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Research Article

Long-tern Changes in Powdery Mildew (*Sphaerotheca macularis*) in Strawberry in Eastern China (1985 – 2018)

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Abstract

The Jiande region is widely known for its high-quality fruit, which are often referred to as "Jiande's strawberries". In this study, the occurrence of powdery mildew on strawberry caused by *Sphaerotheca macularis* was monitored from 1985 to 2018. In 1985, there were only 1.94 ha of strawberry planted in Jiande, Zhejiang province, which were grown using traditional open field production methods. Since 1993, greenhouse production has been widely adopted and 'Fengxiang' was the dominant cultivars until 2010. Beginning in 2011, 'Fengxiang' was replaced by the 'Hongxia' and 'Zangji' which became the primary cultivars grown. A total of 29 kinds of infective diseases were observed, and anthracnose (*Colletotrichum gloeosporioides*), grey mold (*Botrytis cinerea*), and powdery mildew (SPM) (*S. macularis*) were the most commonly found. The presence of SPM was slight before 1989 when open field cultivation was widespread. During this time, the first serious occurrence appeared during 1995-1999. After 1999, the presence of SPM decreased in most years until 2013. A significant correlation was found between the percent yield loss and SPM, the percent disease index (Y = 0.8774X - 0.2624, R2 = 0.9624), and the percent incidence (Y = 3.307X + 0.6513, R2 = 0.8373). Our results indicate that the occurrence of SPM is affected by growing conditions, cultivar, and climate, which will provide guidance for the reduction in pathogen pressure in strawberry production.

Keywords: Strawberry Production; Disease Monitor; Powdery Mildew; Yield Loss; Disease Occurrence

Introduction

Strawberry (*Fragaria × ananassa*) is a perennial plant in the *Rosacea* family that was first formally documented in detail 250 years ago. The fruit crop is now one of the most important small fruits globally. China has both the largest area in production (133,000 ha) and highest production by weight (220,000 tons) of strawberry in a year in the world [1]. Strawberry fruits produced in Zhejiang province are popular, and are of a high quality and yield, with yield outputs greater than 1 billion of CNY (China Yuan) in 2018. Currently, strawberry is one of the leading agricultural industries in the area of Jiande in Zhejiang province, where is famous for "Jiande's Strawberry" for its advanced cultivated and management techniques around China. Strawberry growers from Jiande plant strawberry in 28 of 31 provinces of China, with a total of 5413.3 ha in production and 3.96 billion CNY in sales.

Powdery mildew is an important fungus disease that causes significant damage to many crops worldwide [2]. In strawberry, powdery mildew is caused by *Sphaerotheca macularis* and causes significant damage, with production loss estimated to be in the range of 20%-30% and as high as 50% under favorable conditions [3]. The fungal pathogen infects leaves, petioles, runners, flowers, and fruits of strawberry [4], and is known as strawberry powdery mildew (SPM). Symptoms initially occur in the form of white patches on the upper or lower surfaces of young leaves and progress to irregular reddish spots as the disease progresses [5,6]. In China, at present there are no strawberry cultivars that are resistant to SPM and other serious diseases meanwhile with acceptable fruit quality and shelf-life [7-9]. Since 1990 in Zhejiang, strawberry have mostly been planted under un-heated plastic covered tunnels, which will create high-temperature and humidity conditions. Research conducted in Israel suggests that factors such as temperature, relative humidity, and light intensity significantly influence the development of SPM. In this study, we monitored the occurrence of SPM from 1985 to 2018 and compared the resistance to SPM of the main strawberry cultivars.

Materials and Methods

Experimental sites

Three typical strawberry sites in Jiande city, Zhejiang were chosen to monitor the occurrence of SPM. At each site, at minimum of five greenhouses were selected and monitored for the development of SPM at 5-day intervals from November to May. Each greenhouse was divided into five zones containing 10 strawberry plants

per zone. On each individual plant, the presence of SPM on leaves and fruit was recorded. Fruit yield from plants was also recorded. Prior to 1988, all strawberry plants that were monitored were cultivated in open fields, but greenhouse production was widely adopted thereafter.

Disease scale

SPM was recorded according to the following scale: 0 = no symptom; 1 = diseased area < 5%; 3 = 5%-15% diseased area; 5 = 16%-25% diseased area; 7 = 26%-50% diseased area; 9 = ≥ 51% diseased area.

The percent of SPM was calculated using the following formula:

$$\frac{disease\ number\ of leaves\ or\ fruits}{total\ number\ of\ leaves\ or\ fruits} \times 100\%$$

The disease index was calculated using the following formula:

$$\frac{\sum (\text{number of diseased leaves or fruits of each class} \times \text{each evaluation class})}{total\ number\ of\ leaves\ or\ fruits \times 9} \times 100\%$$

Damage scale

Damage due to SPM was calculated as percent of yield loss using the following yield-loss scale: 1 = ≤ 2%; 2 = 2.01%-5%; 3 = 5.01%-8%; 4 = 8.01%-10%; 5 = ≥10.01%.

Yield loss was calculated using the following formula =

$$\frac{yield\ per\ helaty\ plant - yield\ per\ naturally\ diseased\ plant}{yield\ per\ helaty\ plant} \times 100\%$$

Results

Overview of long-term change of strawberry production

In 1985, only 1.94 ha of strawberry was planted in Jiande in Zhejiang province, and the traditional open field production was most common (Table 1). From 1990 to 1992, the cultural mode transitioned, and by 1993, production under un-heated plastic covered tunnels was most common until 2018 although some glass greenhouses were introduced since 2003.

Year	Area (ha)	Cultivar *	Cultural mode
1985	1.94	Shanghai, Geleila, Baojiao, Lihong	Open field
1986	2.48	Geleila, Baojiao, Lihong	Open field
1987	3.10	Geleila, Baojiao, Lihong	Open field
1988	3.84	Geleila Baojiao, Lihong	Open field
1989	4.45	Geleila, Baojiao, Lihong	Open field
1990	5.41	Baojiao, Fengxiang, Mingbao, Meiliu	Open field + un-heated plastic covered tunnels (UPT)
1991	7.71	Baojiao, Fengxiang, Mingbao, Meiliu	Open field + UPT
1992	14.04	Baojiao, Fengxiang, Mingbao, Meiliu	Open field + UPT
1993	25.57	Fengxiang	UPT
1994	57.63	Fengxiang	UPT
1995	112.82	Fengxiang/Chunxiang/Nvfeng	UPT
1996	217.40	Fengxiang, Chunxiang, Nvfeng	UPT
1997	694.40	Fengxiang/Guinvgan/Nvfeng	UPT
1998	894.53	Fengxiang, Guinvgan, Nvfeng, Zangji	UPT
1999	885.33	Fengxiang, Guinvgan, Nvfeng, Zangji	UPT
2000	1014.40	Fengxiang, Nvfeng, Zangji	UPT
2001	1021.20	Fengxiang, Hongxia, Zangji	UPT
2002	1060.33	Fengxiang, Xinxiang, Hongxia, Zangji	UPT
2003	1205.80	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2004	1336.00	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2005	1475.47	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2006	1343.33	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2007	1361.93	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2008	1342.33	Fengxiang, Hongxia, Zangji	UPT+ glass greenhouse
2009	1343.87	Fengxiang, Hongxia, Zangji, Zuohe	UPT+ glass greenhouse
2010	1347.53	Fengxiang, Hongxia, Zangji, Zuohe	UPT+ glass greenhouse
2011	1353.73	Hongxia, Zangji	UPT+ glass greenhouse
2012	1368.27	Hongxia, Zangji	UPT+ glass greenhouse
2013	1369.60	Hongxia, Zangji	UPT+ glass greenhouse
2014	1372.67	Hongxia, Zangji	UPT+ glass greenhouse
2015	780.00	Hongxia Zangji	UPT+ glass greenhouse
2016	841.07	Hongxia, Zangji	UPT+ glass greenhouse
2017	937.49	Hongxia, Zangji	UPT+ glass greenhouse
2018	1080.00	Hongxia, Zangji	UPT+ glass greenhouse

Table 1: Strawberry production in Jiande city, Zhejiang province during 1985 and 2018.

*Cultivar were listed from largest area in production to smallest area in production.

The cultivar Fengxiang was dominant until 2010, and was a cultivar that was adopted for a long time. The largest production area occurred in 2005 and was 1476 ha. From 2004 and 2015, the production area ranged from 1336 to 1476 ha. After 2011, Fengxiang was replaced by Hongxia and Zangji which became the most commonly grown cultivars.

SPM epidemiology trends during 1985 and 2018

From 1985 to 2018, a total 29 infective diseases were observed on strawberry in our experimental sites (Table 2). Anthracnose, grey mold, and powdery mildew were the most commonly recorded and were observed to be widely distributed and cause measurable damage. The disease incidence of SPM was greatest on leaves slightly before 1989, when open field cultivation was widespread at the monitoring sites. From 1990 to 1995, the disease index slowly increased, with the first serious outbreak occurring from 1995 to 1999. After this period, SPM on leaves decreased in most years until 2013. From 2014 to 2018, SPM on leaves has been at a high level (Figure 1). A similar pattern was observed for the disease index of SPM on fruits from 1985 through 2017 (Figure 2).

Diseases	Distribution regions	Damaged plant parts	Damage degree
Anthracnose	City-wide	Leaf, stolon	+++
Grey mold	City-wide	Leaf, flower, stolon, fruit	+++
Powdery mildew	City-wide	Leaf, fruit	+++
Fusarium wilt	Local	Systematic	+
Verticillium wilt	Local	Systematic	+
Leaf blight	Local	Leaf	+
Southern blight	Local	Crown	+
Phomopsis leaf blight	Small	Leaf, petiole	+
White leaf spot	Small	Leaf	+
Angular leaf spot	Small	Leaf	+
Black spot	Local	Leaf, fruit	+
Brown spot	Local	Leaf	+
V-type brown spot	Small	Leaf	+
Sclerotinia rot	Local	Root	+
Root rot	Local	Root	+
Red stele root rot	Local	Root	+
Bud blight	Local	Stolon, leaf	+
Myxomycosis	Local	Leaf, stolon	+
Phytopathora fruit rot	Local	Root, fruit	+
Rhizoctonia rot	Local	Fruit	+
Fruit rot	Local	Fruit	+
Bacterial wilt	Small	Systematic	+
Bacterial leaf blight	Small	Leaf, stolon	+
Mottle virus (SMoV)	Local	Systematic	+
Mild yellow edge virus (SMYEV)	Small	Systematic	+
Vein banding virus (SVBV)	Small	Systematic	+
Crinkle virus (SCrV)	Local	Systematic	+
Witches broom virus (SWB)	Local	Systematic	+
Root knot nematode	Local	Root	+

Table 2: Types of strawberry diseases found in Zhejiang and their estimated damage.

+++ represents serious damage, ++ represents secondary serious damage, + represents mild damage.

Relation between yield loss and SPM

For SPM occurrence on leaves, we found a relationship between yield loss (%) and both the disease incidence (%) (Y = 0.2989 x -0.0188, R2 = 0.6288) and disease index (%) (Y = 0.5838 x + 0.9622, R^2 = 0.5441) (Fig. 5A and B). We also found a strong correlation between yield loss (%) of fruit and the disease index (%) (Y = 0.8774 x -0.2624, R^2 = 0.9624) and the incidence (%) (Y = 3.307 x + 0.6513, R^2 = 0.8373) (Figure 3C and D).

Resistance to SPM between two main varieties

The cultivars Hongxia and Zangji have been widely cultivated in Zhejiang province, becoming the two most important cultivars since 2011 (Table 1). We compared the occurrence of SPM using the disease index of the two varieties (Figure 4) and found that the occurrence of SPM increased in both cultivars over time. While we did find a significant difference in the disease index of several one year (2013,2014), we did not find any significant difference in mean disease index from 2012 through 2017. Qualitatively, we found that SPM was first observed on fruits of Hongxia in 2014.

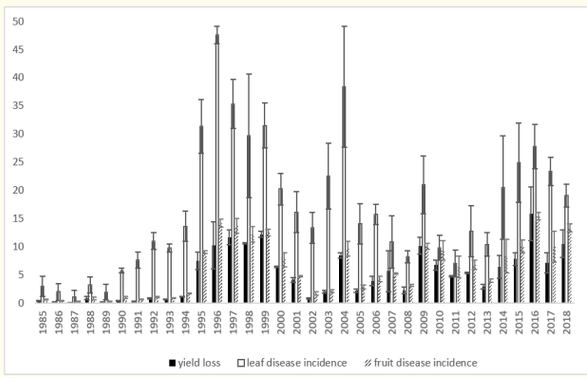


Figure 1: Yield loss (%) and disease incidence (%) of powdery mildew on fruits of strawberry during 1985 and 2018 in Jiande, Zhejiang province.

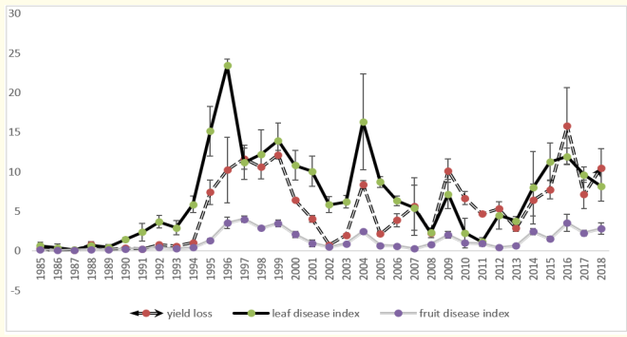
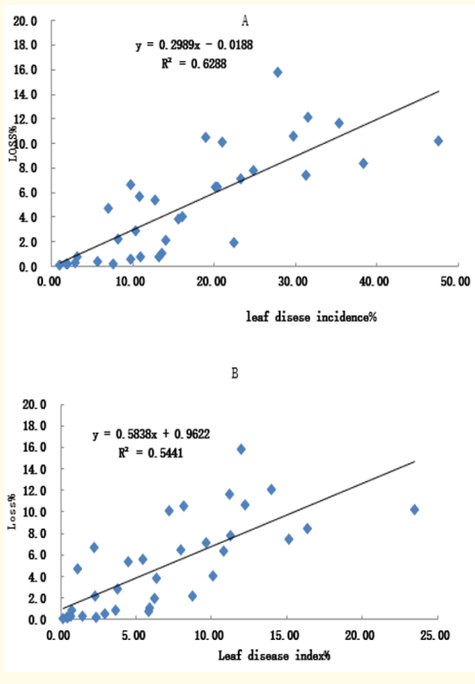


Figure 2: Yield loss (%) and disease index (%) of powdery mildew on strawberry during 1985 and 2018 in Jiande, Zhejiang province.



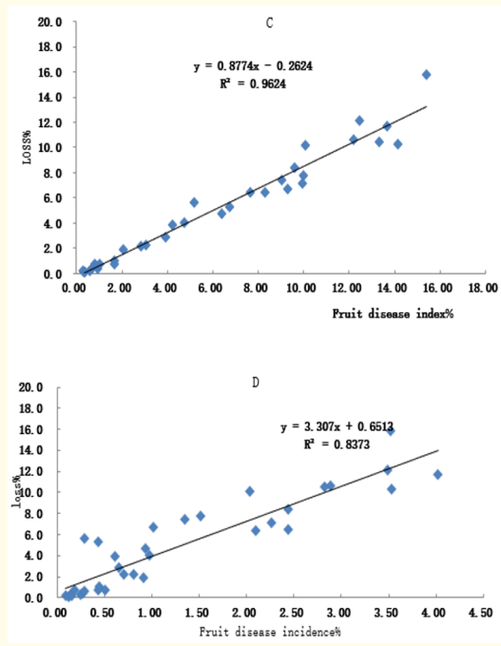


Figure 3: Relationship analysis between yield loss and powdery mildew on strawberry

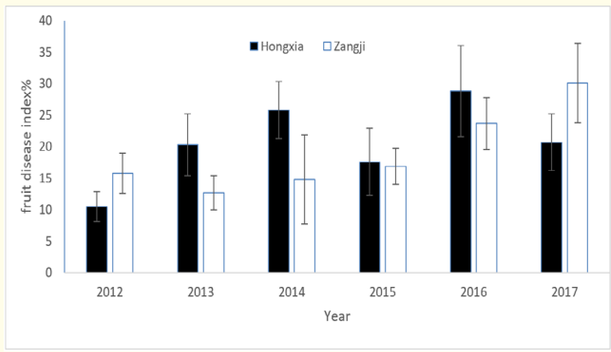


Figure 4: Disease index between Hongxia and Zangji for powdery mildew on strawberry.

Discussion

From 1985 to 2018, we identified a total of 29 diseases on the strawberry plants we monitored. Anthracnose, grey mold, and powdery mildew were the top 3 important diseases affecting strawberry production due to their wide distribution and serious damage. Anthracnose and grey mold in strawberry have been extensively reported in China [10-13], and over our 34-year study monitoring SPM, we found it to be a serious disease threatening strawberry production in Zhejiang Province, China. We also found that the effect of SPM on yield was statistically significant, and that there was a relationship between the development of SPM and resulting yield loss. Both the incidence and disease index of SPM were linearly correlated with strawberry yield, especially between the disease index of strawberry fruit and yield loss. In hop (Podosphaera macularis), powdery mildew has also been reported to cause serious economic

loss due to reductions in cone yield and quality [2]. The same effect has also been reported in wine grapes grape, where Uncinula necator has negatively affected yield and quality [14].

Previous studies suggest that temperatures near 20°C and a high relative humidity are favorable conditions for the development of SPM [3,4]. In our research, we found that when open field cultivation was adopted, SPM occurred less than in the greenhouse environment. Thus, we believe that the decrease in air circulation, (list other reasons here) in the greenhouse environment created a favorable climate for SPM development. Moreover, the cultivars Hongxia and Zangji have been widely cultivated in Zhejiang province for about 10 years, and we observed an increased trend in the development of SPM. SPM was observed on the fruits of Hongxia in 2017 before being observed on the leaves. In agreement with Nelson., *et al.* [5,6], we believe that it is important to monitor the long-term changes in resistances of strawberry to SPM [15-17].

Conclusion

In summary, SPM occurred more in greenhouse production than open beds, and significantly affected the yield of strawberry production in China. Thus, more attention should to be paid to understanding its development.

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