	–	–	–	–	–	3	-	–	–
F. graminearum	11	5	17	11	73	1	–	–	–	–	–	–	4	–	–	–	1	–	–
F. nygamai	–	–	–	–	–	–	–	3	5	–	–	–	2	–	–	–	-	–	–
F. oxysporum	7	5	30	1	7	1	–	4	7	–	4	16	21	5	2	–	3	–	–
F. poae	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. proliferatum	4	6	3	1	4	–	–	–	3	1	–	3	7	3	–	12	1	–	1
F. sacchari	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. semitectum	21	10	14	5	4	1	–	1	–	–	–	1	2	5	1	3	12	2	–
F. solani	74	79	167	2	13	9	17	14	1	1	18	41	251	10	74	55	79	8	45
F. sporotrichioides	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
F. sterilihyphosum	–	–	–	–	1	–	–	–	–	–	–	1	1	–	–	–	–	–	–
F. subglutinans	9	4	7	3	2	1	–	–	–	2	3	3	8	1	6	–	1	–	–
F. verticillioides	–	–	1	–	1	–	–	–	–	–	–	1	5	–	–	–	1	–	–

*Notes:**Refer to Table 2. **Not detected

Among all the sampling sites, the majority (21.39%) of *Fusarium* isolates was recovered from Fraser's Hill (C13) and the least number of isolates (0.28%) were from sugarcane field (C10) in Cameron Highlands. The results of the present study showed that a variety of *Fusarium* species occurs in tropical highland areas in Malaysia. *Fusarium* species which are commonly found in the temperate region were also found in tropical highland although in fewer numbers such *as F. graminearum, F. culmorum, F. sporotrichioides* and *F. avenaceum,* and several of these species are pathogenic to agricultural crops. Most of *Fusarium* species found in tropical region such as *F. solani, F. oxysporum* and *F. semitectum* can also be found in temperate region. Further studies on these species should be conducted to determine whether the species are climate or geographically dependent.

Table 4: Number of *Fusarium* isolates recovered from different substrates.

Species	Substrate	Number of isolates
F. solani (958)	Soils	239
	Pines	155
	Flowers	127
	Mosses	120
	Trees	117
	Grasses	72
	Fruits	27
	Ferns	23
	Lichens	21
	Algae	19
	Mushrooms	15
	Insect/Invertebrate	9
	Faeces	3
	Weeds	3
	Debris	3
	Air sampling	3
	Humus	2
F. graminearum (123)	Grasses	73
	Flowers	31
	Pines	14
	Ferns	3
	Mosses	2
F. oxysporum (113)	Soils	31
	Flowers	33
	Grasses	22
	Mosses	8
	Asparagus	7
	Pines	7
	Lichens	4
	Air sampling	1

(*continued on next page*)

Table 4: (*continued*)

Species	Substrate	Number of isolates
F. semitectum (82)	Flowers	22
	Pines	20
	Mosses	14
	Grasses	13
	Soils	9
	Air sampling	1
	Sugarcane	1
	Asparagus	1
	Mushroom	1
F. subglutinans (50)	Flowers	16
	Pines	10
	Mosses	9
	Soils	6
	Grasses	5
	Air sampling	2
	Sugarcane	2
F. proliferatum (49)	Asparagus	14
	Pines	15
	Grasses	9
	Flowers	5
	Air sampling	2
	Mushrooms	2
	Soil	1
	Sugarcane	1
F. compactum (13)	Pine	6
	Soils	4
	Mosses	3
F. equiseti (11)	Grasses	5
	Asparagus	4
	Mosses	2
F. nygamai (8)	Asparagus	5
	Flowers	3
F. culmorum (9)	Grasses	5
	Pines	4
F. crookwellense (7)	Grasses	7
F. verticillioides (9)	Mosses	5
	Pines	2
	Grasses	2

(*continued on next page*)

Table 4: (*continued*)

Species	Substrate	Number of isolates
	Mosses	3
F. decemcellulare	Pines	2
(8)	Soil	1
	Weed	1
	Flower	1
F. sterilihyphosum	Fern	1
(3)	Flower	1
	Pine	1
F. avenaceum	Moss	1
(1)		
F. camptoceras	Pine	1
(1)		
F. chlamydosporum	Pine	1
(1)		
F. poae	Pine	1
(1)		
F. sacchari	Grass	1
(1)		

ACKNOWLEDGEMENT

USM Fellowship was granted to the first author and Research University Postgraduate Research Grant Scheme (1001/PBIOLOGI/833011) from Universiti Sains Malaysia is duly acknowledged. The project was also supported by Research University Grant (1001/PBIOLOGI/811179).The authors would like to thank Mohd Kamarudin Mohd Maidin, Siti Norsyila Mahmud, Nurul Farizah Azzudin, Noor Fazila Mohamed Yahaya, Bintra Mailina and Darnetty for their cooperation and contribution in sample collection.

REFERENCES

Andrews R L and Freestone C S. (1972). *A geography of Indonesia, Malaysia, Singapore*, 2nd ed. Australia: George Philip & O'Neil Pty Ltd.

Arney K L, Tiernan R and Judson M A. (1997). Primary pulmonary involvement of *Fusarium solani* in lung transplant recipient. *The American College of Chest Physicians* 112(4): 1128–1130.

Baayen R P, O'Donnell K, Bonants P J M, Cigelnik E, Kroon L P N M, Roebroeck E J A and Waalwijk C. (2000). Gene genealogies and AFLP analyses in the *Fusarium oxysporum* complex identify monophyletic and nonmonophyletic formae specials causing wilt and rot disease. *Phytopathology* 90(8): 891–900.

Backhouse D and Burgess L W. (2002). Climatic analysis of the distribution of *Fusarium graminearum*, *F. pseudograminearum* and *F. culmorum* on cereals in Australia. *Australasian Plant Pathology* 31(4): 321–327.

———. (1995). Mycogeography of *Fusarium*: Climatic analysis of the distribution within Australia of *Fusarium* species in section Gibbosum. *Mycological Research* 99(10): 1218–1224.

Booth C. (1971). *The genus* Fusarium. Kew, Surrey, England: Commonwealth Mycological Institute.

Britz H, Steenkamp E T, Coutinho T A, Wingfield B D, Marasas W F O and Wingfield M J. (2002). Two new species of *Fusarium* section Liseola associated with mango malformation. *Mycologia* 94(4): 722–730.

Burgess L W. (1981). General ecology of Fusaria. In P E Nelson, T A Toussoun and R J Cook (eds.). Fusarium: *Diseases, biology, and taxonomy*. Pennsylvania, USA: Pennsylvania State University Press, 276–286.

Burgess L W and Summerell B A. (1992). Mycogeography of *Fusarium*: Survey of *Fusarium* species from subtropical and semiarid grassland soils from Queensland Australia. *Mycological Research* 96(9): 780–784.

Burgess L W, Nelson P E, Toussoun T A and Forbes G A. (1988). Distribution of *Fusarium* species in section Roseum, Arthrosporiella, Gibbosum and Discolor recovered from grassland, pasture and pine nursery soils of Eastern Australia. *Mycologia* 80(6): 815–824.

Burgess L W, Summerell B A, Bullock S, Gott K P and Backhouse D. (1994). *Laboratory manual for* Fusarium *research*. Sydney: University of Sydney, 116–117.

Engelbrecht M C, Smit W A and Knox-Davies P S. (1983). Damping off of rooibos tea, *Aspalathus linearis*. *Phytophylactica* 15(3): 121–124.

Flood J. (2006). A review of fusarium wilt of oil palm caused by *Fusarium oxysporum* f. sp. *elaeidis*. *Phytopathology* 96(6): 660–662.

Friebe A, Vilich V, Hennig I, Kluge M and Sicker D. (1998). Detoxification of benzoxazolinone allelochemicals from wheat by *Gaeumannomyces graminis* var. *tritici*, *G. graminis* var. *graminis*, *G. graminis* var. *avenar,* and *Fusarium culmorum*. *Applied and Environmental Microbiology* 64(7): 2386–2391.

Fugro P A. (1999). A new disease of okra (*Abelmoschus esulentus* L.) in India. *Journal of Mycology and Plant Pathology* 29(2): 264.

Gerlach W and Nirenberg H I. (1982). *The genus* Fusarium *– A pictorial atlas. Mitteilungen aus der Biologischen Bundesanstalt für Land-und Forstwirtschaft Berlin-Dahlem*, 209. Germany: Kommissionsverlag Paul Parey.

Gordon W L. (1960). The taxonomy and habitats of *Fusarium* species from tropical and temperate regions. *Canadian Journal of Botany* 38(4): 643–658.

Gordon T R and Martyn R D. (1997). The evolutionary biology of *Fusarium oxysporum*. *Annual Review of Phytopathology* 35: 111–128.

Goswami R S and Kistler H C. (2004). Heading for disaster: *Fusarium graminearum* on cereal crops. *Molecular Plant Pathology* 5(6): 515–525.

Hoefnagels M H and Linderman R G. (1999). Biological suppression of seedborne *Fusarium* spp. during cold stratification of Douglas-fir seeds. *Plant Disease* 83(9): 845–852.

Inch S A and Gilbert J. (2003). Survival of *Gibberella zeae* in *Fusarium*-damaged wheat kernels. *Plant Disease* 87(3): 282–287.

Iqbal Z, Mehboob-ur-Rahman, Dasti A A, Saleem A and Zafar Y. (2006). RAPD analysis *Fusarium* isolates causing “Mango Malformation” disease in Pakistan. *World Journal Microbiology and Biotechnology* 22(11): 1161–1167.

James R L. (1993). *Fusarium* species associated with post-emergence damping-off and root disease of young conifer-grown Douglas-fir seedlings in USDA Forest Service Nursery, Coeur d’Alene, Idaho. *Northern Region Nursery Disease Notes #129*. USA: US Department of Agriculture.

James R L and Perez R. (1999). Pathogenic characteristics of *Fusarium sporotrichioides* isolated from inland Pacific Northwest forest nurseries. *Forest Health Protection Report 99-8.* USA: US Department of Agriculture.

Jeschke N, Nelson P E and Marasas W F O. (1990). *Fusarium* spp. isolated from soil samples collected at different altitudes in the Transkei, southern Africa. *Mycologia* 82(6): 727–733.

Jimenez M, Huerta T and Mateo R. (1997). Mycotoxin production by *Fusarium* species isolated from bananas. *Applied and Environmental Microbiology* 63(2): 364–369.

Joffe A Z. (1974). A modern system of *Fusarium* taxonomy. *Mycopathologia* 53(1): 201–228.

Kommedahl T, Abbas H K, Burnes P M and Mirocha C J. (1988). Prevalence and toxigenicity of *Fusarium* spp. from soils of Norway near the Arctic Circle. *Mycologia* 80(6): 790–794.

Latiffah Z, Mohd. Zariman M and Baharuddin S. (2007). Diversity of *Fusarium* species in cultivated soils in Penang. *Malaysian Journal of Microbiology* 3(1): 27–30.

Latiffah Z, Nurul Izzati H and Baharuddin S. (2010). *Fusarium* species isolated from peat soil of Pondok Tanjung and Sungai Beriah, Perak. *Malaysian Journal of Microbiology* 6(1): 102–105.

Latiffah Z, Padzilah M I, Baharuddin S and Maziah Z. (2009). *Fusarium* species in forest soil of Bird Valley. *Malaysian Journal of Microbiology* 5(2): 132–133.

Leslie J F and Summerell B A. (2006). *The* Fusarium *laboratory manual*. Oxford, UK: Blackwell Publishing Ltd.

Leslie J F, Pearson C A S, Nelson P E and Toussoun T A. (1990). *Fusarium* species from corn, sorghum, and soybean fields in the central and eastern United States. *Phytopathology* 80(4): 343–350.

Magnoli C E, Saenz M A, Chiacchiera S M and Dalcero A M. (1999). Natural occurrence of Fusarium species and fumonisin-production toxigenic strains isolated from poultry feeds in Argentina. *Mycopathologia* 145(1): 35–41.

Mandeel Q A. (2006). Biodiversity of the genus *Fusarium* in saline soil habitats. *Journal of Basic Microbiology* 46(6): 480–494.

Marasas W F O, Burgess L W, Anelich R Y, Lamprecht S C and Van Shalkwyk D J. (1988). Survey of *Fusarium* species associated with plant debris in South African soils. *South African Journal of Botany* 54(1): 63–71.

Marasas W F O, Ploetz R C, Wingfield M J and Steenkamp E T. (2006). Mango malformation disease and the associated *Fusarium* species. *Phytopathology* 96(6): 667–672.

Mielniczuk E, Kiecana I and Perkowski J. (2004). Susceptibility of oat genotypes to *Fusarium crookwellense* Burgess, Nelson and Toussoun infection and mycotoxins accumulation in kernels. *Biologia Bratislava* 59(6): 809–816.

Money D C. (1972). *Climate, soils and vegetation*. London: University Tutorial Press.

Moss M O and Smith J E. (1984). *The applied mycology of* Fusarium. New York: Cambridge University Press.

Nash S N and Snyder W C. (1962). Quantitative estimations by plate counts of propagules of the bean rot Fusarium in field soils. *Phytopathology* 52: 567–572.

Nelson P E, Toussoun T A and Marasas W F O. (1983). Fusarium *species: An illustrated manual for identification*. Pennsylvania, USA: Pennsylvania State University Press.

Nelson P E, Dignani M C and Anaissie E J. (1994). Taxonomy, biology and clinical aspect of *Fusarium* species. *Clinical Microbiology Review* 7(4): 479–504.

Ooi J-B. (1976). *Peninsular Malaysia*. London: Longman Group Limited.

Ooi K H and Salleh B. (1999). Vegetative compatibility groups of *Fusarium oxysporum*, the causal organism of vascular wilt on Roselle in Malaysia. *Biotropia* 12: 31–41.

Perkowski J, Kiecana I, Stachowiak J and Basinski T. (2003). Natural occurrence of scirpentriol in cereals infected by *Fusarium* species. *Food Additives and Contaminants* 20(6): 572–578.

Ploetz R, Vazquez A and Benscher D. (1996). First report of *Fusarium decemcellulare* as a pathogen of mango in the United States. *Plant Disease* 80(10): 1207.

Sangalang A E, Backhouse D and Burgess L W. (1995a). Survival and growth in culture of four *Fusarium* species in relation to occurrence in soils from hot climatic regions. *Mycological Research* 99(5): 529–533.

Sangalang A E, Burgess L W, Backhouse D, Duff J and Wurst M. (1995b). Mycogeography of *Fusarium* species in soils from tropical, arid and Mediterranean regions of Australia. *Mycological Research* 99(5): 523–528.

Sarquis M I M and Borba C M. (1997). *Fusarium* species in sandy soils from Ipanema Beach, Rio de Janeiro, Brazil. *Journal of Basic Microbiology* 37(6): 425–439.

Satyaprasad K, Bateman G L and Read P J. (1997). Variation in pathogenicity on potato tubers and sensitivity to thiabendazole of the dry rot fungus *Fusarium avenaceum*. *Potato Research* 40(4): 357–366.

Stover R H. (1981). *Fusarium* diseases in the tropics. In P E Nelson, T A Toussoun and R J Cook (eds.). Fusarium: *Diseases, biology and taxonomy.* Pennsylvania USA: Pennsylvania State University Press, 114–120.

Summerell B A, Rugg C A and Burgess L W. (1993). Mycogeography of *Fusarium*: Survey of *Fusarium* species associated with forest and woodland communities in north Queensland, Australia. *Mycological Research* 97(8): 1015–1019.

Summerell B A, Salleh B and Leslie J F. (2003). A utilitarian approach to *Fusarium* identification. *Plant Disease* 87(2): 117–128.

Summerell B A, Laurence M H, Liew E C Y and Leslie J F. (2010). Biogeography and phylogeography of *Fusarium*: A review. *Fungal Diversity* 44(1): 3–13.

Voss K A, Smith G W and Haschek W M. (2007). Fumonisins: Toxicokinetics, mechanism of action and toxicity. *Animal Feed Sciences and Technology* 137(3–4): 299–325.

Wollenweber H W and Reinking O A. (1935). *Die Fusarien, ihre Beschreibung, Schadwirkung und Bekampfung.* Berlin: Paul Parey.

Young N A, Kwon-Chung K J, Kubota T T, Jennings A E and Fisher R I. (1978). Disseminated infection by *Fusarium moniliforme* during treatment for malignant lymphoma. *Journal Clinical Microbiology* 7(6): 589–594.