Epidemiology and management of rice viruses and virus diseases

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Abstract

The majority of the over 30 rice viruses and diseases occur in American and Asian countries. In Africa, only about five viruses (*Rice stripe necrosis furovirus*, Rice crinkle disease, *Maize streak geminivirus* strain A, *African cereal streak virus*, and *Rice yellow mottle sobemovirus*) have been known to infect rice in nature. Most of the rice viruses are transmitted by either plant- or leafhoppers. A few are transmitted through mechanical sap inoculation, contact, soil, and seed, while other viruses are transmitted by rice mealy bugs, beetles, aphids, and fungus *(Polymyxa graminis).* The causes of the virus epidemics and their pests' outbreaks are primarily based on the intensification of rice cultivation and the introduction of new, high yielding varieties. It is also due to the increased use of irrigation, fertilizer, and pesticides, changing cultural practices, crop monoculture, and mechanical contamination. The management of rice virus diseases includes breeding and screening for varietal resistance, efficient cultural practices, and integrated pest and disease management strategies. Priority research gaps are also enumerated.

Résumé

La majeure partie des plus de 30 virus et maladies qui attaquent le riz se trouve en Amérique et en Asie. En Afrique, seulement cinq virus ont été identifiés sur le riz à l'état naturel : le furovirus de la nécrose à rayure du riz, le Rice crinkle disease, le geminivirus de souche A de la striure du maïs, le virus africain de la striure des céréales et le sobemovirus de la marbrure jaune du riz. La plupart des virus du riz sont transmis par les cicadelles des plantes ou des feuilles. Quelques uns sont transmis par inoculation mécanique de la sève, le contact, le sol ou les semences, tandis que d'autres sont transmis par les cochenilles du riz, les coléoptères, les pucerons, et les champignons (*Polymyxa graminis*). Les épidémies de viroses et les pullulements de leurs agents pathogènes sont avant tout dus à l'intensification de la riziculture et l'introduction de

nouvelles variétés à haut rendement. Ils sont également induits par d'autres facteurs tels que le recours de plus en plus fréquent à l'irrigation, aux engrais et pesticides, à des pratiques culturales variables, à la monoculture et à la contamination mécanique. La lutte contre les viroses du riz comporte plusieurs volets : sélection et criblage pour la résistance variétale, pratiques culturales efficaces et approches de lutte intégrée. Cette communication relève également les insuffisances de la recherche qui doivent bénéficier d'une attention spéciale.

Introduction

Three decades ago, virus diseases of rice were seen as unimportant, especially in Africa. However, with the outbreaks of pests and the virus diseases they transmit as well as increased study and awareness, this opinion has changed. At the moment, over 30 rice viruses and the diseases they cause occur in Africa, Asia, Latin America, the United States of America, and the rest of the world. While most of these viruses occur in the American and Asian countries, only five viruses (*Rice stripe necrosis virus* [RSNV] genus *Furovirus, Rice crinkle disease, Maize streak virus* [MSV] genus *Geminivirus* strain A, *African cereal streak virus*, and *Rice yellow mottle virus* [RYMV] genus *Sobemovirus*) have so far been reported to infect rice in nature. However, some viruses are infectious to rice in experimental tests only, while others infect rice in nature. Twenty-six of the rice viruses are of economic importance to rice while the rest such *Sugarcane potyvirus*, *Maize dwarf mosaic virus* (MDMV) genus *Potyvirus, Maize rough dwarf virus* (MRDV) genus *Fijivirus, Ryegrass mosaic virus*, *Brome mosaic virus* (BMV) genus *Bromovirus, Barley stripe mosaic virus* (BSMV) genus *Hordeivirus, Barley yellow dwarf virus* (BYDV) genus *Luteovirus, Oat pseudorosette virus* genus *Tenuivirus*, and *Wheat streak mosaic virus* (WSMV) genus *Rymovirus* have been found to infect rice in experimental tests only (Khan and Dickerson 1957; Harder and Bakker 1973; Bakker 1974). These rice viruses are transmitted by leafhoppers, plant-hoppers, beetles, aphids, mealy bugs, and fungus (*Polymyxa graminis)*. A few others are transmitted by contact and mechanical sap inoculations as well as soil. Only two viruses (*Rice wrinkled stunt* and *Rice witches broom*) are seedborne (Table 1).

This paper gives a synthesis of the underlying causes of rice epidemics, their transmission, host range, and management strategies of the virus diseases. Priority research gaps are also highlighted.

Table 1. Vector specificity in the transmission of rice viruses.

Types of vectors/ transmission sources	Group of viruses transmitted
Plant-hopper-borne	*Rice black streaked dwarf fijivirus, Rice grassy stunt tenuivirus, Rice hoja blanca tenuivirus, Rice ragged stunt phytoreovirus, Rice stripe tenuivirus, Rice wilted stunt virus*
Leafhopper-borne	*Rice bunchy stunt phytoreovirus, Rice dwarf phytoreovirus, Rice gall dwarf phytoreovirus, Rice transitory yellowing rhabdovirus, Maize streak germinivirus strain A, Rice orange leaf virus, Rice waika machlovirus, Rice tungro badnavirus, Rice tungro helper machlovirus, African cereal streak virus*
Beetles *(Chrysomelidae* and *phytophagus Coccinelidae)*	*Rice yellow mottle sobemovirus*
Aphid-borne	*Rice guillame luteovirus*
Fungus *(Polymyxa graminis)*	*Rice necrosis mosaic luteovirus, Rice stripe necrosis luteovirus*
Rice mealy bug	*Rice chlorotic streak virus*
Soil	*Rice crinkle virus disease*
Seedborne	*Rice wrinkled stunt disease,* witches' broom disease
Mechanical/contact	*Rice mosaic virus, Rice yellow mottle sobemovirus*

Underlying causes of rice virus diseases

Many factors are known to influence the incidence of virus diseases which, in most cases, lead to epidemics (Buddenhagen 1983; Thresh 1989). According to Thresh (1983, 1989) and Abo and Sy (1998) the factors that contribute to the causes of rice pests and diseases are:

- Intensification and modification of rice culture. Growing improved susceptible varieties as well as the use of pesticides and fertilizers reveal this. The continuous change of farming systems also alters the natural ecology of crops and viruses.
- Planting rice without dry-season gaps. The availability of irrigation facilities extends the growing season leading to short intervals between successive plantings. The continuous use of irrigation also leads to the survival and perennation of pests and pathogens as well as the growth of weeds, which play a role in the survival of viruses (Duffus 1971).
- The use of pesticides normally destroys natural enemies, leading to pest resurgence while the use of fertilizer can influence plant growth favoring pest population buildup and the survival of viruses.

- New varieties are inherently more vulnerable to pests and diseases than the traditional landraces they have replaced. The horizontal resistance of landraces to pests and diseases has been replaced in modern varieties by vertical resistance.
- The introduction and extensive cultivation of the modern varieties coupled with monoculture, especially of highly susceptible varieties over large areas by farmers. In most cases, these modern varieties are exposed to new areas without adaptive testing and so become vulnerable to pests and pathogens leading to serious outbreaks.
- Some viruses can be carried by wind to areas far from their origin (e.g., *Rice hoja blanca virus* (RHBV) genus *Tenuivirus*). Also vector migration could lead to the introduction of a virus to a new area.
- Mechanical sap inoculations, and contact by humans, animals, and farm tools.
- Some seedlings could be infected from the nursery and be carried to the fields during transplanting.
- Most viruses that are seedborne can be carried along with the seeds.

Rice viruses and virus diseases and management strategies

The geographical distribution, host range, and transmission/vector information are presented in Table 2. The majority of rice viruses are transmitted by leafhoppers. *Rice tungro machlovirus/badnavirus*, *Rice grassy stunt virus* (RGSV) genus *Tenuivirus*, and *Rice ragged stunt virus* (RRSV) genus *Oryzavirus* are the only viruses known to have co-evolved with rice (Buddenhagen 1983).

A few viruses and the diseases they cause are described below.

Rice black-streaked dwarf virus (RBSDV) genus *Fijivirus*

The *Rice black-streaked dwarf virus (RBSDV)* genus *Fijivirus* (Kuribayashi and Shinkai 1952) is a spherical (isometric) polyhydral particle measuring between 60 and 120 nm in diameter (Shikata et al.1967; Kitagawa and Shikata 1969). It is essentially a phloem gall disease (Ou 1985). The diseased plants are normally stunted, contain dark colored foliage, and produce excessive tillers (Kajino 1997). Leaf blades appear twisted and heads do not normally form. The heads when formed contain dark-brown blotches.

It is known that the perpetuation of the virus from one season to another is through overwintering plant-hoppers (Shinkai 1962). Exotic rice cultivars are known to be more susceptible to the virus than native ones (Mikoshiba et al. 1983; Shikata and Kitagawa 1977). The management of virus diseases is based on the screening and development of varieties (Kitagawa and Shikata 1969) and use of insecticide sprays (Kim et al. 1988). It also involves the combination of cultural practices such as the elimination of the virus source and the exclusion of weeds and crops, which increase vector density (Honda and Kameya-Iwaki 1991). Early or optimum sowing dates to escape peak periods of

Table 2. Rice virus diseases: group, mode of transmission, vectors, host plants, and geographical distribution.

Virus group/disease	Transmission/vector	Host plants	Geographical distribution	Selected references
Rice black streaked dwarf; fijivirus (RBSDV)	Persistent; Delphasidae (*Laodelphax*), Striatellus, Unkanodes Sappononus, Ribautodelphax, Albifascia	*Oryza sativa, Alopecurus aequalis,* several cereals and other *graminae*	Japan, Korea, China	Kuribayashi & Shinkai 1952; Honda & Kameya-Iwaki 1991
Rice bunchy stunt phytoreovirus (RBSV)	Persistent cicadellidae (*Nephottetix cincticeps, N. virescens)*	*Oryza sativa*	China	Xie et al. 1981; Xie & Lin 1983.
Rice dwarf phytoreovirus (RDV)	Persistent cicadellidae *(Nephottetix cincticeps, N. nigropictus apicalis, Recilia dorsalis)*	*Oryza sativa, Echinochloa crus-galli, Alopecurus fulvius, Panicum miliaceum, Avena sativa, Poa pratense, Secale cereale, Triticum aestivum*	Japan, Korea, China, Nepal	Takata 1985; Omura et al. 1986
Rice gall dwarf phytoreovirus (RGDV)	Persistent Cicadelidae *(Nephottetix nigropictus)*	*Oryza sativa, Avena sativa, Hordeum vulgare, Lolium multiflorum, Secale cereale, Triticum aestivum*	Thailand, China	Omura et al. 1980, 1982; Omura & Inoueye 1985
Rice grassy stunt tenuivirus, (RGSV) synonym: Rice rosette tenuivirus (RSV)	Persistent Dephacidae (*Nilaparvata lugens*)	*Oryza sativa, Echinochloa colonum, O. punctata, Cynodon dactylon, Cyperus rotundus, Leersia hexandra, Monochoria vaginalis*	China, Japan, Indonesia, Taiwan, Malasia, Thailand	Hibino et al. 1977; Brunt et al. 1990
Rice hoja blanca tenuivirus (RHBV)	Persistent Dephacidae (*Sogatodes oryzicola, S. cubens),* Cicadellidae (*Hortensia similis*)	*Oryza sativa, Avena sativa, Digitaria* spp. *Hordeum vulgare Leptochloa* spp. *Secale cereale, Triticum aestivum, Echinochloa colonum*	Colombia, Costa Rica, Dominican Rep., Ecuador, Honduras, Cuba, Panama, Peru, Nicaragua, Surinam, El Salvador, Venezuela, USA	Grace's 1940; Malaguti et al. 1957; Morales & Niessan, 1985
Rice guillame (RGV) luteovirus (a strain of barley dwarf luteovirus (BDV)	Aphidae (*Rhopalosiphum padi*)	*Oryza sativa, Leersia oryzoides, Echinochloa crus-galli, Holcus lanatus, Lolium perenne, Panicum dichotomiflorum*, oats, wheat, barley.	Italy	Amici et al. 1974; Brunt et al. 1990

Table 2. (Continued).

Virus group/disease	Transmission/vector	Host plants	Geographical distribution	Selected references
Rice transitory yellowing rhabdovirus (RTYV)	Persistant Cicadelidae (*Nephottetix nigropictus, N. cicticeps, N. virescens)* mechanical	*Oryza sativa, Leersia hexandra, Panicum maximum, Nicotiana rustica*	Taiwan, China	Chiu et al. 1980; Shikata 1972
Rice yellow dwarf myco-plasma-like organisms (RYDMLO's)	Persistent Cicadellidae (*Nephottetix* nigropictus, *N. cincticeps, N. virescens*)	*Oryza sativa, Alopecurus aequalis, Glyceria acutiflora, Paspalum distinchum, Leptochloa chinnesis, Leersia hexandra*	Throughout Asia	Kurosawa 1940; Plavsic et al. 1973
Rice necrosis mosaic luteovirus (RNMV)	Mechanical Plasmodiaphorales (*Polymyxa graminis)*	*Oryza sativa*	Japan	Fujii et al. 1967; Ghosh 1981
Rice ragged stunt phytoreovirus (RRSV)	Persistent Delphacidae (*Nilaparvata lugens)*	*Oryza sativa, O. Latifolia, O. nivara, Hordeum vulgare, Zea mays*	Indonesia, the Philippines, Thailand, Malaysia, China, Japan, Taiwan, India, Sri Lanka, Bangladesh	Hibino et al. 1977 Milne et al. 1982; Boccardo & Milne 1984
Rice stripe necrosis furovirus (RSNV)	Plasmodiaphorales (*Polyrnyxa graminis)*	*Oryza sativa, Chenopodium amaranticolor, Nicotiana benthamiana*	Côte d'Ivoire	Louvel & Bidaux 1977; Fauquet & Thouvenel 1983
Rice stripe (RSV) tenuivirus	Persistent Dephacidae (*Loadelphax striatellus, Unkanodes sapporonus, Ribautodelphax albifascia*)	*Oryza sativa,* many other members of the graminae	Japan, South Korea, Russia, Taiwan, China	Kuribayashi 1931; Yamada & Yamamoto 1956; Koganezawa et al. 1975, Reifman et al. 1978; Toriyama 1983, 1986
Rice chlorotic streak virus (RCSV), group not yet established	Nonpersistent: rice mealy bug (*Brevennia rehi, = Heterococcus rehi* or *Ripersia oryzae*)	*Oryza sativa*	India	Anjaneyulu et al. 1988
Rice mosaic virus (RMV), group not yet established	Mechanical	*Oryza sativa, Zea mays*	The Philippines	Martinez et al. 1960
Maize streak geminivirus (MSV) strain A	Persistent Cicadellidae (*Cicadulina* [spp], *Agrobacterium tumefaciens)*	Very wide host range in the graminae family	Africa, Madagascar, Yemen, Mauritius, Réunion, India, Vanuatu, São Tomé & Principe	Storey 1925; Bock 1974

Table 2. (Continued).

Virus group/disease	Transmission/vector	Host plants	Geographical distribution	Selected references
Rice orange leaf virus (ROLV), group not yet established	Semipersistent; Cicadellidae (*Recilia inazuma dorsalis*)	*Oryza sativa*	Thailand, The Philippines, Sri Lanka, Malaysia, Australia, India,	Ou 1963, Wu et al. 1980
Rice waika machlovirus (RWV)	Semipersistent; Cicadellidae (*N. cincticeps, N. virescens, N. nigropictus N. malayanus*)	*Oryza sativa*	Japan	Nishi et al. 1975; Doi et al. 1975; Inoue 1978
Rice wilted stunt virus (RWSV), group not yet determined but is related to *Grassy stunt tenuivirus* (RGSV)	Semipersistent; Dephacidae (*Nilaparvata lugens)*	*Oryza sativa*	Taiwan	Chen et al. 1978;
Rice wrinkled stunt disease (RWSD)., aetiology and group not yet worked out	Seedborne	*Oryza sativa*	Suriname	Ou 1985
Witches broom disease WBD) aetiology and group not yet worked out	Seedborne	*Oryza sativa*	Suriname	Ou 1985
Rice crinkle virus disease	Soil	*Oryza savita* (Upland)	Sierra Leone, Côte d'Ivoire, Liberia, Nigeria	Buddenhagen 1983
Rice tungro helper machlovirus (RTV)	Nonpersistent; *Cicadellidae (Nephottetix virescens, N. nigropictus*, *N. malayanus, N. parvus*, *Recilia dorsalis*	*Oryza sativa, Echinochloa colonum, E. crus-galli, Eleusine indica*, many species of wild rice, *Cynodon dactylon, Ischaemum aegyptium, Paspalum distichum*	The Philippines, Malaysia, Indonesia, Thailand, India, Bangladesh, China, Japan	IRRI 1963; Ou & Ling 1966; Galvez 1968, 1971; Thomas & John, 1980

Table 2. (Continued).

Virus group/disease	Transmission/vector	Host plants	Geographical distribution	Selected references
Rice tungro badnavirus (RTV) Synonyms: *Rice waika virus*, *Rice mentek* virus, *Rice penyakit merah virus*, *Rice yellow orange leaf virus, Cadang cadang yellowing* requires helper *machlovirus* for expression)	Persistent Cicadellidae (*Nephottetix virescens, N. nigropictus N. parvus*)	*Oryza sativa,* many species of wild rice, *Echinochloa* spp, *Eleusine indica*, *Leersia hexandra,* and many other Graminae as in *machlovirus*	South and southeast Asia, Japan, China & as in *machlovirus*	Saito 1977; Anjanenyulu et al. 1988.

insect attack are also utilized (Zhou et al. 1998). A plant spacing of 30 × 10 cm reduced infection of the virus (Jin and Jung 1989).

Rice bunchy stunt (?)*Phytoreovirus*

The virus particles are spherical (Xie et al. 1981). The disease is characterized by dwarfing and profuse tillering. Sometimes tillers culminate in a witch's broom. Apart from its distribution, host-plant range, and mode of transmission (Table 2), no further information is available on this virus. However, the disease is sometimes confused with dwarf disease or grassy stunt disease (Xie et al. 1979).

Rice dwarf virus (RDV) genus *Phytoreovirus*

This virus is hexagonal, measuring 70 nm in diameter (Fukushi and Shikata 1963). The distinguishing symptoms of the disease are stunting of the whole plant with chlorotic specks on leaves and leaf sheath (Ou 1985). The virus is known to cause mortality and also fecundity of insects.

Varietal resistance and chemical control of the insect vectors have been used to check the spread of the disease.

Rice gall dwarf virus (RGDV) genus *Phytoreovirus*

It has polyhedral particles measuring 65 nm in diameter (Omura et al. 1980). The characteristic symptoms of the disease are stunting, formation of galls on the leaf blades and sheaths, and slight twisting of diseased plants. The epidemiology and control methods are yet to be clearly worked out.

Rice grassy stunt virus (RGSV) genus *Tenuivirus*

It is an isometric particle measuring 20 nm in diameter (Shikata et al. 1980). The diseased plants are severely stunted, producing excessive tillering and abnormal erect growth. The leaves contain irregular blotches and are short, stiff, narrow, erect, and pale green or yellow. The infected plants may or may not produce panicles.

The management of the disease includes destruction of the vector, removal of infected stubble, and the use of resistant varieties (FAO 1994).

Rice hoja blanca virus (RHBV) genus *Tenuivirus*

The *Rice hoja blanca virus* (RHBV) genus *Tenuivirus* otherwise known as "white leaf" is a long, flexuous, thread-like, spherical particle of variable length and diameter (Herold 1968; Shikata and Galvez 1969; Kitajima and Galvez 1973).

The infected plants are stunted and contain poorly filled spikelets. The leaves develop chlorotic stripes. The control of the disease involves the use of resistant varieties such as CICA7 and CICA9. However, spraying for insect vector control had led to the

resurgence of the vector and high incidence of the disease in Ecuador and Colombia (Buddenhagen 1983).

Rice tungro bacilliform virus (RTBV) genus *Badnavirus/Rice tungro spherical virus* (RTSV) genus *Waikavirus*

The virus complex causing the important rice tungro disease consists of two viruses, *Rice tungro bacilliform virus* (RTBV) genus *Badnavirus* and *Rice tungro spherical virus* (RTSV) genus *Waikavirus* (Hibino et al. 1978). RTBV is a single-stranded RNA (ssRNA) while RTSV is a single-stranded DNA (ssDNA). The particles of these viruses vary (Hibino et al. 1979).

The disease leads to degenerated growth of affected plants. Conspicuous symptoms include stunting, discoloration of leaves and young infected leaves may have a mottled appearance. Old leaves will show rust-colored specks of varying sizes. There is delayed flowering and the panicles are normally small, incompletely exerted, and often occur with dark-brown specks.

Management practices for the disease include removal and burning of infected stubble, eradication of weeds and vectors, and above all, the use of tungro-resistant varieties such as Neela, CR 163-3-CRRP-50, and Pankhari 203.

Rice yellow mottle virus (RYMV) genus *Sobemovirus*

This virus is a single-stranded, positive sense RNA (SSRNA) measuring about 28 ± 3 nm in diameter (Bakker 1974; Fauquet and Thouvenel 1977). It is specific to the African continent.

The disease is identified by mottled and yellowing symptoms of varying intensities depending on the genotype (Thottappilly and Rossel 1993). Additional symptoms include stunting, grain or spikelet sterility, and grain discoloration (Bakker 1975). In severe cases, diseased plants may die. It is the only rice disease of economic importance in Africa.

The management strategies of the virus disease involve the use of varietal resistance and chemical treatment, cultural practices, training for disease management and diagnosis, and Task Force mechanisms (Abo et al. 1998; Abo and Sy 1998).

Future research needs and priority research gaps

Remarkable achievements have been made in ecological characterization, breeding for resistance, varietal improvement, inheritance and mechanisms of resistance, isolate variability studies, mode of transmission, and genetic engineering of rice against the viruses. However, priority research gaps still remain to be adequately covered in order to fully understand the epidemiology of the viruses. These gaps are:

- Pattern and sequence of virus spread in the field.
- Characterization of pathogen diversity in terms of serological, molecular, and biological studies.
- Additional identification and characterization of donors for breeding purposes.
- Studies on the occurrence of the insect vectors and their population dynamics.
- Search for additional vectors of the viruses.
- Evaluation of transgenic plants in hot spots for virus resistance.
- Increased study on the inheritance and mechanisms of resistance. Resistant genes should also be mapped.
- Assessment of the economic impact of the viruses.
- Investigation of the effect of environmental factors and changing cropping practices on the incidence of the virus diseases.
- Establishing how the virus persists and subsists in the field.
- Strategies for integrated pest and disease management. The limitations in the implementations of the management strategies should be highlighted or investigated.

Conclusion

There has been considerable improvement on the study of rice viruses and the diseases they cause in the world. However, most of the viruses are localized. Some are confined to specific areas. The RYMV is confined to Africa (Abo et al. 1998). The *Rice tungro virus* disease is restricted to Asia, RHBV to the Americas, and *Rice wrinkled virus* disease has been reported only in Suriname. However, most of these viruses have the potential of disseminating far from their areas of origin.

The control of these virus diseases can be achieved through integrated pest and disease management strategies.

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