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Human Activity Played a Key Role in Rice Stripe Disease Epidemics: From an Empirical Evaluation of over a 10-Year Period

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Abstract: Paddy is an artificial ecosystem driven by human activities, such as adjustment of cropping systems, deployment of resistant varieties and pesticides use. Inappropriate human intervention aggravated the disruption of ecosystems, which resulted in rice viral disease epidemics characterized by fulminant, migrating and intermittent outbreaks. Rice stripe disease (RSD), lasting for over 10 years from 2000, was modeled for exploring better management strategies of plant viral disease transmitted by insect vectors. In eight counties of Jiangsu province, China, the biotic, abiotic and human factors between 2000 and 2012 were monitored to determine key factors of human activities related to RSD epidemics. RSD severity was significantly related to resistance, the interval of wheat harvest and rice sowing (WHRS) and inconsecutive interval of wheat sowing and rice harvest (WSRH). The relationship between human activities and the small brown planthopper (SBPH) showed that the resistance was more significantly associated with SBPH viruliferous rate in the preceding year than that of the current year but not correlated with SBPH density. Resistance could impact the SBPH viruliferous rate in the preceding year indirectly through transmission probability and, thereafter, the continuing disease epidemics. The insignificant interactive effects among resistance, WHRS and WSRH on disease severity meant that these three factors could be taken into consideration separately in agricultural practice according to rice chronological order. The quantitative field study conducted in Jiangsu province presented a good example of plant viral disease management, guided by which could not only avoid pointless actions but, most importantly, generate more efficient and economic returns. Therefore, in order to improve the management of RSD, it should focus on the adjustment of these human factors independently and sequentially in combination with the forecast of RSD.

Keywords: rice stripe disease; viruliferous rate; small brown planthopper; human activity; resistance; integrated pest management

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Citation: Ma, Y.-L.; Lin, W.-W.; Guo, S.-S.; Xie, L.-H.; He, D.-C.; Cheng, Z.-B. Human Activity Played a Key Role in Rice Stripe Disease Epidemics: From an Empirical Evaluation of over a 10-Year Period. *Agriculture* **2022**, *12*, 1484. https://doi.org/10.3390/agriculture12091484

Academic Editor: Wenqing Zhang

Received: 8 August 2022
Accepted: 14 September 2022
Published: 16 September 2022

1. Introduction

Rice, as one of the main nutrient supplies of the world, is especially important in less developed Asian countries [1]. Over the years, rice stripe disease (RSD) epidemics, caused by the pathogen *Rice stripe virus* (RSV), have occurred many times in eastern Asian countries, including some intermittent occurrences in Japan from 1950 to 1980 and continuing epidemics in Japan, China and Korea between 1963 and 1967 [2–8]. It is one of the most important rice diseases in East Asia, causing great grain loss and thereby threatening rice production and global food security [9]. Like other plant viral diseases, RSD is ineffectively treated by the therapeutic agents in practice. In this circumstance, indirect methods, such as insecticides application to control insect vectors (small brown planthopper, SBPH), deployment of disease-resistant rice varieties and optimization of cropping system, were usually adopted to manage RSD [10].

However, plant viral diseases like RSD still broke out frequently and in despite many efforts on managing disease epidemics and exploring the mechanism of viral pathogenesis [11]. The major cause is that we lack a comprehensive understanding of the interaction of biotic and abiotic factors with human activities which is crucial for the management of agro–ecosystems and effective control of disease epidemics [9,12]. Paddy is a typical artificial ecosystem in which all factors have traces of human production activities. As the creator and mover of artificial ecosystems, human activities are bound to play a leading role in the occurrence and development of plant disease in the interaction system of abiotic, biotic and human factors [9,11,12]. It suggests that in addition to the natural factors, the management of plant viral diseases must take into account the human factors responsible for plant disease epidemics.

Most of the previous descriptions of disease management cases were built on qualitative analysis, which can poorly provide useful strategies for efficient RSD control. One of the possibilities is that the data on disease epidemics in consecutive years required for systematically quantitative analyses is difficult to obtain due to the fulminant, migrating and intermittent traits of rice viral disease epidemics [13]. In this scenario, the application priority of each method as well as the significance of each epidemic-associated factor is hard to be determined for effectively controlling the disease. Therefore, insecticides were always put at the first application and subsequently integrated with other methods, with the expectation of reducing yield loss caused by disease epidemics, which, however, exacerbated the dilemma of repeated and irrational management and irreversible impact on the environment [11].

The biotic factors, as well as abiotic factors, which are directly correlated with RSD, are relatively uncontrollable compared with human activities. Human activities could be responsible for RSV disease epidemics [14–21] and are more likely to be adjusted [22]. Therefore, a systemic and quantitative investigation of how human activities affect RSD epidemics is required for proper responses to a new round of RSD epidemics and future plant disease management. From 2000 to 2012, RSD epidemics lasted for over 10 years in Jiangsu province, China, which became a good case study of the epidemiology of plant viruses [22,23]. Therefore, the data collected in consecutive years during the period of RSD epidemics creates the possibility for quantitative research.

According to the previous analyses on the abiotic and biotic factors of RSV disease epidemics [23], and considering the unique paddy ecosystem of Jiangsu province, the data such as the deployment of disease-resistant rice varieties, sowing and harvest time of rice and wheat, cultural systems, pesticide use, etc., obtained from the fields over a 10-year epidemic period were evaluated in parallel with insect vector and disease data, aiming at quantitatively studying the relationship between human factors and RSV disease epidemics and developing a lower cost, more effective and ecologically friendly strategy for managing RSD and other insect-borne plant virus diseases. The specific goals of the current study are to: (1) determine the main human factors and their interactive effects responsible for the RSD epidemics, (2) clarify the correlation of human factors and biotic factors and systematically understand the causes of RSV disease epidemics and (3) provide a new, economic and effective strategy based on the key factors to manage RSV disease epidemics.

2. Materials and Methods

Spatiotemporal dynamic data of rice stripe disease severity, small brown planthopper (SBPH) density and viruliferous rate were recorded and calculated using the same methods as described previously [23]. Human activities including sowing, transplanting and harvest of five major varieties of rice and wheat planted across eight counties of Jiangsu province were annually monitored between 2002 and 2012. The midpoint of the period of each year in each county was calculated as the sowing, transplanting and harvesting date, respectively.

The interval of wheat harvest and rice sowing (WHRS), interval of wheat sowing and rice harvest (WSRH) and interval of rice transplanting and sowing (RTRS) in each county were estimated. In association with analyses of disease severity, SBPH density, viruliferous rate and the temporal parameters, the raw data was converted into the gap between wheat harvest, transplanting, rice sowing and 1 May, and the gap between rice harvest, wheat sowing and 1 October, respectively. The major planting methods of rice and wheat in each county were grouped into 4 types (1: manual transplanting; 2: machine transplanting; 3: seedling throwing; 4: direct seeding) and 3 types (1: zero-tillage; 2: shallow rotary tillage; 3: deep tillage), respectively. Rice variety's resistance was recorded using a six–grade evaluation system (1: high susceptibility; 2: medium susceptibility; 3: low susceptibility; 4: low resistance; 5: medium resistance; 6: high resistance). Resistance grades of all varieties were obtained from the Plant Protection Institute of Jiangsu Academy of Agricultural Sciences. The total resistance grade (R_t) of each county in each year was calculated using the following formula and the value obtained was rounded off to the nearest integer.

$$R_t = \sum R_i \, P_i \; (i = 1, 2, \ldots, 5), \quad (1)$$

where R_i is the resistance grade of the ith variety. P_i is the percentage determined by dividing of planting area of the ith variety by the total rice fields in each county. i is the random order of these eight counties.

Total resistance grade (R_t) across the eight counties in each year was calculated as the following, and the value obtained was rounded off to the nearest integer.

$$R_{t8} = \sum R_{ti} \, P_{ti} \; (i = 1, 2, \ldots, 8), \quad (2)$$

where R_{ti} is the total resistance grade of the ith county. P_{ti} is the percentage determined by dividing of planting area of the ith county by the total rice fields across eight counties. i is the random order of these eight counties.

Total disease severity across the eight counties was calculated using the same methods as described previously [23]. The cumulative area of controlling SBPH and disease during a whole rice growth period was estimated as the control area of each year. An unsprayed (no insecticide application) field with a size of ~667 m^2 was used as a control in the villages of each county, as described previously [23]. The gap in disease severity between sprayed and unsprayed fields was estimated as the disease control effect. Total occurrence and control area of SBPH and disease were obtained from the Plant Protection Stations of Jiangsu province. The national occurrence and control area of rice stripe disease was obtained from National Agro-Tech Extension and Service Center.

The association between disease severity, SBPH density, viruliferous rate and human activity parameters including resistance deployment, sowing and harvest date of rice and wheat, planting way, pesticide application, etc., were analyzed using Spearman's correlation, as described previously [23].

The raw data of WSRH and WHRS were converted into the ordinal value using a six–grade system (1: <5 days; 2: 5–10 days; 3: 10–15 days; 4: 15–20 days; 5: 20–25 days; 6: $\geq$25 days), and then the contributions of WSRH, WHRS, R_t and their interaction effects on rice stripe disease severity were assessed using multivariate analysis of variance (MANOVA).

The model of disease severity and human factors including R_t, WSRH and WHRS was established using the Regression analysis method, respectively. Several possible models and their curves were conducted as well as the Chi-square goodness of fit test, and then the curve of the greatest of the adjusted R^2 value was selected to establish the regression equation accordingly. All the statistical analyses were performed using IBM SPSS 19.0 software (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Associations of RSV Disease Severity with Human Factors

Over the period of the study, the total resistance grade (R_t) of rice varieties in Jiangsu province in 2003 was the lowest but then rose quickly from 2004 to 2008, after which the grade was kept at a similar level (Figure 1A). On the contrary, disease severity increased to the peak in 2004 before gradually decreasing to the lowest level in 2012 (Figure 1B). Disease severity was negatively and significantly correlated with the total resistance grade of each county (R_t) ($r_{74} = -0.700$). The relationship between disease severity and R_t fitted the model as expressed by $y = (13.109/R_t - 2.735)/100$, where y is the expected disease severity. Disease severity in the following year showed a similar correlation with R_t in the current year (Table 1).

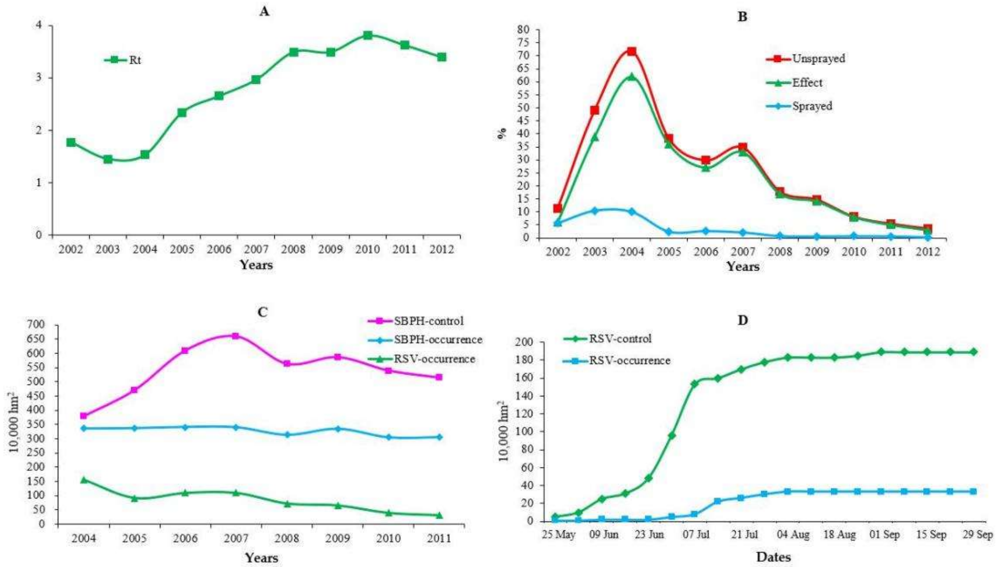

Figure 1. Temporal dynamics of rice resistance, RSD epidemics and control effects. (**A**) R_t is total resistance grade of each county in each year. The temporal dynamic trend was relatively lower before 2004, especially at the lowest in 2003. After 2005, the resistances showed an upward trend until they remained at a higher level. (**B**) Temporal dynamics of pesticide spraying effects (the gap between sprayed and unsprayed fields). The temporal dynamic trend of disease severity and pesticide sprayed effects was relatively consistent, which peaked in 2004 and then decreased gradually [10]. (**C**) Temporal dynamics of RSD and SBPH occurrence and control area in Jiangsu province. Over the period of the study, there was less temporal variation in SBPH occurrence area. SBPH control area rose quickly to peak in 2007 before gradually decreasing to ~450 hm^2 in 2011. RSD incident area showed a downward trend after 2004. (**D**) Temporal dynamics of RSD incident and control area in China (2011). RSD occurred in June and kept stable incident area after August. A total of ~0.3 million hm^2 paddies occurred in RSD accompanied by a cumulative control area of ~2 million hm^2 in 2011.

Table 1. Associations of rice stripe disease severity with rice resistance.

	Disease Severity in Sprayed Fields	
	Current Year	**Following Year**
R_t in current year	−0.700 **	−0.552 **

R_t: total resistance grade of each county in each year. ** significant at $p \leq 0.01$.

Disease severity was negatively and significantly correlated with wheat harvest and rice sowing (WHRS) of each county in the current year. The relationship between disease severity and WHRS fitted the model as expressed by $y = (0.113\, x_2 + 1.514)/100$, where

y is the expected disease severity and x_2 is the WHRS of the current year. Disease severity in the following year showed a similar correlation with R_t in the current year (Table 2). Disease severity was correlated with the wheat sowing date of the previous year ($r = -0.597$), WHRS ($r = 0.384$), rice sowing date ($r = -0.358$), transplanting date ($r = -0.248$) and wheat sowing and rice harvest (WSRH) of the previous year ($r = -0.354$), in turn, but not with wheat harvest date, rice harvest date of the previous year and rice transplanting and sowing (RTRS) (Tables 2 and 3).

Table 2. Associations of rice stripe disease severity with planting and harvest dates and ways of wheat and rice.

	Preceding Year			Current Year			
	Wheat Planting Way	**Rice Harvest Date**	**Wheat Sowing Date**	**Wheat Harvest Date**	**Rice Planting Way**	**Rice Sowing Date**	**Rice Transplanting Date**
Severity in sprayed fields	−0.133	−0.121	−0.597 **	0.142	0	−0.358 **	−0.248 *
Severity in unsprayed fields	0.325 **	−0.243	−0.608 **	0.403 **	−0.026	−0.559 **	−0.309 **

** significant at $p \leq 0.01$; * significant at $p \leq 0.05$.

Table 3. Associations of rice stripe disease severity with the intervals.

	Preceding Year	Current Year	
	Interval of Wheat Sowing and Rice Harvest (WSRH)	**Interval of Wheat Harvest and Rice Sowing (WHRS)**	**Interval of Rice Transplanting and Sowing (RTRS)**
Severity in sprayed fields	−0.354 **	0.384 **	0.181
Severity in unsprayed fields	−0.182	0.556 **	0.355 **

** significant at $p \leq 0.01$.

The small brown planthopper (SBPH) occurrence area was significantly positive with the rice stripe disease (RSD) area of Jiangsu province ($r_7 = 0.784$, $p = 0.021$). The SBPH control area reached a peak in 2007 and was not correlated with the occurrence area of SBPH and disease and showed a great difference, respectively (Figure 1C). The effect of disease control peaked in 2004 before gradually decreasing to the lowest level in 2012 (Figure 1B). There is a great scissors gap between disease control and occurrence area in China in 2011 (Figure 1D).

Among human factors, the significant degree of correlation with disease severity was ranked as: resistance grade > wheat sowing date of preceding year > WHRS > rice sowing date > WSRH > rice transplanting date.

3.2. Effects of Human Factors and Their Interaction on RSV Disease Severity

Analysis of variance (ANOVA) analysis revealed a significant impact of resistance grade on disease severity ($p = 0.001$) and WHRS ($p = 0.024$), but no impact of WSRH ($p = 0.873$), and an interactive effect among these factors were found in the current study (Table 4). A good explanatory power for the analytical model (adjusted $R^2 = 0.734$) was achieved.

3.3. Associations of SBPH Traits with Human Factors

SBPH viruliferous rate in the current year was significantly correlated with the wheat sowing date ($r_{54} = -0.690$), R_t ($r_{54} = -0.639$), WSRH ($r_{54} = -0.361$) and rice sowing date ($r_{54} = -0.269$) but not with other human factors. SBPH viruliferous rate in the following year was significantly correlated with R_t ($r_{54} = -0.616$). SBPH density was significantly correlated with the rice transplanting date ($r_{54} = -0.401$), RTRS ($r_{54} = -0.323$), rice harvest date ($r_{54} = 0.254$) and wheat planting way ($r_{54} = -0.442$) but not with other human factors (Tables 5–7).

Table 4. Analysis of variance evaluating the effects of the intervals, variety resistance and their interaction with disease severity.

	P	F	DF
Corrected Model	0.003 **	4.350	61
Intercept	0.000 **	127.135	1
WSRH	0.873	0.561	18
WHRS	0.024 *	3.191	12
R_t	0.001 **	9.648	3
WSRH × WHRS	0.172	1.893	4
WSRH × R_t	0.986	0.047	3
WHRS × R_t	0.842	0.174	2
Error		13	

R_t: total resistance grade of each county in each year, WSRH: interval of wheat sowing and rice harvest, WHRS: interval of wheat harvest and rice sowing. ** significant at $p \leq 0.01$; * significant at $p \leq 0.05$.

Table 5. Associations of rice resistance with small brown planthopper density and viruliferous rate of following year.

	Current Year		Following Year	
	Q_0	V_0	Q_0	V_0
R_t in preceding year	−0.139	−0.639 **	−0.219	−0.616 **

R_t: total resistance grade of each county in each year, Q_0: over wintering small brown planthopper (SBPH) density, V_0: viruliferous rate of overwintering small brown planthopper (SBPH). ** significant at $p \leq 0.01$.

Table 6. Associations of small brown planthopper density and viruliferous rate with planting and harvest dates and ways of wheat and rice in preceding year.

	Wheat Planting Way	Rice Harvest Date	Wheat Sowing Date	Wheat Harvest Date	Rice Planting Way	Rice Sowing Date	Rice Transplanting Date
Q_0	−0.442 **	0.254 *	0.171	0.116	0.227	0.029	−0.401 **
V_0	0.119	−0.143	−0.690 **	−0.040	−0.098	−0.269 *	−0.106

Q_0: over wintering small brown planthopper (SBPH) density, V_0: viruliferous rate of over wintering small brown planthopper (SBPH). ** significant at $p \leq 0.01$, * significant at $p \leq 0.05$.

Table 7. Associations of the intervals in preceding year with small brown planthopper density and viruliferous rate.

	Interval of Wheat Sowing and Rice Harvest (WSRH)	Interval of Wheat Harvest and Rice Sowing (WHRS)	Interval of Rice Transplanting and Sowing (RTRS)
Q_0	−0.11	0.069	−0.323 **
V_0	−0.361 **	0.224	0.214

Q_0: overwintering small brown planthopper (SBPH) density, V_0: viruliferous rate of overwintering small brown planthopper (SBPH). ** significant at $p \leq 0.01$.

4. Discussion

Rice stripe disease (RSD) epidemics are significantly correlated with human factors, such as the resistance of rice cultivars, interval of wheat harvest and rice sowing (WHRS) and interval of wheat sowing and rice harvest (WSRH), successively (Tables 1 and 3), but no interactive effects on disease epidemics were detected among these human parameters (Table 4). The result demonstrates that rice resistance, rather than other factors, plays a primary role in RSD epidemics and disease control, suggesting that no other measures need to be taken synchronically to manage RSD if resistant varieties are planted in most of the fields. During the early stage of the epidemic period, there was less spatiotemporal variation in a lower grade of rice resistance (Figure 1A) but at a higher level of viruliferous rate of the small brown planthopper (SBPH) [23], and pesticide is used as the main method for disease control in practice [24]. Nevertheless, resistant variety deployment was proposed to control RSD in a combination of 2–4 means in the later stage [25].

The viruliferous rate of SBPH rather than the absolute number of vectors plays an important role in RSD epidemics and could be a good indicator of RSD epidemics [23]. Therefore, the conclusion that rice resistance rather than other factors plays the primary role in RSD epidemics is also supported by a significant association of rice resistance grade with SBPH viruliferous rate but no association with total SBPH density (Table 5). It means that the mechanism of resistant varieties controlling RSD epidemics is not through decreasing total SBPH density but by reducing SBPH viruliferous rate, as reported earlier [26].

The significant correlations of disease severity with WHRS and WSRH (Tables 6 and 7) indicate that the adjustments of WHRS or WSRH should be given priority consideration to control RSD in the absence of resistant varieties and/or available RSV therapeutic agents. In this scenario, the intervals reflect that SBPH and RSV alternately transited between paddy and wheat fields during the epidemic period.

It is considered that the planting and harvest dates of rice and wheat would impact RSV disease occurrence and epidemics [27]. However, in addition to the sowing date of rice [28], few quantitative analyses of the effects on RSD of these dates are conducted. The arrangements of planting and harvest dates of rice and wheat are important factors of human activities, which can also reflect the rotation system of the crops. Not unexpectedly, these dates only showed the important temporal points of the rotation of rice and wheat [29]. In practice, crops for rotation together played a role in disease occurrence rather than the single date of rice or wheat independently [27]. To reflect the key intervals in rice and wheat rotation, the human factors WHRS and WSRH were further defined, which is an innovation of the current study.

Integrated disease management (IDM) has been always used as the main strategy during the whole epidemic period of rice viral diseases [30]. However, our results (Tables 1–4) showed that RSV disease severity correlates with resistance, WHRS and WSRH independently. It suggests that these methods can be adopted separately to manage RSD in combination with the forecast of disease epidemic potential. This strategy is different from the IDM applied in the agricultural practices and views reported as described previously [31], which could be not only in line with the actual agricultural production but also an important innovation.

Disease epidemics are influenced by biological factors directly and by human intervention indirectly [32]. Human activities driven by economic rules play a decisive role in the interaction of biological factors contributing to RSD epidemics and control [33]. Therefore, this paper attempts to create a basis for exploring how economic factors impact RSD epidemics through human intervention from a socioeconomic point of view, which is also the focus of our studies in the future.

5. Conclusions

Like all other vector–transmitted diseases, rice stripe disease (RSD) epidemics result from a complex interaction among biotic and abiotic factors interfered with by human activities [9]. In the early and middle stages of the RSD epidemics between 2002 and 2012, the effort has been made in a collaboration between farmers, government and scientists which includes heavy pesticide spraying, but tends to be very little. It means that the determination of the human activities contributing to the biotic and abiotic factors influencing RSD epidemics could be of value if applied to manage vector-transmitted diseases. Regarding the current epidemic cycle, we showed that RSD epidemics are significantly associated with the resistance of rice cultivars, the interval of wheat harvest and rice sowing (WHRS) and interval of wheat sowing and rice harvest (WSRH), successively. It can be speculated that the deployment of resistant varieties cropping could be used preferentially for RSD management; however, modifying the intervals of WHRS or WSRH should be primarily adopted to control RSD in the absence of resistant variety. The two intervals reflect that small brown planthopper (SBPH) and *Rice stripe virus* (RSV) alternately transited between paddy and wheat fields during the epidemic period, which is a novelty of this study. Alongside this, another main innovation we found in this study showed that when applying resistance, the adjustment of WHRS and WSRH can be independently applied to control RSD, which is different from previous practices and views of integrated disease management. In order to improve the efficiency and benefit of RSD management, future research should focus on the knowledge of the economic factors impacting RSD epidemics via human activities.

Author Contributions: Conceptualization, D.-C.H. and Z.-B.C.; data curation, Y.-L.M., W.-W.L. and S.-S.G.; formal analysis, Y.-L.M., W.-W.L., S.-S.G. and D.-C.H.; funding acquisition, D.-C.H.; investigation, Y.-L.M. and S.-S.G.; methodology, Y.-L.M. and W.-W.L.; software, Y.-L.M. and W.-W.L.; project administration, L.-H.X. and Z.-B.C.; writing—original draft preparation, Y.-L.M., L.-H.X. and D.-C.H.; writing—review and editing, L.-H.X., D.-C.H. and Z.-B.C.; supervision, L.-H.X., D.-C.H. and Z.-B.C. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China, grant number 72073028, the Natural Science Foundation of Fujian province, China, grant number 2022J01960 and 2021J011227, and the Fujian Social Science Foundation, grant number FJ2021BF010 and FJ2021C018.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We thank the assistance of scientists in the plant protection stations of Hongze, Yandu, Xinghua, Dongtai, Jiangyan, Jingjiang, Wujin and Jintan county, Jiangsu province in data collection.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. He, D.C.; Ma, Y.L.; Li, Z.Z.; Zhong, C.S.; Cheng, Z.B.; Zhan, J. Crop rotation enhances agricultural sustainability: From an empirical evaluation of eco-economic benefits in rice production. *Agriculture* **2021**, *11*, 91. [CrossRef]
2. Kisimoto, R. Genetic variation in the ability of a planthopper vector, *Laodelphax striatellus* (Fallen) to acquire the rice stripe virus. *Virology* **1967**, *32*, 144–152. [CrossRef]
3. Kisimoto, R. Biology and monitoring of vectors in rice stripe epidemiology. *ASPAC Food Fertilzer Technol. Cent.* **1993**, *373*, 1–8.
4. Kiyosawa, S. Genetics and epidemiological modeling of breakdown of plant disease resistance. *Annu. Rev. Phytopathol.* **1982**, *20*, 93–117. [CrossRef]
5. Shinkai, A. Present situation of rice stripe disease. *Plant Prot. Jpn.* **1985**, *11*, 503–507.
6. Wei, T.Y.; Yang, J.; Liao, F.R.; Gao, F.; Lu, L.M.; Zhang, X.T.; Li, F.; Wu, Z.J.; Lin, Q.Y.; Xie, L.H.; et al. Genetic diversity and population structure of rice stripe virus in China. *J. Gen. Virol.* **2009**, *90*, 1548. [CrossRef]
7. Otuka, A. Migration of rice planthoppers and their vectored re-emerging and novel rice virus in East Asia. *Front. Microbiol.* **2013**, *4*, 309. [CrossRef]
8. Lee, J.A.; Halbert, S.E.; Dawson, W.O.; Robertson, C.J.; Keesling, J.E.; Singer, B.H. Asymptomatic spread of huanglongbing and implications for disease control. *Proc. Natl. Acad. Sci. USA* **2015**, *24*, 7605–7610. [CrossRef] [PubMed]
9. He, D.C.; Zhan, J.; Xie, L.H. Problems, challenges and future of plant disease management: From an ecological point of view. *J. Integr. Agric.* **2016**, *154*, 60345–60352. [CrossRef]
10. Khatun, M.T.; Nessa, B.; Salam, M.U.; Kabir, M.S. Strategy for rice disease management in Bangladesh. *Bangladesh Rice J.* **2021**, *25*, 23–36. [CrossRef]
11. He, D.C.; Burdon, J.; Xie, L.H.; Zhan, J. Triple bottom-line consideration of sustainable plant disease management: From economic, sociological and ecological perspectives. *J. Integr. Agric.* **2021**, *20*, 2–12. [CrossRef]
12. He, D.C.; He, M.H.; Amalin, D.; Liu, W.; Alvindia, D.; Zhan, J. Biological control of plant diseases: An evolutionary and eco-economic consideration. *Pathogens* **2021**, *10*, 1311. [CrossRef] [PubMed]
13. Liu, D.; Liu, Y.; Liu, L.; Cui, X.; Shen, Z.; Liu, J.; Yu, X.G.; Wang, Z.; Zhang, S.; Mu, Q.Q. Prevalence characteristics of rice black-streaked dwarf virus disease and continuous control strategies. *Asian Agric. Res.* **2021**, *13*, 5.
14. Kiritani, K.; Plumb, R.T.; Thresh, J.M. Changes in cropping practices and the incidence of hopper-borne diseases of rice in Japan. *Plant Virus Epidemiol.* **1983**, *9*, 239–247.
15. Kisimoto, R. Planthopper-rice virus epidemiology model: Rice stripe and small brown planthopper, Laodelphax striatellus fallen. In *Plant Virus Epidemics Monitoring Modelling & Predicting Outbreaks*; Academic Press: Cambridge, MA, USA, 1986; pp. 327–344.

16. Kiritani, K.; Nakasuji, F.; Miyai, S.I. Systems approaches for management of insect-borne rice diseases. *Curr. Top. Vector Res.* **1987**, *3*, 57–80.
17. Hayakawa, T.; Zhu, Y.; Itoh, K.; Kimura, Y.; Izawa, T.; Shimamoto, K.; Toriyama, S. Genetically engineered rice resistant to rice stripe virus, an insect-transmitted virus. *Proc. Natl. Acad. Sci. USA* **1992**, *89*, 9865–9869. [CrossRef]
18. Bae, S.D.; Kim, D.K. Occurrence of small brown planthopper (*Laodelphax striatellus* Fallen) and incidence of rice virus disease by different seeding date in dry seeded rice. *Korean J. Appl. Entomol.* **1994**, *3*, 173–177.
19. Endo, S.; Tsurumachi, M. Insecticide resistance and insensitive acetylcholinesterase in small brown planthopper, *Laodelphax striatellus*. *J. Pestic. Sci.* **2000**, *25*, 395–397. [CrossRef]
20. Endo, S.; Tsurumachi, M. Insecticide susceptibility of the brown planthopper and the white-backed planthopper collected from Southeast Asia. *J. Pestic. Sci.* **2001**, *26*, 82–86. [CrossRef]
21. Xiao, D.; Li, W.; Wei, T.; Wu, Z.; Xie, L. Advances in the studies of rice stripe virus. *Front. Agric. China* **2010**, *4*, 287–292. [CrossRef]
22. Tian, B.; Xie, J.; Fu, Y.; Cheng, J.; Li, B.; Chen, T.; Zhao, Y.; Gao, Z.X.; Yang, P.; Barbetti, M.; et al. A cosmopolitan fungal pathogen of dicots adopts an endophytic lifestyle on cereal crops and protects them from major fungal diseases. *ISME J.* **2020**, *14*, 3120–3135. [CrossRef] [PubMed]
23. He, D.C.; Zhan, J.; Cheng, Z.B.; Xie, L.H. Viruliferous rate of small brown planthopper is a good indicator of rice stripe disease epidemics. *Sci. Rep.* **2016**, *6*, 21376. [CrossRef] [PubMed]
24. Zhang, C.; Shi, G.; Shen, J.; Hu, R. Productivity effect and overuse of pesticide in crop production in China. *J. Integr. Agric.* **2015**, *14*, 1903–1910. [CrossRef]
25. Zhang, K.; Xu, H.; Zhuang, X.; Guo, X.; He, Z.; Xu, K.; Liu, F. Sensitive and high-throughput polyclonal antibody-based serological methods for rice stripe virus detection in both rice and brown planthopper. *Crop. Prot.* **2021**, *144*, 105599. [CrossRef]
26. Murakami, M.K.T. Occurrence of insect pests in rice stripe disease resistant cultivar. *Proc. Kanto-Tosan Plant Prot. Soc.* **1986**, *33*, 186–187.
27. Zhu, J.L.; Zhu, Z.R.; Zhou, Y.; Lu, Q.; Sun, X.L.; Tao, X.G.; Chen, Y.; Wang, H.D.; Cheng, J.A. Effect of rice sowing date on occurrence of small brown planthopper and epidemics of planthopper-transmitted rice stripe viral disease. *Agric. Sci. China* **2009**, *8*, 332–341. [CrossRef]
28. Arata, G.; Martínez, M.; Elguezábal, C.; Rojas, D.E.; Cristos, D.; Dinolfo, M.; Arata, A. Effects of sowing date, nitrogen fertilization, and *Fusarium graminearum* in an argentinean bread wheat: Integrated analysis of disease parameters, mycotoxin contamination, grain quality, and seed deterioration. *J. Food Compost. Anal.* **2021**, *107*, 104364. [CrossRef]
29. Ahn, E.K.; Hyun, U.J.; Jung, K.H.; Won, Y.J.; Hong, H.C.; Park, H.M.; Chang, J.K.; Lee, J.H.; Sung, N.S.; Suh, J.P.; et al. 'Keunpum': A mid-late maturing, high yielding, giant embryo rice cultivar with resistance to multiple diseases and used as germinated brown rice. *Korean J. Breed. Sci.* **2021**, *53*, 515–525. [CrossRef]
30. Naseri, B.; Hemmati, R. Bean root rot management: Recommendations based on an integrated approach for plant disease control. *Rhizosphere* **2017**, *4*, 48–53. [CrossRef]
31. Kim, K.H.; Cho, J.; Lee, Y.; Lee, W.S. Predicting potential epidemics of rice leaf blast and sheath blight in South Korea under the RCP 4.5 and RCP 8.5 climate change scenarios using a rice disease epidemiology model, epirice. *Agric. For. Meteorol.* **2015**, *203*, 191–207. [CrossRef]
32. Barnett, O.W.; Main, C.E. Plant virus disease—Economic aspects. *Encycl. Virol.* **1999**, *16*, 1318–1326.
33. Hao, Z.; Wang, L.; He, Y.; Liang, J.; Tao, R. Expression of defense genes and activities of antioxidant enzymes in rice resistance to rice stripe virus and small brown planthopper. *Plant Physiol. Biochem. PPB* **2011**, *49*, 744–751. [CrossRef] [PubMed]