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广东月露瓜镰刀菌果腐病菌的鉴定、生物学特性及对杀菌剂敏感性测定

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摘 要:【目的】明确广东月露瓜镰刀菌果腐病菌的种类及生物学特性,筛选防治药剂。**【方法】**自广州市增城区采集病害样本,采用组织分离法分离病原菌;结合形态特征和多基因系统发育分析确定病原菌的分类地位;测定温度、pH、光照、碳源、氮源和杀菌剂对病原菌生长的影响。**【结果】**分离菌株在PDA上成熟时淡黄色,背面米黄色。产孢细胞瓶梗状,单生或复生,在低营养合成琼脂(SNA)上,长2.72~49.69 μm(*n*=80);在康乃馨叶片琼脂(CLA)上,长3.63~52.65 μm(*n*=80)。大型分生孢子镰刀形,顶端渐尖稍弯曲,1~5个分隔,在SNA上大小为(17.45~46.78) μm×(2.62~4.93) μm(*n*=80),在CLA上大小为(15.84~44.27) μm×(2.71~4.95) μm(*n*=80)。厚垣孢子球形。基于*CaM*、*EF-1α*和*RPB2*基因序列联合构建系统发育树,确定病原菌是伯氏镰刀菌(*Fusarium pernambucanum*)。病原菌最适生长温度为26~28 ℃,pH为7~9。碳源葡萄糖、可溶性淀粉和有机氮源蛋白胨、牛肉浸粉和酵母膏均利于菌丝生长和产孢。咯菌腈和咪鲜胺对病菌有较好的抑制作用,EC_{50}分别为0.014 7 mg·L^{-1}和0.637 3 mg·L^{-1}。**【结论】**广东月露瓜镰刀菌果腐病菌为伯氏镰刀菌(*Fusarium pernambucanum*),病原菌适宜相对较高温度及中性至偏碱环境,对咯菌腈和咪鲜胺敏感。本研究结果可为病害诊断和防治提供理论依据。

关键词:月露瓜;果腐病;病原鉴定;伯氏镰刀菌;生物学特性;药剂筛选

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Identification, Biological characteristics and fungicide selection of the pathogen causing Yuelu melon *Fusarium* fruit rot in Guangdong

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Abstract:【Objective**】** The Yuelu melon is a premium melon variety. After being introduced and cultivated in limited quantities in Hainan, Fujian, and Guangdong provinces, it has demonstrated significant economic value. In 2025, a *Fusarium* fruit rot disease affecting Yuelu melon was discovered in Guangzhou, with an incidence rate ranging from 5% to 8%. The disease altered the aroma, flavor, and quality of the melon, thereby diminishing its nutritional and commercial value. During cultivation, symptoms were observed exclusively within the fruit, with no visible external manifestations, which significantly increased the challenges associated with disease detection and management. The study aimed to identi-

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fy the pathogen and elucidate its suitable growth conditions, including temperature, pH, light, as well as carbon and nitrogen sources. In addition, the toxicity of various fungicides to the pathogen was evaluated to assess their efficacy, thereby providing insights for effective disease control.【Methods】From April to June 2025, a survey was conducted to assess the incidence and severity of fruit rot in Yuelu melon at the Xiangfeng Special Fruit Industrial Park in Zengcheng District, Guangzhou City. Field symptoms were documented photographically. Diseased tissue samples were collected and, following surface disinfection, they were cultured on potato dextrose agar (PDA) at 26 ℃ for 3 days using the tissue isolation method. Mycelia from the margins of developing colonies were then transferred to PDA plates. Purified strains were obtained through single-spore isolation and stored at 4 ℃ for subsequent use. Pathogenicity was confirmed through two inoculation methods. The first involved mycelia inoculation: The mycelia surfaces of the tested strains were adhered to the puncture site of the melon fruits, with blank agar discs used as controls. The second method employed spore suspension inoculation: 100 μL of spore suspension (5×10^6 spores · mL^{-1}) was injected into the fruit from the tail end. All treated fruits were incubated at 26 ℃. Once softening or clear symptoms developed, the pathogens were isolated and purified again for verification in accordance with Koch's postulates. The strains were inoculated on potato dextrose agar (PDA), synthetic nutrient-poor agar (SNA), and carnation leaf agar (CLA) in the dark at 26 ℃ for 10 days. Mycelia, conidiophores, conidia attachment patterns, conidia and chlamydospores were observed under an optical microscope, and the size of conidiophores and conidia were measured (n=80). Genomic DNA was extracted from the tested strains, and the calmodulin (*CAM*), translation elongation factor 1-alpha (*EF1-α*), and the second largest subunit of RNA polymerase Ⅱ (*RPB2*) gene regions were amplified via PCR. The products were sequenced by Shanghai Sangon Biotech Co., Ltd. The resulting sequences were submitted to the NCBI database to obtain accession numbers. Concurrently, BLAST analyses were performed on NCBI to identify and retrieve sequences of closely related species from GenBank. Sequence alignment was conducted using Mega 7.0 software, followed by manual splicing of the aligned datasets. A phylogenetic tree was constructed using the concatenated sequences of *CAM*, *EF1-α*, and *RPB2* through the neighbor-joining method implemented in MEGA 7.0 to confirm species identification. Furthermore, the tested strains were cultured in an incubator under varying growth conditions, including temperature, pH, light intensity, carbon sources, and nitrogen sources, to determine the optimal culture environment for mycelia growth and spore production. Subsequently, to evaluate the sensitivity of the pathogen to various fungicides, eight commercial fungicides were tested. Mycelia discs were inoculated onto potato dextrose agar (PDA) plates supplemented with each fungicide at designated concentrations and incubated at 26 ℃. Colony diameters were measured after 5 days of incubation.【Results】The external appearance of diseased fruits showed no visible symptoms in the field. However, their tail ends felt soft to the press, and internal examination revealed brown, water-soaked rot, occasionally accompanied by a thin layer of white mold on the diseased areas. A total of 27 *Fusarium* spp. isolates with similar morphological characteristics were obtained. Pathogenicity tests revealed that artificial inoculation with strains YLG-4, YLG-13, and YLG-21 produced symptoms consistent with those observed under field conditions. On PDA medium, the colonies were initially white and later turned light yellow with cotton-like and abundant aerial mycelia. Conidiogenous cells were phialidic, 2.72 to 49.69 μm (n=80) on SNA medium and 3.63 to 52.65 μm (n=80) on CLA medium. Macroconidia were falcate, slightly curved, tapering apically with 1 to 5 septa, (17.45−46.78) μm×(2.62−4.93) μm (n=80) on SNA medium, (15.84−44.27) μm×(2.71−4.95) μm (n=80) on CLA medium, borne false heads from monophialides and polyphialides. Chlamydospores were spherical on both media. The *CAM, EF1-*

α, and *RPB2* gene fragments of strains YLG-4, YLG-13, and YLG-21 were amplified and sequenced, producing fragments approximately 550 bp, 840 bp, and 600 bp in length, respectively. BLAST analysis against the GenBank database showed that the nucleotide sequences of the *CAM*, *EF1-α* and *RPB2* regions from these strains shared 99.29% to 100% identity with corresponding sequences of *Fusarium pernambucanum* strains CBS 791.70, CBS 132194, CBS 132894, and CBS 133024. A phylogenetic tree was constructed based on the concatenated sequences of *CAM*, *EF1-α*, and *RPB2* using the neighbor-joining method, which demonstrated that YLG-4, YLG-13, and YLG-21 form a cluster with *F. pernambucanum*. Integrating morphological characteristics and molecular evidence, strains YLG-4, YLG-13, and YLG-21 were identified as *F. pernambucanum.* The optimal temperature range for mycelia growth of strain YLG-13 was 24−30 ℃, with the most rapid colony expansion observed at 26−28 ℃ and the highest conidia production occurring at 30 ℃. Mycelia growth was favorable within a pH range of 5−10, with an optimum at pH 7−9. Light promoted mycelia development. Carbon sources such as glucose and soluble starch, as well as organic nitrogen sources including tryptone, beef extract powder, and yeast extract, were found to enhance both mycelia growth and spore production in YLG-13. Among the eight fungicides tested, all exhibited varying degrees of inhibition on mycelia growth. Fludioxonil showed the strongest inhibitory effect, with an EC_{50} value of 0.014 7 mg·L^{-1}, followed by prochloraz, which had an EC_{50} value of 0.637 3 mg·L^{-1}.【Conclusion】In this study, the causal agent of fruit rot in Yuelu melon was identified as *Fusarium pernambucanum* through pathogenicity tests, morphological characterization, and multi-locus phylogenetic analysis based on the *CAM*, *EF1-α*, and *RPB2* gene regions. The pathogen showed adaptation to relatively high temperatures and neutral to alkaline conditions. Fungicide assays revealed that fludioxonil and prochloraz exhibited the strongest antifungal activity, suggesting their potential as effective agents for disease control. These findings offer a theoretical foundation for diagnosing and managing this disease.

Key words: Yuelu melon; Fruit rot; Pathogen identification; *Fusarium pernambucanum*; Biological characteristics; Fungicide selection

月露瓜（*Cucumis melo* L.）原产于日本，是光皮甜瓜的一种，因其浅色果皮上点缀着深色斑点而被命名，口感软糯细腻，是高档甜瓜品种。目前，在海南、福建和广东等地少量引入种植，获得较高的经济价值。但随着种植年限的增加，病害种类也逐年增加。其中，镰刀菌果腐病在栽培期和采后期均可发生，可改变甜瓜的气味、风味、品质等，从而降低其营养和商业价值[1]。已报道能侵染甜瓜并引起果腐的镰刀菌种类包括砖红镰刀菌（*Fusarium lateritium*）[2]、木贼镰刀菌（*Fusarium equiseti*）[3]、变红-木贼镰刀菌复合种群（*Fusarium incarnatum-equiseti* species complex）[4]、变红镰刀菌（*Fusarium incarnatum*）[5-6]、层出镰刀菌（*Fusarium proliferatum*）[7]、*Fusarium luffae*[8]、亚洲镰刀菌（*Fusarium asiaticum*）[9]、苏拉威西镰刀菌（*Fusarium sulawesiense*）[10]、*Fusarium nanum* [11]、厚垣镰刀菌（*Fusarium chlamydosporum*）[12] 和 *Fusarium ipomoeae* 等[13]。De Almeida Nogueira 等[1]利用巴西当地的5种优势镰刀菌（*Fusarium falciforme*、*F. sulawesiense*、*F. pernambucanum*、*Fusarium kalimantanense* 和 *Fusarium* sp.）刺伤接种4种甜瓜品种，结果显示5种镰刀菌均可导致不同甜瓜品种果实腐烂，表明随着研究的深入，将鉴定出更多能侵染甜瓜果实的镰刀菌种。

2025年4—6月，在广州市增城区乡丰特色水果产业园进行病害调查，发现月露瓜果腐病发生危害，发生率为5%~8%。与以往文献报道镰刀菌[5-7]、青霉菌[14]和丝核菌[15]等病原侵染甜瓜后，果腐症状先从外部表现不同，在月露瓜种植过程中，果腐从内部开始，采摘时外观无症状，这明显增加了防治难度。本研究采用组织分离法分离病原菌，通过柯赫氏法则验证其致病性；基于形态特征和系统发育分析鉴定病原菌，测定其生物学特性；明确病原菌对常用药剂的敏感性，旨在为病害诊断和防治提供理论依据。

1 材料和方法

1.1 病害样品的采集及菌株分离

2025年4—6月，在广州市增城区乡丰特色水果产业园（113.827 8° E，23.291 0° N）分3次进行调查，每次调查100个月露瓜，按压果实尾部，若感觉组织发软，则纵切观察果实内部是否发病，计算果腐病发生率，拍照记录田间病状。从病果病健交界处切取组织样本（3 mm×3 mm），通过常规组织分离法，表面消毒后接种至马铃薯葡萄糖琼脂（potato dextrose agar，PDA）上[16]，26 ℃黑暗培养3 d，挑取菌落边缘菌丝接种至PDA平板，26 ℃培养至产生孢子，单孢分离后获得纯化菌株，4 ℃保存备用。

1.2 分离菌株致病性测定

选择无病害、未成熟的月露瓜果实，用2% NaClO溶液浸泡2 min，无菌水冲洗、晾干。采用2种接种方法：一是菌丝块接种：使用无菌接种针刺伤果实，将供试菌株菌丝面贴覆于果实刺伤处，以空白琼脂块刺伤接种作为对照；另外，将供试菌株菌丝面贴覆于无伤甜瓜果实，以空白琼脂块无伤接种作为对照。每次处理3个果实，每个果实为2个接种点，3次重复，接种后使用灭菌脱脂棉蘸取无菌水进行保湿。二是孢子悬浮液接种：使用无菌水制备5×10^6个·mL^{-1}供试菌株孢子悬浮液，用微型注射器将100 μL悬浮液从果实尾部注入，每次处理3个果实，以注射无菌水作为对照，3次重复。各处理均在26 ℃保湿培养，观察并记录发病情况，果实按压变软或出现明显症状后，再次分离并纯化病原菌，进行柯赫氏法则验证。

1.3 病原菌形态观察

将供试菌株接种至PDA平板上，26 ℃黑暗培养，每天观察并记录菌落直径、形态和颜色变化；另接种至低营养合成琼脂（synthetic nutrient-poor agar，SNA）[17]和康乃馨叶片琼脂（carnation leaf agar，CLA）[18]上，26 ℃黑暗培养10 d，制片，在光学显微镜下观察并拍照记录病原菌菌丝、分生孢子梗、分生孢子着生方式、分生孢子和厚垣孢子形态，同时测量分生孢子梗长度（n=80）和分生孢子大小（n=80）。

1.4 病原菌的系统发育分析

供试菌株接种于马铃薯葡萄糖培养液中，26 ℃、150 r·min^{-1}振荡培养3 d，收集菌丝，用真菌基因组DNA抽提试剂盒提取基因组DNA，使用引物CL1[5′- GA(GA)T(AT)CAAGGAGGCCTTCTC- 3′]/CL2（5′-TTTTTGCATCATGAGTTGGAC-3′）、TEF1[5′- ATGGGTAAGGA(A/G)GACAAGAC- 3′]/TEF2[5′-GGA(G/A)GTACCAGT(G/C)ATCATGTT-3′]、5F2（5′- GGGGWGAYCAGAAGAAGGC- 3′）/7cR（5′-CCCATRGCTTGYTTRCCCAT-3′）分别扩增钙调蛋白（*CAM*）[19]、转录延伸因子（*EF1-α*）[20]和RNA聚合酶Ⅱ第二大亚基（*RPB2*）基因[21]部分序列。20 μL反应体系：100 ng·μL^{-1} DNA模板1 μL、50 μmol·L^{-1}正向反向引物各1 μL、2×PCR Mix预混液8.5 μL、ddH_2O 8.5 μL。反应程序：94 ℃预变性3 min，94 ℃变性30 s，55 ℃退火30 s，72 ℃延伸1 min，34个循环，72 ℃延伸10 min，扩增产物纯化后送至生工生物工程（上海）股份有限公司测序。将相关序列提交至NCBI，获得登录号。同时，在NCBI上进行BLAST比对，提取GenBank中近缘种序列，用Mega 7.0软件进行序列比对后拼接。采用邻接法（neighbor joining，NJ）构建基于*CAM*、*EF1-α*和*RPB2*序列的多基因系统发育进化树，确定供试菌株的分类地位，系统发育树各个分支的支持强度通过1000次重复自展检验数值进行评估。

1.5 温度、pH值、光照对病原菌菌丝生长和产孢量的影响

温度：制备PDA平板，接种供试菌株菌丝块（d = 6 mm），设置15、20、22、24、26、28、30、32、34和37 ℃共10个温度梯度，放入培养箱黑暗培养。

pH值：将PDA培养基灭菌后冷却至约45 ℃，在无菌条件下，使用HCl和NaOH溶液分别调节培养基pH至3、4、5、6、7、8、9、10、11，制成平板，接入同上菌丝块，26 ℃黑暗培养。

光照：制备PDA平板，接入同上菌丝块，分别置于全光照、全黑暗及12 h光暗交替条件下，26 ℃培养。光照条件为5 W LED灯管，平板与灯管距离为30 cm。

以上每次处理设置3个平板，3次重复，培养5 d后，采用十字交叉法测量菌落直径。培养10 d后，在平板中加入10 mL无菌水，用涂布棒轻轻刮下分生孢子，混合均匀制成悬浮液，用血球计数板测定分生孢子量[16]。

1.6 不同碳源对病原菌菌丝生长和产孢量的影响

以查彼（Czapek）琼脂为基础培养基[16]，将碳源

蔗糖分别用葡萄糖、蔗糖、麦芽糖、木糖、可溶性淀粉、甘露糖、山梨醇和甘油替代，制备不同碳源培养基，以无碳源为对照。灭菌制成平板，接入同上菌丝块，每处理3个平板，3次重复，26 ℃黑暗培养6 d，观察菌落形态，同上测量菌落直径。培养10 d，同上测定分生孢子量。

1.7　不同氮源对病原菌菌丝生长和产孢量的影响

以Czapek琼脂为基础培养基，将氮源硝酸钠分别用蛋白胨、牛肉浸粉、酵母膏、硝酸钠、硫酸铵、天门冬酰胺、酪氨酸和尿素替代，制成不同氮源培养基，以无氮源为对照。灭菌后制成平板，接入同上菌丝块，每处理3个平板，3次重复，26 ℃黑暗培养6 d，观察菌落形态，同上测量菌落直径。培养10 d，同上测定分生孢子量。

1.8　不同杀菌剂对病原菌的抑制效果

采用菌丝生长抑制法，经预备试验确定各供试杀菌剂浓度范围，使用无菌水将杀菌剂进行梯度稀释。吸取1 mL药液加入49 mL PDA培养基（45 ℃）中，混合均匀，使杀菌剂浓度为试验所需系列浓度，平均倒入3个平皿，制成含药平板，接入菌丝块，以无菌水为对照，3次重复。26 ℃培养5 d后，用十字交叉法测量菌落直径，计算药剂抑制率，使用DPS 19.05软件计算线性回归方程及相关参数。表1为供试药剂及处理浓度。

表1　供试药剂及其有效成分处理浓度

Table 1　Tested fungicides and their treatment concentration of active ingredient

杀菌剂 Fungicide	生产厂家 Manufacturer	有效成分处理浓度 Treatment concentration of active ingredient/（mg·L^{-1}）
50%咯菌腈可湿性粉剂 50% fludioxonil WP	先正达（苏州）作物保护有限公司 Syngenta Suzhou Crop Protection Co., Ltd	0，0.001，0.005，0.01，0.05，0.1
30%噁霉灵水剂 30% hymexazol AS	四川润尔科技有限公司 Sichuan Runer Technology Co., Ltd.	0，0.01，0.1，1，10，100
10%苯醚甲环唑水分散粒剂 10% difenoconazole WG	先正达（南通）作物保护有限公司 Syngenta Nantong Crop Protection Co., Ltd	0，0.01，0.1，1，10，100
15%咪鲜胺微乳剂 15% prochloraz ME	海南博士威农化学有限公司 Hainan Borui Agrochemical Co., Ltd.	0，0.05，0.1，0.5，1，5
50%福美双可湿性粉剂 50% Thiram WP	河北冠龙农化有限公司 Hebei Guanlong Agrochemical Co., Ltd.	0，0.5，1，5，10，50
25%吡唑醚菌酯悬浮剂 25% pyraclostrobin SC	浙江中山化工集团股份有限公司 Zhejiang Zhongshan Chemical Group Stock Co., Ltd.	0，5，10，50，100，500
430 g·L^{-1}戊唑醇悬浮剂 430 g·L^{-1} tebuconazole SC	拜耳股份公司 Bayer, A. G	0，0.1，0.5，1，5，10
50%多菌灵可湿性粉剂 50% carbendazim WP	河北冠龙农化有限公司 Hebei Guanlong Agrochemical Co., Ltd.	0，1，5，10，50，100

1.9　数据处理与统计分析

使用Excel 2010软件对试验数据进行整理和绘图，使用DPS软件进行数据统计，采用Duncan多重比较法进行差异显著性检验（$P<0.05$）。

2　结果与分析

2.1　月露瓜果腐病症状

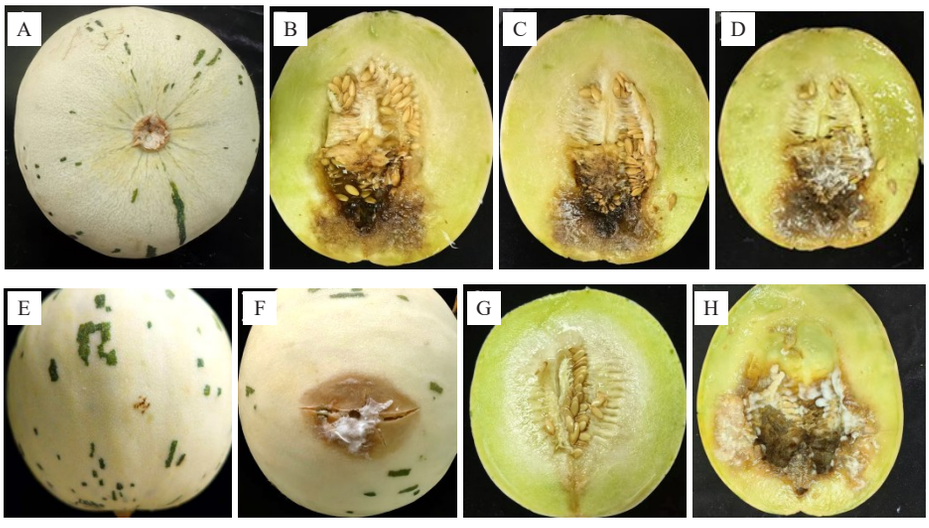
田间病害调查发现，5月中下旬月露瓜开始采收时，田间病果外观与健康果实一致，无明显果腐症状（图1-A），但按压病果尾部时会感觉发软，切开后可见果实尾部呈褐色水渍状腐烂（图1-B），发病部位有时出现稀薄白色霉层（图1-C~D）。在月露瓜种植过程中，田间病果外部不表现果腐症状，易错失最佳防治时机。3次调查显示，月露瓜的果腐病发病率分别是5%、6%和8%。

2.2　菌株分离

共采集8个病果样本分离病原菌，获得27株形态特征相似的真菌菌株。经菌株*EF-1α*序列的PCR扩增和测序比对，显示27株真菌均为镰刀菌，编号为YLG-1~YLG-27。随机选择菌株YLG-4、YLG-13和YLG-21进行形态特征描述、致病力测定和系统发育分析，选择YLG-13进行生物学特性研究和药剂筛选试验。

2.3　分离菌株致病性测定

刺伤接种时，对照果实未表现症状（图1-E），接种供试菌株菌丝块3 d，月露瓜果实出现水渍状腐烂病斑，继续保湿，病斑变大，发病部位出现白色菌丝（图1-F）。菌丝块无伤接种时，果实不发病。注射接



A. 病果外观；B. 病果内部；C. 病果内部；D. 病果内部；E. 空白琼脂块刺伤接种症状；F. 菌丝块刺伤接种症状；G. 无菌水注射接种症状；H. 孢子悬浮液注射接种症状。

A. The appearance of diseased fruit; B. The inside of the diseased fruit; C.The inside of the diseased fruit; D. The inside of the diseased fruit; E. Symptoms of wound inoculation with blank agar plugs; F. Symptoms of wound inoculation with mycelia plugs; G. Symptoms of inoculation by injection with sterile water; H. Symptoms of inoculation by injection with conidia suspension.

图1 月露瓜果腐病的田间及接种症状

Fig. 1 The field and inoculation symptoms of fruit rot on Yuelu melon

种时，对照果实内部未表现症状（图1-G）；接种供试菌株孢子悬浮液7 d，月露瓜果实外部无症状，切开后可见内部呈褐色水渍状腐烂，继续保湿，病斑处迅速长出大量白色菌丝（图1-H），发病症状与田间基本一致。从病果上再次分离获得的菌株与原接种菌株形态一致，符合柯赫氏法则。

2.4 病原菌形态特征

菌株YLG-4、YLG-13和YLG-21形态特征相似，在PDA培养基上，菌落初期为白色，后期转为淡黄色，气生菌丝棉絮状、丰富，菌落背面米黄色（图2-A~B），26 ℃黑暗培养，生长速度为10.2~13.5 mm·d^{-1}。

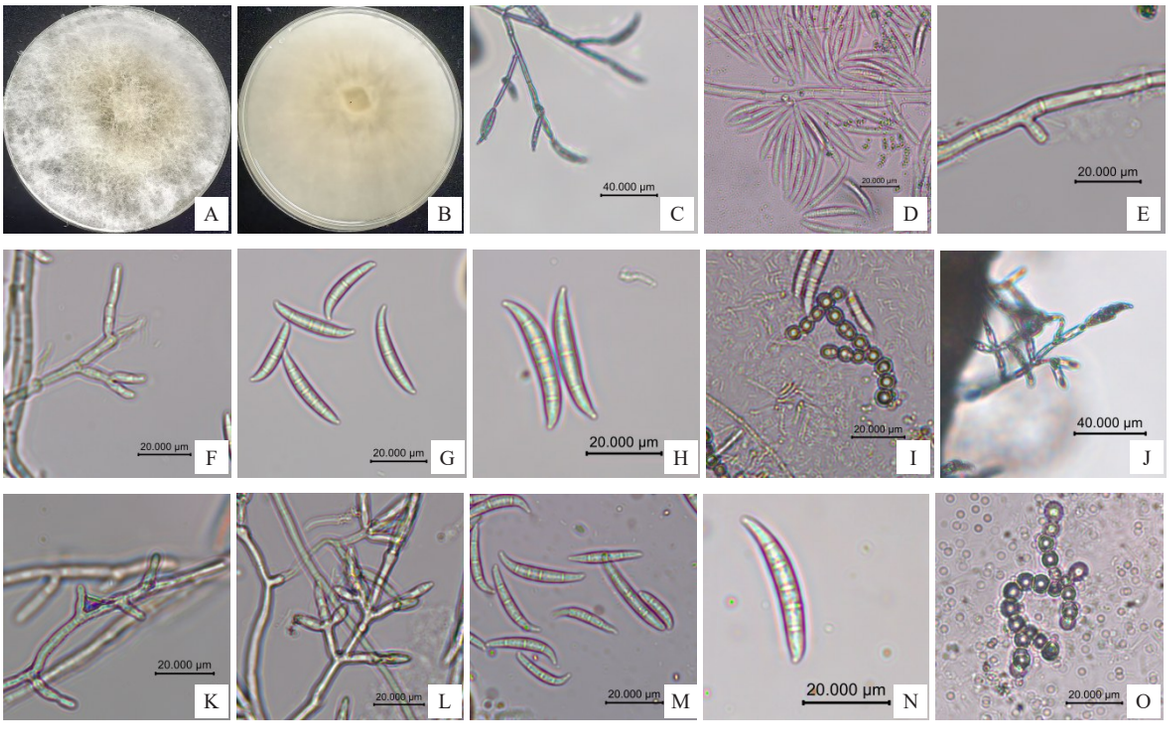
在SNA培养基上，病原菌分生孢子在产孢细胞顶端聚集成假头状（图2-C~D），产孢细胞瓶梗状，单生（图2-E）或复生（图2-F），长度为2.72~49.69 μm（*n*=80），大型分生孢子镰刀形，顶端渐尖稍弯曲，足跟明显，1~5个分隔，大小为（17.45~46.78）μm×（2.62~4.93）μm（*n*=80，图2-G~H），未见小型分生孢子。厚垣孢子球形，多呈链状（图2-I）。

在CLA培养基上，使用灭菌刀片自培养基内康乃馨叶片上刮取少量菌丝体和黏孢团，进行制片观察，病原菌分生孢子在产孢细胞顶端聚集成假头状（图2-J），产孢细胞瓶梗状，单生（图2-K）或复生（图2-L），长度为3.63~52.65 μm（*n*=80），大型分生孢子镰刀形，顶端渐尖稍弯曲，足跟明显，1~5个分隔，大小为（15.84~44.27）μm×（2.71~4.95）μm（*n*=80，图2-M~N）。未见小型分生孢子。厚垣孢子球形，多呈链状（图2-O）。

月露瓜果腐病菌在SNA和CLA两种镰刀菌鉴定培养基上的形态特征基本一致，与相关文献对比发现，该病原菌的菌落形态颜色、孢子着生方式、产孢细胞形态及长度、分生孢子形态大小等特征，与Da Silva Santos等[22]报道的伯氏镰刀菌（*Fusarium pernambucanum*）极为相似。

2.5 病原菌的系统发育分析

使用特异性引物扩增菌株YLG-4、YLG-13和YLG-21的*CAM*、*EF-1α*和*RPB2*部分基因，分别获得约550、840和600 bp条带，并在GenBank获得登录号（表2）。将相关基因序列在GenBank上进行比对，3个菌株的*CAM*、*EF-1α*和*RPB2*序列与*F. pernambucanum*模式菌株CBS 791.70、CBS 132194、CBS 132894和CBS 133024对应基因序列一致率为99.29%~100%。下载*Fusarium*属内近缘种的相关基因序列，联合*CAM*、*EF-1α*和*RPB2*基因片段构建系统发育树。聚类分析结果（图3）显示，YLG-4、YLG-13和YLG-21与*F. pernambucanum*的4个模式



A. PDA 上菌落正面；B. PDA 上菌落背面；C、D. SNA 上分生孢子着生方式；E、F. SNA 上分生孢子梗；G、H. SNA 上大型分生孢子；I. SNA 上厚垣孢子；J. CLA 上分生孢子着生方式；K、L. CLA 上分生孢子梗；；M、N. CLA 上大型分生孢子；O. CLA 上厚垣孢子。

A. Colony on the above of PDA; B. Colony on the back of PDA; C, D. The mode of conidial attachment on SNA; E, F. Conidiophores on SNA; G, H. Macroconidia on SNA; I. Chlamydospore on SNA; J. The mode of conidial attachment on CLA; K, L. Conidiophores on CLA; M, N. Macroconidia on CLA; O. Chlamydospore on CLA.

图 2　月露瓜果腐菌的形态特征

Fig. 2　Morphological characteristics of fruit rot pathogen on Yuelu melon

菌株聚为一个独立分支，与近缘种 *F. sulawesiense* 明确区分，与 *F. incarnatum* 亲缘关系相对较远。结合形态学特征，将广东月露瓜果腐菌鉴定为伯氏镰刀菌（*F. pernambucanum*）。

2.6　温度、pH 和光照对病原菌菌丝生长和产孢量的影响

在 15 ℃时，病原菌生长缓慢，37 ℃时停止生长。菌丝生长的适宜温度为 24~30 ℃，其中 26~28 ℃时病原菌生长最快，30 ℃时产孢量最大（图 4-A），表明病原菌适宜在相对较高温度下生长和产孢。

当 pH=3~11 时，病原菌均可生长；pH=5~10 时，菌丝生长良好；pH=7~9 最为适宜。产孢量的变化趋势与菌丝生长基本一致（图 4-B），表明病原菌在酸性、中性和碱性环境下均能生长，尤其适宜中性至偏碱性环境。

在全光照、12 h 光暗交替和全黑暗处理下，病原菌均能正常生长和产孢。全光照条件下，病原菌菌落直径为 54.83 mm，显著高于 12 h 光暗交替和全黑暗处理；3 种处理下的产孢量无显著差异（图 4-C），表明光照利于菌丝生长。

2.7　不同碳源对病原菌菌丝生长和产孢量的影响

在无碳对照培养基上，病原菌菌丝能够生长，但菌落极稀疏；培养 10 d 后，菌落可产生孢子，产孢量达 4.81×10^6 个•mL^{-1}。当葡萄糖、可溶性淀粉和蔗糖为碳源时，菌丝生长速度最快，26 ℃黑暗培养 6 d，菌落直径达 63 mm 及以上，优于其他碳源，且菌落浓密。葡萄糖、山梨醇和可溶性淀粉利于孢子产生，产孢量均在 10×10^6 个•mL^{-1} 以上（表 3）。

2.8　不同氮源对病原菌菌丝生长和产孢量的影响

在无氮对照培养基上，病原菌菌丝能够生长，但菌落极稀疏，产孢量极少。有机氮源蛋白胨、牛肉浸粉和酵母膏利于菌丝生长和产孢，培养 6 d，菌落直径均在 68.00 mm 以上，且菌落极浓密；培养 10 d，产孢量在 6.50×10^6 个•mL^{-1} 以上。硫酸铵则不利于菌丝生长和产孢（表 4）。

表2 本研究使用的菌株及其GenBank登录号

Table 2 Strains used in this study and their GenBank accession numbers

种 Species	菌株 Strains	GenBank登录号 GenBank accession number		
		CaM	EF-1α	RPB2
供试菌株 Tested strains	YLG-4	PV995081	PV995083	PV995082
	YLG-13	PV995084	PV995086	PV995085
	YLG-21	PV995087	PV995089	PV995088
Fusarium bubalinum	CBS 161.25	MN170314	MN170448	MN170381
Fusarium caatingaense	CBS 976.97	MN170315	MN170449	MN170382
Fusarium camptoceras	CBS 193.65	MN170316	MN170450	MN170383
Fusarium chlamydosporum	CBS 145.25	MN120695	MN120754	MN120735
Fusarium clavum	CBS 131787	MN170327	MN170461	MN170394
Fusarium clavum	CBS 140912	MN170328	MN170462	MN170395
Fusarium coffeatum	CBS 430.81	MN120697	MN120756	MN120737
Fusarium equiseti	CBS 185.34	MN170332	MN170466	MN170399
Fusarium equiseti	CBS 414.86	MN170333	MN170467	MN170400
Fusarium equiseti	CBS 119663	MN170334	MN170468	MN170401
Fusarium incarnatum	CBS 132.73	MN170342	MN170476	MN170409
Fusarium incarnatum	CBS 132907	MN170343	MN170477	MN170410
Fusarium incarnatum	NRRL 13379	GQ505503	GQ505591	GQ505769
Fusarium incarnatum	NRRL 32866	GQ505527	GQ505615	GQ505793
Fusarium irregulare	CBS 132190	MN170346	MN170480	MN170413
Fusarium irregulare	NRRL 34011	GQ505546	GQ505634	GQ505812
Fusarium luffae	CBS 131097	MN170348	MN170482	MN170415
Fusarium luffae	NRRL 32522	GQ505524	GQ505612	GQ505790
Fusarium multiceps	NRRL 43639	GQ505577	GQ505666	GQ505844
Fusarium pernambucanum	CBS 791.70	MN170357	MN170491	MN170424
Fusarium pernambucanum	CBS 132194	MN170358	MN170492	MN170425
Fusarium pernambucanum	CBS 132894	MN170359	MN170493	MN170426
Fusarium pernambucanum	CBS 133024	MN170360	MN170494	MN170427
Fusarium sulawesiense	CBS 131.73	MN170366	MN170500	MN170433
Fusarium sulawesiense	CBS 163.57	MN170367	MN170501	MN170434
Fusarium sulawesiense	CBS 193.60	MN170368	MN170502	MN170435
Fusarium sulawesiense	CBS 622.87	MN170369	MN170503	MN170436
Fusarium sulawesiense	CBS 122439	MN170370	MN170504	MN170437

2.9 不同杀菌剂对病原菌的毒力测定

8种杀菌剂对月露瓜果腐菌菌丝生长均有一定的抑制作用。其中，咯菌腈的抑菌作用最强，对YLG-13的EC_{50}为0.014 7 mg·L^{-1}；其次是咪鲜胺，EC_{50}为0.637 3 mg·L^{-1}；戊唑醇、噁霉灵、苯醚甲环唑、福美双和多菌灵的抑菌作用一般，EC_{50}位于1~50 mg·L^{-1}之间；吡唑醚菌酯的抑菌作用最差，EC_{50}高达160.111 2 mg·L^{-1}（表5）。

3 讨 论

*F. pernambucanum*是变红-木贼镰刀菌复合群（*F. incarnatum-equiseti* species complex，FIESC）的成员之一[23-24]，可危害多种果树。如侵染百香果引起花朵干枯[25]、侵染李[26]和芒果[27]引起叶斑、侵染荔枝引起僵果[28]、侵染葡萄[29]和香蕉[30]引起花梗腐烂、侵染木瓜引起根茎腐病[31]等，可见该镰刀菌种是一类重要的植物病原真菌。FIESC的成员致病力相对较弱或是次生侵入菌[32-33]，研究表明*F. pernambucanum*需要借助伤口才能侵入寄主。如Guo等[27]报道在芒果叶片表面存在伤口时，该菌才能入侵造成叶斑；王伟博等[28]证实，荔枝果实表面在农事操作，大风导致机械摩擦损伤以及荔枝蝽危害等方式造成伤口时，*F. pernambucanum*才能入侵致病，若果皮无伤口则不致病。以往报道表明，多种镰刀菌种类可侵染甜瓜并引

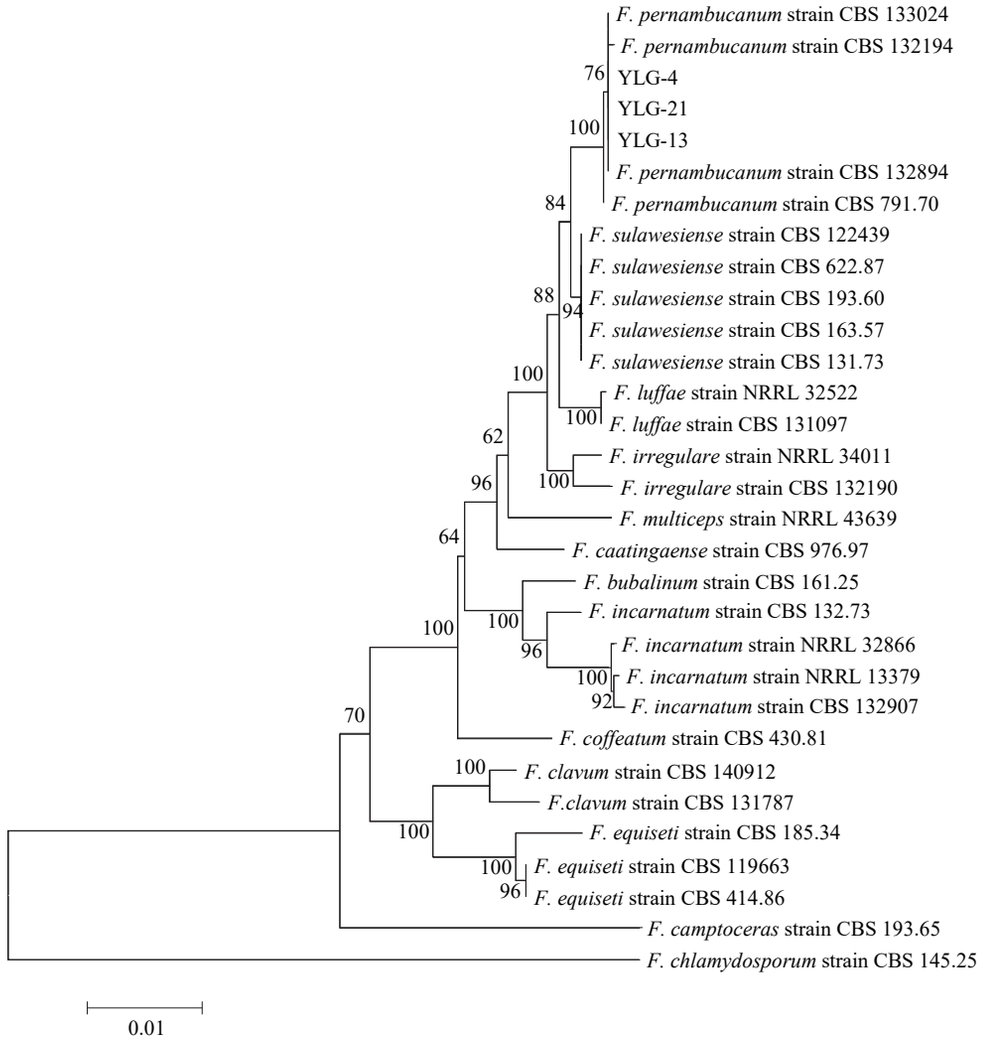
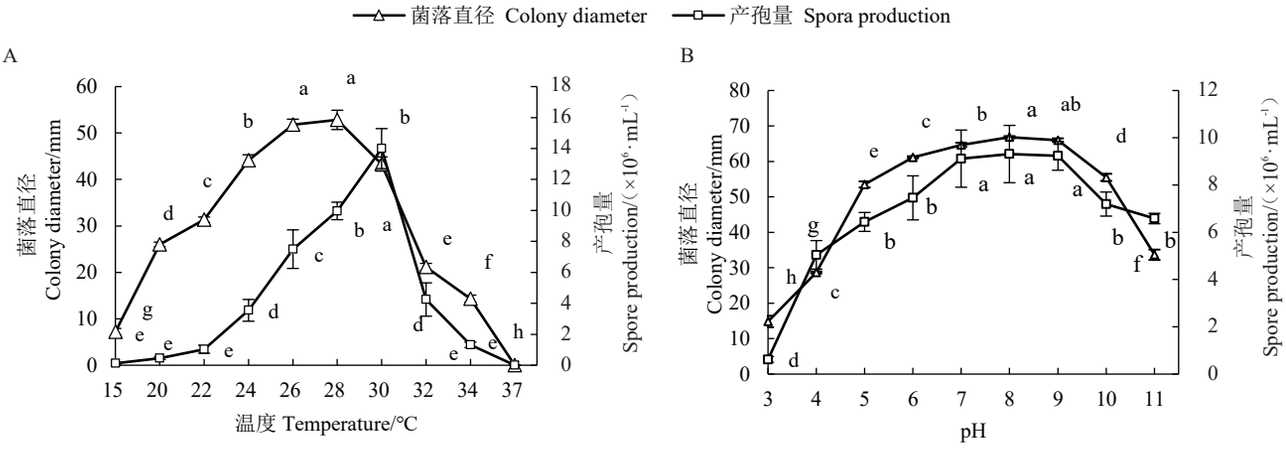


图 3　基于 *CAM*、*EF-1α* 和 *RPB2* 基因序列构建的系统发育树

Fig. 3　Phylogenetic tree based on sequences of *CAM*, *EF-1α* and *RPB2* genes



不同小写字母表示在 $P<0.05$ 差异显著。

Different small letters indicate significant difference at $P<0.05$.

图 4　温度（A）、pH（B）和光照（C）对月露瓜果腐菌菌丝生长和产孢量的影响

Fig. 4　Effect of temperature (A), pH (B) and light (C) on mycelia growth and spore production of *F. pernambucanum*

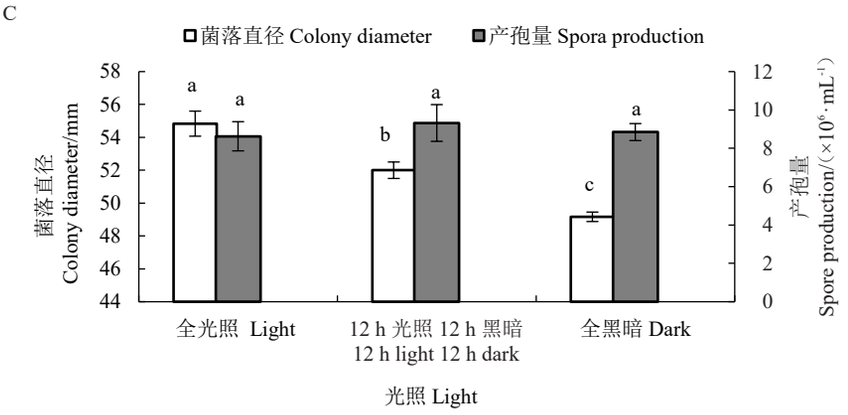


图 4 （续） Fig. 4 (Continued)

表 3 不同碳源对月露瓜果腐菌菌丝生长和产孢量的影响

Table 3 The effect of different carbon sources on mycelia growth and spore production of *F. pernambucanum*

碳源 Carbon sources	菌落直径 Colony diameter/mm	产孢量 Spore production/(×10⁶·mL⁻¹)	菌落形态 Colony morphology
葡萄糖 Glucose	65.17±0.29 a	12.68±0.44 a	浓密 Thick
蔗糖 Sucrose	63.00±1.50 a	5.92±0.18 d	浓密 Thick
麦芽糖 Maltose	54.33±2.52 b	7.59±1.38 c	浓密 Thick
木糖 Xylose	53.00±1.80 bc	3.44±1.11 e	稀薄 Sparse
可溶性淀粉 Soluble starch	64.33±1.04 a	10.62±0.96 b	浓密 Thick
甘露糖 Mannitol	50.83±1.04 c	9.02±1.11 c	稀薄 Sparse
山梨醇 Sorbitol	54.50±2.00 b	11.07±0.59 b	稀薄 Sparse
甘油 Glycerol	54.17±1.15 b	8.87±0.95 c	稀薄 Sparse
无碳 No carbon	54.50±1.73 b	4.81±0.47 de	极稀薄 Very sparse

注：同栏不同小写字母表示在 $P<0.05$ 差异显著。下同。

Note: Different small letters in the same column indicate significant difference at $P<0.05$. The same below.

表 4 不同氮源对月露瓜果腐菌菌丝生长和产孢量的影响

Table 4 The effect of different nitrogen sources on mycelia growth and spore production of *F. pernambucanum*

氮源 Nitrogen sources	菌落直径 Colony diameter/mm	产孢量 Spore production/(×10⁶·mL⁻¹)	菌落形态 Colony morphology
蛋白胨 Tryptone	73.33±0.29 a	6.53±1.83 bc	极浓密 Very thick
牛肉浸粉 Beef extract powder	73.67±1.44 a	7.25±0.79 b	极浓密 Very thick
酵母膏 Yeast extract	68.17±1.53 b	9.67±0.76 a	极浓密 Very thick
硝酸钠 $NaNO_3$	63.33±2.57 c	5.57±0.73 c	浓密 Thick
硫酸铵 $(NH4)_2SO_4$	14.50±1.32 g	0.20±0.11 e	浓密 Thick
天门冬酰胺 Asparagine	42.17±1.53 e	2.95±0.37 d	浓密 Thick
酪氨酸 Tyrosine	50.67±1.04 d	3.73±0.89 d	浓密 Thick
尿素 Urea	29.00±1.00 f	1.50±0.37 e	稀薄 Sparse
无氮 No nitrogen	49.50±2.18 d	0.18±0.14 e	极稀薄 Very sparse

起果腐，但均从果实外部伤口侵染并开始发病，再逐步向内扩展[6-8]。而 *F. pernambucanum* 侵染月露瓜时，病原菌先在果实内部引起发黑腐烂，再由内向外扩展；田间调查发现，至采收时，果实外部仍未表现果腐症状。致病性试验证实，果实无伤口时，*F. pernambucanum* 不能侵染月露瓜，表明病原菌不是从外部伤口侵入，且内部果腐症状集中在果实尾端。推测该病与火龙果心腐病相似[34]，病原菌的初始侵染点可能是雌花柱头，病菌孢子可直接或通过花粉携带定殖于雌花柱头，随着授粉授精、果实发育，先引

表5　不同杀菌剂对月露瓜果腐菌的毒力测定

Table 5　Toxicity of different fungicides to *F. pernambucanum*

杀菌剂 Fungicide	毒力方程 Toxic regression equation	相关系数 Correlation coefficient，R^2	抑制中浓度 EC_{50}/（mg·L^{-1}）	95% 置信区间 95% confidence interval
咯菌腈 Fludioxonil	y=6.726 6+0.942 2x	0.975 0	0.014 7	0.010 4~0.020 8
噁霉灵 Hymexazol	y=4.467 8+0.692 8x	0.983 0	5.863 9	3.221 2~10.697 0
苯醚甲环唑 DIfenoconazole	y=4.412 8+0.528 3x	0.986 9	12.927 4	5.559 0~30.062 1
咪鲜胺 Prochloraz	y=5.139 9+0.714 9x	0.994 7	0.637 3	0.401 5~1.011 4
福美双 Thiram	y=3.980 5+1.029 6x	0.993 9	9.776 5	6.784 2~14.088 6
吡唑醚菌酯 Pyraclostrobin	y=3.390 6+0.730 1x	0.994 4	160.111 2	89.982 5~284.894 9
戊唑醇 Tebuconazole	y=4.698 2+0.911 5x	0.998 2	2.143 4	1.458 5~3.150 0
多菌灵 Carbendazim	y=3.651 7+0.820 0x	0.996 6	44.076 1	26.385 9~73.626 4

起内部发黑腐烂，再由内向外扩展。明确病原菌的初始侵染点和初始侵染时期，对该病的防治具有重要意义。

Da Silva Santos 等[22]从昆虫上分离得到FIESC的真菌，通过形态学和分子生物学特征，建立新种 *F. pernambucanum*。Cao 等[4]从外部腐烂的甜瓜上分离得到一株致病真菌，鉴定为FIESC的成员，但未明确到种。Hao 等[35]以研究简报的形式报道了 *F. pernambucanum* 可侵染甜瓜并引起果腐，其病状表现在甜瓜外部，与本研究的月露瓜果腐症状明显不同，且未针对该病菌进行生物学特性研究和防治药剂筛选。*F. pernambucanum* 定种时间较短，相关研究多集中于病原菌鉴定方面，至今尚无该菌在其他寄主上的生物学特性研究和防治药剂筛选的报道。但FIESC群内其他成员的相关研究仍具有一定的参考价值。如哈密瓜果腐菌 *F. incarnatum* 在25~30 ℃、pH为7~9范围内生长较好[6]。苜蓿根腐菌 *F. ipomoeae* 适宜生长温度为25~30 ℃，适宜pH值为6~10[36]。唐健林等[37]报道当温度为25~30 ℃、pH值为7~11时，利于黄蜀葵枯萎病菌 *F. equiseti* 的菌丝生长。本研究发现 *F. pernambucanum* 在24~30 ℃、pH值为5~10范围内生长良好；在26~28 ℃时菌丝生长最快；在30 ℃时产孢量最大；pH值为7~9时最适宜菌丝生长和产孢；光照促进菌丝生长，表明 *F. pernambucanum* 的生物学特性与FIESC群内其他成员相似，均适宜较高的生长温度和中性至稍偏碱性环境。广州市增城区乡丰特色水果产业园采用设施种植模式，所用基质有机物含量丰富，pH中性，适宜病原菌生长。月露瓜于2月初在大棚内种植，3月初开花并准备授粉。广州3月气温在10~30 ℃之间，而病原菌在15~34 ℃范围内均可生长和产孢。因此，灌溉时土壤中病原菌孢子可通过水滴溅射到雌花柱头上并定殖，随着授粉受精、果实发育进入果实内部。4—5月，平均气温上升至28 ℃，利于病原菌生长，*F. pernambucanum* 可在果实内部迅速增殖并造成果腐。可见，该病原菌较好地适应了种植区的环境条件。本研究选择可普遍抑制多种镰刀菌的8种杀菌剂进行毒力测定，发现咯菌腈和咪鲜胺对 *F. pernambucanum* 抑制作用最强，EC_{50} 分别为0.014 7和0.637 3 mg·L^{-1}。杜莉芳等[6]报道50%咪鲜胺锰盐可湿性粉的质量分数为0.025%时能完全抑制FIESC群内 *F. incarnatum* 生长；唐健林等和敖显禧等的研究表明咪鲜胺对 *F. equiseti* 的抑制效果较好，EC_{50} 分别为0.071 2 mg·L^{-1}和0.000 6 mg·L^{-1}[37-38]；董文志等[39]测定精甲•咯菌腈对 *F. equiseti* 的 EC_{50} 为1.809 mg·L^{-1}；索欣等[36]报道咯菌腈对FIESC群内 *F. ipomoeae* 的抑制效果 EC_{50} 为0.142 mg·L^{-1}。综上所述，咯菌腈和咪鲜胺对FIESC群内成员普遍具有较好的抑制效果。因此，建议在月露瓜开花授粉时喷施杀菌剂咯菌腈或咪鲜胺，以提前预防果腐病的发生。

4　结　论

基于菌株致病性、形态特征和多基因系统发育分析明确广东月露瓜果腐病菌为伯氏镰刀菌（*Fusarium pernambucanum*），该菌适宜相对较高的生长温度和中性至稍偏碱性的环境。杀菌剂咯菌腈和咪鲜胺对病原菌抑菌效果最强，可作为病害防治的候选药剂，建议在月露瓜开花授粉时喷施，以提前预防病害的发生。本研究为月露瓜果腐病的诊断和防治提供了重要的理论依据，下一步将进行咯菌腈和咪鲜胺的大田防治试验，以明确两种杀菌剂的田间防治效果。

参考文献 References：

[1] De Almeida Nogueira G，Costa Conrado V S，De Almeida Freires A L，De Souza J J F，Figueiredo F R A，Barroso K A，Araújo M B M，Nascimento L V，De Lima J S S，Neto F B，Da Silva W L，De Queiroz Ambrósio M M. Aggressivity of different *Fusarium* species causing fruit rot in melons in Brazil[J]. Plant Disease，2023，107(3)：886-892.

[2] 柴兆祥，李金花，李敏权，樊小军 . 白兰瓜果腐病优势病菌鉴定及其产孢条件研究[J]. 果树学报，2005，22(1)：40-43.
Chai Zhaoxiang，Li Jinhua，Li Minquan，Fan Xiaojun. Identification of the superior pathogen of muskmelon fruit rot and producing condition of its conidium[J]. Journal of Fruit Science，2005，22(1)：40-43.

[3] 肖敏，吉训聪，王运勤，陈绵才，芮凯，张荣意 . 海南岛甜瓜镰刀菌果腐病药剂防治研究[J]. 长江蔬菜，2011(2)：63-65.
Xiao Min，Ji Xuncong，Wang Yunqin，Chen Miancai，Rui Kai，Zhang Rongyi. Research of chemical control on muskmelon *Fusarium* rot in Hainan Island[J]. Journal of Changjiang Vegetables，2011(2)：63-65.

[4] Cao P，Li C，Xiang W，Wang X，Zhao J. First report of *Fusarium incarnatum-equiseti* species complex causing fruit rot on muskmelon (*Cucumis melo*) in China[J]. Plant Disease，2019，103(7)：1768.

[5] 王燕，王春伟，王琳，李志远，张曦倩，刘峥，陈二毛，王美琴，张作刚，王建明 . 甜瓜镰刀菌果腐病新病原菌 *Fusarium incarnatum* 的鉴定及生物学特性[J]. 园艺学报，2019，46(3)：529-539.
Wang Yan，Wang Chunwei，Wang Lin，Li Zhiyuan，Zhang Xiqian，Liu Zheng，Chen Ermao，Wang Meiqin，Zhang Zuogang，Wang Jianming. Identification and biological characteristics of a novel pathogen *Fusarium incarnatum* causing muskmelon fruit *Fusarium* rot[J]. Acta Horticulturae Sinica，2019，46(3)：529-539.

[6] 杜莉芳，曾晴，徐晶，张思怡，俞国相，郭天荣，莫亿伟 . 哈密瓜镰刀果腐菌的鉴定、生物学特性和室内防治药剂的筛选[J]. 果树学报，2022，39(5)：855-869.
Du Lifang，Zeng Qing，Xu Jing，Zhang Siyi，Yu Guoxiang，Guo Tianrong，Mo Yiwei. Identification，biological characteristics and indoor fungicide selection of *Fusarium incarnatum* in hami melon[J]. Journal of Fruit Science，2022，39(5)：855-869.

[7] Yu X Y，Zhang J，Guo L F，Yu A R，Wang X J，Xiang W S，Zhao J W. First report of *Fusarium proliferatum* causing fruit rot on muskmelon (*Cucumis melo*) in China[J]. Plant Disease，2022，106(4)：1305.

[8] Zhang X P，Cao X D，Dang Q Q，Liu Y G，Zhu X P，Xia J W. First report of fruit rot caused by *Fusarium luffae* in muskmelon in China[J]. Plant Disease，2022，106(6)：1763.

[9] 郝芳敏，臧全宇，丁伟红，马二磊，黄芸萍，王毓洪 . 甜瓜新镰刀菌果腐病病原菌 *Fusarium asiaticum* 的生物学特性研究及抗病品种筛选[J]. 中国瓜菜，2023，36(6)：16-22.
Hao Fangmin，Zang Quanyu，Ding Weihong，Ma Erlei，Huang Yunping，Wang Yuhong. Biological characteristics of a new pathogen *Fusarium asiaticum* causing melon fruit *Fusarium* rot and selection of disease-resistant varieties[J]. China Cucurbits and Vegetables，2023，36(6)：16-22.

[10] Liu Y G，Zhang X P，Liu S M，Zhu X P，Xia J W. First report of muskmelon fruit rot caused by *Fusarium sulawesiense* in China[J]. Plant Disease，2023，107(10)：3313.

[11] Zhang X P，Dang Q Q，Cao X D，Liu Y G，Bi Z B，Zhu X P，Xia J W. First report of muskmelon fruit rot caused by *Fusarium nanum* in China[J]. Plant Disease，2023，107(1)：226.

[12] 李文静，王宁，赵丹，李克梅，林辰壹 . 甜瓜致病菌的鉴定及实葶葱花序浸提液对其防治效果[J]. 中国生物防治学报，2024，40(2)：458-468.
Li Wenjing，Wang Ning，Zhao Dan，Li Kemei，Lin Chenyi. Identification of pathogens in *Cucumis melo* and assessment of control effect of inflorescence extracts from *Allium galanthum*[J]. Chinese Journal of Biological Control，2024，40(2)：458-468.

[13] Zhang S L，Wang J J，Shi C E，Shi Z R，Luan F G. First report of fruit rot disease on melon (*Cucumis melo*) caused by *Fusarium ipomoeae* in China[J]. Plant Disease，2024，108(9)：2923.

[14] 孙蕾，白雪，白庆荣，赵廷昌 . 甜瓜青霉果腐病的病原鉴定及药剂筛选[J]. 北方园艺，2019(18)：52-57.
Sun Lei，Bai Xue，Bai Qingrong，Zhao Tingchang. Pathogen identification and screening of the fungicides of muskmelon fruit rot caused by *Penicillium oxalicum*[J]. Northern Horticulture，2019(18)：52-57.

[15] 刘志恒，侯悦，胡积祥，滕晓菲，黄欣阳，王世维，赵廷昌 . 辽宁省甜瓜果腐病病原菌鉴定及生物学特性初探[J]. 园艺学报，2013，40(1)：89-97.
Liu Zhiheng，Hou Yue，Hu Jixiang，Teng Xiaofei，Huang Xinyang，Wang Shiwei，Zhao Tingchang. Identification and biological characteristics of muskmelon fruit rot pathogen in Liaoning province[J]. Acta Horticulturae Sinica，2013，40(1)：89-97.

[16] 方中达 . 植病研究方法[M]. 3 版 . 北京：中国农业出版社，1998.
Fang Zhongda. Methodology for plant pathology[M]. 3rd ed. Beijing：China Agriculture Press，1998.

[17] Nirenberg H. Untersuchungen über die morphologische und biologische differenzierung in der *Fusarium-Sektion Liseola*[M]. Berlin：Parey，1976.

[18] Fisher N L，Burgess L W，Toussoun T A，Nelson P E. Carnation leaves as a substrate and for preserving cultures of *Fusarium* species[J]. Phytopathology，1982，72(1)：151.

[19] Pedrozo R，Fenoglio J J，Little C R. First report of seedborne *Fusarium fujikuroi* and its potential to cause pre- and post-emergent damping-off on soybean (*Glycine max*) in the United States[J]. Plant Disease，2015，99(12)：1865.

[20] O'Donnell K，Kistler H C，Cigelnik E，Ploetz R C. Multiple evolutionary origins of the fungus causing panama disease of banana：Concordant evidence from nuclear and mitochondrial gene

genealogies[J]. Proceedings of the National Academy of Sciences，1998，95(5)：2044-2049.

[21] Han S L，Wang M M，Ma Z Y，Raza M，Zhao P，Liang J M，Gao M，Li Y J，Wang J W，Hu D M，Cai L. *Fusarium* diversity associated with diseased cereals in China，with an updated phylogenomic assessment of the genus[J]. Studies in Mycology，2023，104(1)：87-148.

[22] Da Silva Santos A C，Trindade J V C，Lima C S，Do Nascimento Barbosa R，Da Costa A F，Tiago P V，De Oliveira N T. Morphology，phylogeny，and sexual stage of *Fusarium caatingaense* and *Fusarium pernambucanum*，new species of the *Fusarium incarnatum-equiseti* species complex associated with insects in Brazil[J]. Mycologia，2019，111(2)：244-259.

[23] O'Donnell K，Sutton D A，Rinaldi M G，Gueidan C，Crous P W，Geiser D M. Novel multilocus sequence typing scheme reveals high genetic diversity of human pathogenic members of the *Fusarium incarnatum-F. equiseti* and *F. chlamydosporum* species complexes within the United States[J]. Journal of Clinical Microbiology，2009，47(12)：3851-3861.

[24] Ramdial H，Latchoo R K，Hosein F N，Rampersad S N. Phylogeny and haplotype analysis of fungi within the *Fusarium incarnatum-equiseti* species complex[J]. Phytopathology，2017，107(1)：109-120.

[25] Liu Y L，Tang J R，Zhou Y H. Identification and description of a new pathogen causing flower dry rot on *Passiflora edulis* in China[J]. Plant Disease，2021，105(7)：1967-1975.

[26] 鲁萌萌，马立安，唐利华，陈小林，郭堂勋，黄穗萍，李其利 . 引起李树叶枯病的镰刀菌种类鉴定[J]. 植物病理学报，2023，53(4)：713-716.
Lu Mengmeng，Ma Li'an，Tang Lihua，Chen Xiaolin，Guo Tangxun，Huang Suiping，Li Qili. Identification of the species of *Fusarium* causing plum leaf blight[J]. Acta Phytopathologica Sinica，2023，53(4)：713-716.

[27] Guo Z N，Yu Z H，Li Q L，Tang L H，Guo T X，Huang S P，Mo J Y，Hsiang T，Luo S M. *Fusarium* species associated with leaf spots of mango in China[J]. Microbial Pathogenesis，2021，150：104736.

[28] 王伟博，李松刚，胡美姣，曹学仁，李敏，李焕苓，李芳，高兆银 . 无核荔枝僵果病的病原菌鉴定、入侵途径及快速检测技术[J]. 热带作物学报，2024，45(3)：602-608.
Wang Weibo，Li Songgang，Hu Meijiao，Cao Xueren，Li Min，Li Huanling，Li Fang，Gao Zhaoyin. Identification，invasion pathway and rapid detection technology of new mummy fruit pathogen of seedless litchi[J]. Chinese Journal of Tropical Crops，2024，45(3)：602-608.

[29] Wang R，Sun W X，Liu J B，Yin H Z，Pan F P，Wei S F，Li Q L. *Fusarium pernambucanum* causing peduncle rot on grape in Guangxi，China[J]. Plant Disease，2024，108(4)：1107.

[30] Zheng W Y，Huang S P，Yu Z H，Tang L H，Xie H H，Jiang Z E，Chen X L，Hsiang T，Guo T X，Li Q L，Wang Y. Peduncle rot of banana caused by *Fusarium petroliphilum* and *F. pernambucanum* in Guangxi，China[J]. Plant Disease，2024，108(12)：3649.

[31] Dos Santos Silva J L，Bento E A，De Moura A P，Costa Alves T R，Pereira da Silva I V，Da Costa Fernandes J，Da Silva Filho S M，Souza V M G，Da Silva W，De Queiroz Ambrósio M M. First report of *Fusarium falciforme* and *Fusarium pernambucanum* causing root and stem rot on papaya plants in Brazil[J]. Plant Disease，2025，109(5)：1172.

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

[33] Leslie J，Summerell B. In search of new *Fusarium* species[J]. Plant Breeding and Seed Science，2011，63(1)：94-101.

[34] 王信入，黄玉晴，范雪婷，秦永华，孙清明，张荣 . 火龙果果实心腐病病原鉴定及初始侵染点研究[J]. 华中农业大学学报，2024，43(6)：253-260.
Wang Xinru，Huang Yuqing，Fan Xueting，Qin Yonghua，Sun Qingming，Zhang Rong. Identification of pathogen causing heart rot of pitaya (*Hylocereus polyrhizus*) and studies on its initial infection point[J]. Journal of Huazhong Agricultural University，2024，43(6)：253-260.

[35] Hao F M，Dong W J，Ma E L，Ding W H，Wang Y H，Zang Q Y. First report of *Fusarium pernambucanum* causing fruit rot of melon in China[J]. Plant Disease，2024，108(7)：2231.

[36] 索欣，牛启尘，郭铖，盖云鹏，陈玲，尹淑霞 . 新型苜蓿镰刀菌根腐病病原菌 FIESC 分离及菌株生物学特性测定[J]. 草地学报，2024，32(5)：1327-1338.
Suo Xin，Niu Qichen，Guo Cheng，Gai Yunpeng，Chen Ling，Yin Shuxia. Isolation of a novel alfalfa *Fusarium* root rot pathogen FIESC and characterization of strain biology[J]. Acta Agrestia Sinica，2024，32(5)：1327-1338.

[37] 唐健林，程亮亮，叶磊，檀根甲 . 黄蜀葵枯萎病病原菌鉴定、生物学特性及其对几种杀菌剂的敏感性测定[J]. 核农学报，2024，38(7)：1416-1423.
Tang Jianlin，Cheng Liangliang，Ye Lei，Tan Genjia. Identification，biological characteristics and fungicide sensitivity of pathogens causing wilt disease in *Abelmoschus manihot*[J]. Journal of Nuclear Agricultural Sciences，2024，38(7)：1416-1423.

[38] 敖显禧，欧阳浩，杨文佳，樊瑞冬，吕周乐，吴朝明，陈孝玉龙 . 贵州省核桃叶斑病病原菌鉴定、生物学特性及防治药剂筛选[J]. 南方农业学报，2024，55(7)：2126-2136.
Ao Xianxi，Ouyang Hao，Yang Wenjia，Fan Ruidong，Lü Zhoule，Wu Chaoming，Chen Xiaoyulong. Identification and biological characteristics of walnut leaf spot disease pathogen in Guizhou and screening of fungicides[J]. Journal of Southern Agriculture，2024，55(7)：2126-2136.

[39] 董文志，许凤，蒋亚莲，杨秀梅，汤东生，张艺萍 . 10 种杀菌剂对德国鸢尾茎腐病菌的室内毒力测定[J]. 中国农学通报，2024，40(19)：142-148.
Dong Wenzhi，Xu Feng，Jiang Yalian，Yang Xiumei，Tang Dongsheng，Zhang Yiping. Laboratory toxicity test of 10 fungicides against pathogens of stem rot of *Iris germanica*[J]. Chinese Agricultural Science Bulletin，2024，40(19)：142-148.