EPIDEMIOLOGY, MOLECULAR CHARACTERIZATION AND YIELD LOSS ASSESSMENT OF RICE DUE TO RICE YELLOW MOTTLE SOBEMOVIRUS IN NORTHERN NIGERIA

BY

ALKALI, Goni
(B.Sc. Agric., M.Sc. Plant Pathology Unimaid)
Ph.D/Agric/00548/2006-2007

A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

IN PARTIAL FULFILMENT FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY IN CROP PROTECTION

DEPARTMENT OF CROP PROTECTION
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA, NIGERIA

DECEMBER, 2012

DECLARATION

I declare that the work in the dissertation entitled 'Epidemiology, Molecular Characterization and Yield Loss Assessment of Rice due to Rice Yellow Mottle Sobemovirus in Northern Nigeria" has been performed by me in the Department of Crop Protection under the supervision of Professor M. D. Alegbejo, Dr. B. D. Kashina and Professor O. O. Banwo. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any University.

ALKALI, Goni

_____ _____

Signature Date

CERTIFICATION

This dissertation entitled 'EPIDEMIOLOGY, MOLECULAR CHARACTERIZATION AND YIELD LOSS ASSESSMENT OF RICE DUE TO RICE YELLOW MOTTLE SOBEMOVIRUS IN NORTHERN NIGERIA" by ALKALI, Goni meets the regulations governing the award of the degree of Doctor of Philosophy of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

Professor M. D. Alegbejo		
Chairman, Supervisory Committee	Signature	Date
Dr. B. D. Kashina		
Member, Supervisory Committee	Signature	Date
Professor O. O. Banwo		
Member, Supervisory Committee	Signature	Date
Professor (Mrs.) A. B. Zarafi		
Head of Department	Signature	Date
Professor A. A. Joshua		
Dean, School of Postgraduate Studies	Signature	Date

DEDICATION

This work is dedicated to my children Ya Falmata, Muhammad Kyari (Late), Ibrahim, Ismail, Muhammad Mustapha and Kaka Ashe.

ACKNOWLEDGEMENTS

All praise is due to Allah, The Most High, Who through His infinite mercy and guidance gave me this opportunity to come this far in my academic programme. And may His peace and Blessings be upon His noble Prophet Muhammad

My profound gratitude to the chairman of my supervisory committee, Professor M.D. Alegbejo, for his timely and prompt responses, effort, support and guidance throughout the period of this research work. His patience, constructive criticism, corrections, suggestions and assistance with relevant publications and other materials toward the outcome of this research is of the highest standard. I am very grateful to him. I express my gratitude also to the members of the supervisory committee, Dr. B. D. Kashina and Professor O. O. Banwo for their timely responses, corrections, suggestions, constructive criticisms, support and assistance with relevant publications and other materials toward making this work a success. I thank DSMZ (German collection of microorganism and cell cultures) for the provision of the antisera.

Thanks to Dr. M. E. Abo of the National Cereal Research Institute, Badeggi, Nigeria for assisting me with relevant literature and Rice seeds. I appreciate the technical support and generosity of Dr. E. E. Ella of the Department of Microbiology, John Shafa of the Department of Biochemistry, Mallam Samir of the Centre for Biotechnology Research and Training, Mallam A. S. Isa of the Department of Agronomy, Alhamdu Bello University (ABU), Zaria, toward the success of this study. I owe a debt of gratitude to Mallam Z. Abdulmalik of the Virology Unit and Mr. Musa I. P. of the Insect museum Department of Crop Protection, Institute for Agricultural Research (IAR) ABU, Zaria, for their contributions toward the success of this study. Thanks to all the academic and non-academic staff of the Department of Crop Protection, IAR/ABU, Zaria, for their helpful contributions and for providing the enabling environment during the research period. I appreciate

the friendliness and encouragement of Dr. M. T. Salaudeen of the Department of Crop Protection, Federal University of Technology, Minna, most especially for exchanging useful ideas during the programme. I acknowledge the encouragement and contributions of my friends, particularly those of the Akenzua hostel, ABU, Zaria, including Ibrahim Umar Wali, Dr. B. S. Waziri, Dr A. U. Kawuyo, Abba Sidi S. Umar. Mallam Muhammad Yunusa, Rabiu Adamu, Architect Mai Haruna, Mallam Bello Amsami and Tella Abba.

I am grateful to the management of University of Maiduguri for the full financial support awarded to me through the study fellowship, my lecturers and colleagues from University of Maiduguri, for their encouragement and various contributions towards this programme. Finally, I am most grateful to the entire members of my family, especially my dear wife Ya Fati Wali for their support, understanding and patience, May Almighty Allah bless you all.

ABSTRACT

Screenhouse and field experiments were conducted between 2008 and 2010 to quantify yield loss due to Rice yellow mottle virus (RYMV) in some selected rice cultivars; determine the epidemiology of RYMV in relation to weather factors on the incidence of RYMV and insect vector population composition and identification studies; identify its alternative hosts; determine serotypes of the pathogen; and molecular characterization of the strains and their distribution in the northern states of Nigeria. The screenhouse experiment was arranged in a strip plot design with three replicates. Significant interaction between the effects of inoculation regimes and rice cultivars were found between the disease, growth and yield parameters. The critical periods of RYMV infection for most of the rice cultivars used was within 4 - 8 Weeks after sowing (WAS). Paddy yield losses of 6.59 - 79.11 % and 3.65 - 81.67 % were recorded on the test cultivars in rainy and dry seasons, respectively. Keeping the plants RYMV- free for up to 10 WAS resulted in grain yield almost similar to control. The epidemiology experiment was laid out in a randomized complete block design (RCBD) with three replicates. Significant positive and negative correlations were recorded between RYMV incidence and severity index, some insect vectors and weather factors. Insect species collected in and around the experimental field, included *Oxya* sp., *Locris rubra* Fabriculus*,, Chnootriba similis* Thunberg, *Chaetocnema* sp., *Cheilomenes* sp*., Zonocerus variegatus* L., *Paratettix* sp., *Conocephalus* sp., *Nezara viridula* L. and *Dactylispa* sp. they transmitted the virus to different degree. Serological studies showed that some weed species with or without symptoms collected, across RYMV infected areas in Northern Nigeria tested positive to RYMV. These included *Imperata cylindrica* L., *Erograstic tenella* L., *E. Ciliaris* L., *Digitaria horizontalis* Wild*., Eleusine indica* (L) Gaertner*., E. corocana* L*., Cynodon dactylon* (L) Pers., *Panicum* sp*., Dactyloctenium aegyptium* L*., Brachiaria lata* (Schumach) C.E. Hubbard ex Robyns., *Axonopus compressus* (Sw.) P. Beauv., *Cyperus rotundus* L., *C. difformis* L., *Oryza barthii* A. Chev., *O. longistaminata* A. Chev.& Roehr. and *Pennisetum pedicellatum* Trin. Six serological profiles (Sep.) or serotypes were identified (Sep A to F) in this study. Sep A was found in Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states, Sep B was found in Borno, Gombe, Kaduna, and Kano, states, Sep C was found in Gombe state, Sep D was found in Borno, Sokoto and Zamfara states, Sep E was found in Borno and Zamfara states and Sep F was found in Kano, Niger and Sokoto states. The molecular characterization of RYMV isolates revealed that more than two strains of the virus were present in northern Nigeria. Strain S1 is widespread in Borno, Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states. By contrast, strain S2 was only detected in Gombe, Kaduna and Niger states. Strains SX occurred in swampy sites in Borno, Gombe, Kaduna, Kano and Zamfara states. The information provided on the vulnerable phase of the plant growth on yield loss to the pathogen can be useful in integrated pest and production management for rice in RYMV endemic areas. The relationship established between RYMV incidences, insect vector population and variation in weather factors data could be used in RYMV disease magnitude prediction. In addition, Knowledge of weed hosts, potential insect vectors in and around RYMV infected fields, and distinction between isolates/strains is critical and would provide useful information in pathogenicity and breeding studies of RYMV in Northern Nigeria.

TABLE OF CONTENT

	Pages
Title page	i
Declaration	ii
Certification	iii
Dedication	iv
Acknowledgement	v
Abstract	vii
Table of Content	viii
List of Figures	xv
List of Tables	xvi
List of Plates	xx
List of Appendices	xxi
Symbols	xxxii
Abbreviations	xxxiii
CHAPTER ONE	
1.0 INTRODUCTION	1
1.1 JUSTIFICATION	4
1.2 OBJECTIVES OF THE STUDY	6
CHAPTER TWO	
2.0 LITERATURE REVIEW	.7
2.1 RICE	7
2.2 IMPORTANCE OF RICE YELLOW MOTTLE VIRUS	7
2.3 DISTRIBUTION OF RICE YELLOW MOTTLE VIRUS	8
2.4 SYMPTOMS OF RICE YELLOW MOTTLE VIRUS	10
2.5 MOLECULAR CHARACTERISTICS AND SEROTYPES OF RICE	

YELLOW MOTTLE VIRUS 13

2.6 TRANSMISSION OF RICE YELLOW MOTTLE VIRUS 15

2.7 HOST RANGE OF RICE YELLOW MOTTLE VIRUS. 16

2.8 EPIDEMIOLOGY OF RICE YELLOW MOTTLE VIRUS. 18

2.9 VARIETAL REACTION AND YIELD LOSS ASSESSMENT . .. 21

2.10 MANAGEMENT STRATEGIES OF RICE YELLOW MOTTLE VIRUS .. 22

CHAPTER THREE

3.0 MATERIALS AND METHODS 26

3.1 EXPERIMENT I: EFFECT OF RYMV ON PLANT GROWTH AND YIELD LOSS ASSESSMENT OF RICE CULTIVARS 26

3.1.1. Data Collection and Analyses 26

3.1.1.1. RYMV Disease assessment 26

3.2. EXPERIMENT 1I: EPIDEMIOLOGY OF RYMV 30

3.2.1. Sampling and identification of insect vector of RYMV associated with rice plant 31

3.2.2. Transmission test of insect associated with rice plants in the Fields. .. 31

3.2.3 Relative abundance of insect vectors associated with rice plant in relation to weather factors and RYMV incidence 32

3.3. EXPERIMENT III: IDENTIFICATION OF WEED HOSTS OF RYMV . 33

3.3.1. Field Survey and Sampling 33

3.3.2. Double Antibody Sandwich Enzyme – Linked Immuno Sorbent Assay . 34

3.4. EXPERIMENT IV: DETERMINATION OF SEROTYPE(S) OF RYMV .. 35

3.4.1. Serological Characterization of RYMV Isolates 36

3.4.1.1. TAS-ELISA 36

3.5. EXPERIMENT V: MOLECULAR CHARACTERIZATION OF RYMV ISOLATES 37

3.5.1. RNA Extraction Protocol 37

3.5.2. Reverse Transcriptase- Polymerase Chain Reaction (RT-PCR) 38

3.5.2.1. First Strand- cDNA Synthesis 38

3.5.3. Polymerase Chain Reaction (PCR) 40

3.5.3.1. PCR Cocktail 40

3.5.4. Agarose gel Electrophoresis of PCR Products 40

CHAPTER FOUR

4.0 RESULTS 42

4.1. SCREENHOUSE EXPERIMENTS 42

4.1.1. Effect of inoculation regime of RYMV on plant height of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 42

4.1.2. Interaction of rice cultivars and inoculation regime of RYMV on plant height in the Screenhouse (Combine analysis) 42

4.1.3. Effect of inoculation regime of RYMV on number of tillers per plant of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 45

4.1.4. Interaction of rice cultivars and inoculation regime on number of tillers per plant in the Screenhouse (Combine analysis) 48

4.1.5. Effect of inoculation regime of RYMV on days to 50 % flowering of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 49

4.1.6. Interaction of rice cultivars and inoculation regime of RYMV on the days to 50 % flowering in the Screenhouse (Combine analysis) 50

4.1.7. Effect of inoculation regime of RYMV on the number of grains per panicle of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 53

4.1.8. Interaction of rice cultivars and inoculation regime of RYMV on the number of grains per panicle in the Screenhouse (Combine analysis) 54

4.1.9. Effect of inoculation regime of RYMV on paddy yield of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009and 2009/ 2010 dry seasons... 57

4.1.10. Interaction of rice cultivars and inoculation regime of RYMV

on paddy yield in the Screenhouse (Combine analysis).. 58

4.1.11. Effect of inoculation regime of RYMV on the paddy yield loss of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 61

4.1.12. Interaction of rice cultivars and inoculation regime of RYMV on paddy yield loss in the Screenhouse (Combine analysis) 62

4.1.13. Effect of inoculation regime of RYMV on the threshing percentage of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 65

4.1.14. Interaction of rice cultivars and inoculation regime of RYMV on threshing percentage in the Screenhouse (Combine analysis) 66

4.1.15. Effect of inoculation regime of RYMV on 1000- grain weight of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 69

4.1.16. Interaction of rice cultivars and inoculation regime of RYMV on 1000-grain weight in the Screenhouse (Combine analysis) 70

4.1.17. Effect of inoculation regime and rice cultivars on the incidence of RYMV in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 73

4.1.18. Interaction of inoculation regime and rice cultivar on the incidence of RYMV in the Screenhouse (Combine analysis) 74

4.1.19. Effect of inoculation regime and rice cultivar on the severity index of RYMV in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons. 77

4. 1.20. Interaction of inoculation regime and rice cultivar on the severity index of RYMV in the Screenhouse (Combine analysis) .. 79

4.1.21. Correlation coefficient for Screenhouse experiments in 2008, 2009 and 2010 rainy, 2008/ 2009 and 2009/ 2010 dry seasons 82

4.2. FIELD EXPERIMENTS 87

4.2.1. Incidence of RYMV insect vectors during the 2008, 2009 and 2010 rainy seasons at Bomo 87

4.2.2 Incidence of RYMV insect vectors during the 2008, 2009 and 2010 rainy seasons at Sayen Gobirawa. 90

4.2.3. Incidence of RYMV insect vectors during the 2008/ 2009 and 2009/2010 dry seasons at Nasarawan Buhari 92

4.2.4. Effect of weather factors on insect vector population, RYMV incidence and severity index at Bomo from 2008-2010 rainy seasons 94

4.2.5. Effect of weather factors on insect vector population, RYMV incidence and severity index at Sayen Gobirawa from 2008-2010 rainy seasons .. 96

4.2.6. Effect of weather factors on insect vector population, RYMV incidence and severity index at Nasarawan Buhari in 2008/ 2009 and 2009/ 2010 dry seasons 98

4.2.7. Effect of RYMV incidence and severity index on paddy yield during the 2008 rainy seasons at Bomo 100

4.2.8. Effect of RYMV incidence and severity index on paddy yield during the 2009 rainy seasons at Bomo 102

4.2.9. Effect of RYMV incidence and severity index on paddy yield during the 2010 rainy seasons at Bomo 106

4.2.10. Effect of RYMV incidence and severity index on paddy yield during the 2008 rainy seasons at Sayen Gobirawa 108

4.2.11. Effect of RYMV incidence and severity index on paddy yield during the 2009 rainy seasons at Sayen Gobirawa 110

4.2.12. Effect of RYMV incidence and severity index on paddy yield during the 2010 rainy seasons at Sayen Gobirawa 113

4.2.13. Effect of RYMV incidence and severity index on paddy yield during the 2008/ 2009 dry season at Nasarawan Buhari 117

4.2.14. Effect of RYMV incidence and severity index on paddy yield during the 2009/ 2010 dry season at Nasarawan Buhari. 118

4.2.15. Transmission test of some insect found in and around the experimental fields 122

4.2.16. Correlation coefficient for the field experiments in 2008, 2009 and 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons 127

4.3. THE WEED HOSTS OF RYMV ACROSS THE SURVEYED STATES .. 140

4.4. SEROLOGICAL PROFILE OF RICE YELLOW MOTTLE VIRUS ISOLATES 142

4.4.1. Hierarchical Cluster Dendrogram analysis of RYMV serological profile .. 146

4.5. MOLECULAR CHARACTERISATION AND DISTRIBUTION OF RYMV ISOLATES 148

4.5.1. Percentage Distribution of RYMV Strains across the Surveyed States .. 151

CHAPTER FIVE

5.0 DISCUSSION 156

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION . .. 176

6.1 SUMMARY AND CONCLUSION 176

6.2. RECOMMENDATION 179

6.3. RESEARCH FINDINGS 181

REFFERENCES 182

APPENDICES 198

LIST OF FIGURES

Figure	Titles	Pages
1	Distribution of Rice yellow mottle virus (RYMV) in Africa ..	9
2	Mean number of insect vectors caught from June to October during the 2008 , 2009 and 2010 rainy seasons at Bomo ..	89
3	Mean number of insect vectors caught from June to October during the 2008 , 2009 and 2010 rainy seasons at Sayen Gobirawa	91
4	Mean number of insect vectors caught from December to April during the 2008 /2009 and 2009/2010 dry seasons at Nasarawan Buhari	93
5	Hierarchical relationship dendrogram of RYMV isolates of seven States in Northern Nigeria derived from 35 serolgical profiles data Using 4 monoclonal antibodies in TAS-ELISA	145
6	Map showing location and distribution of serological profiles of Rice yellow mottle virus (RYMV) isolates collected	147
7	Map showing locations and distributions of RYMV strains collected	150

LIST OF TABLES

Table	Title	Pages
4.1.	Effect of inoculation regime of RYMV on plant height of rice cultivars in the screenhouse-..	43
4.2.	Interaction of rice cultivars and inoculation regime of RYMV on plant height in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons	44
4.3.	Effect of inoculation regime of RYMV on the number tillers per rice cultivars in the screenhouse	46
4.4.	Interaction of rice cultivars and inoculation regime of RYMV on the number of tillers per plant in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons	47
4.5.	Effect of inoculation regime of RYMV on the number of days to 50% flowering of some rice cultivars in screenhouse	51
4.6.	Interaction of rice cultivars and inoculation regime of RYMV on the number of days to 50% flowering in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons	52
4.7.	Effect of inoculation regime of RYMV on the number of grains per panicle of rice cultivars in the screenhouse	55
4.8.	Interaction of rice cultivars and inoculation regime of RYMV on the number of grains per panicle in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.	56
4.9.	Effect of inoculation regime of RYMV on the paddy yield (g) of rice cultivars in the screenhouse	59
4.10.	Interaction of rice cultivars and inoculation regime of RYMV on the paddy yield (g) in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons..	60
4.11.	Effect of inoculation regime of RYMV on paddy yield loss (%) of rice cultivar in the screenhouse	63
4.12.	Interaction of rice cultivars and inoculation regime of RYMV on paddy yield loss in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons..	64
4.13.	Effect of inoculation regime of RYMV on the threshing percentage of rice cultivars in the screenhouse	67

4.14. Interaction of rice cultivars and inoculation regime of RYMV on the threshing percentage in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons. 68

4.15. Effect of inoculation regime of RYMV on the 1,000- grain weight (g) of rice cultivars in the screenhouse. 71

4.16. Interaction of rice cultivars and inoculation of regime of RYMV on 1,000 grain weight (g) in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons 72

4.17. Effect of inoculation regime and rice cultivar on the incidence of RYMV in the screenhouse 75

4.18. Interaction of inoculation regime and rice cultivar on the incidence of RYMV in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons 76

4.19. Effect of inoculation regime and rice cultivars on the severity index of RYMV in the screenhouse 80

4.20. Interaction of rice cultivar and inoculation regime on the severity index of RYMV in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.. 81

4.21. Effect of weather factors on insect vector population density, Rce yellow mottle virus incidence and severity index at Bomo from 2008 to 2010 rainy seasons 95

4.22. Effect of weather factors on insect vector population density, Rice yellow mottle virus incidence and severity index at Sayen Gobirawa from 2008 to 2010 rainy seasons.. 97

4.23. Effect of the weather factors on insect vector population density, Rice yellow mottle virus incidence and severity index at Nasarawan Buhari from 2008/ 2009 to 2009/ 2010 dry seasons.. 99

4.24. Effect of rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2008 rainy season 104

4.25. Effect of rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2009 rainy season 105

4.26 Effect of rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2010 rainy season 107

4.27 Effect of rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2008 rainy season 111

4.28 Effect of rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2009 rainy season 115

4.29 Effect of rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2010 rainy season 116

4.30 Effect of rice yellow mottle virus incidence, severity index and paddy yield at Nasarawan Buhari during 2008/ 2009 dry season .. 120

4.31 Effect of rice yellow mottle virus incidence, severity index and paddy yield at Nasarawan Buhari during 2009/ 2010 dry season .. 121

4.32 Transmission test of RYMV by some rice insects found in the experimental fields at Bomo (B) and Sayen Gobirawa (S.G.).. 123

4.33 Correlation coefficient for the field experiment at Bomo in 2008 rainy season 128

4.34 Correlation coefficient for the field experiment at Bomo in 2009 rainy season 129

4.35 Correlation coefficient for the field experiment at Bomo in 2010 rainy season 132

4.36 Correlation coefficient for the field experiment at Sayen Gobirawa in 2008 rainy season 133

4. 37 Correlation coefficient for the field experiment at Sayen Gobirawa in 2009 rainy season 136

4.38 Correlation coefficient for the field experiment at Sayen Gobirawa in 2010 rainy season1 137

4.39 Correlation coefficient for the field experiment at Nasarawan Buhari in 2008/ 2009 dry season 138

4.40 Correlation coefficient for the field experiment at Nasarawan Buhari in 2009/ 2010 dry season 139

4.41 Results of Double Antibody Sandwich Enzyme- Linked Immuno-Sorbent Assay (DAS-ELISA) test showing reaction profiles of the weed hosts of Rice yellow mottle virus in northern Nigeria 141

4.42. Number of isolates of Rice yellow mottle virus collected from rice (*Oryza sativa* L.) in seven Northern states of Nigeria 142

4.43. Serological profile of RYMV isolate detected with monoclonal antibodies in Triple antibody sandwich enzyme linked immunosorbent assay (TAS ELISA) 144

4.44. Polymerase chain reaction of some Rice yellow mottle virus isolates to two specific pair of primers designed to amplify Strain S1 and S2 and non specific hexamer (random) primer . .. 149

4.45 Percentage distribution of RYMV strains across the surveyed states .. 152

LIST OF PLATES

Plate	Title	Pages
I	Yellowing, stunted growth and reduced tillering of rice..	11
II	Mottling, yellowing and reddening of rice leaves	11
III	Poor panicle development and sterility in rice..	11
IV	*Zonocerus variegatus* L	124
V	*Oxya* sp.	124
VI	*Dactylispa* sp	124
VII	*Chaetocnema* sp	124
VIII	*Chnootriba similis* Thunberg	125
IX	*Conocephalus* sp	125
X	*Trichispa sericea* Guerin	125
XI	*Cheilomenes sp.*	125
XII	*Nezara viridula.* L	126
XIII	*Locris rubra* Fabricus	126
XIV	RYMV detection by PCR using S1 Strain specific primer pairs . ..	153
XV	RYMV detection by PCR using S2 Strain specific primer pairs	154
XVI	RYMV detection by PCR using S1 Strain specific primer pairs . ..	154
XVII	RYMV detection by PCR using random hexamer primer	155
XVIII	RYMV detection by PCR using S1 Strain specific primer pairs . ..	155

LIST OF APPENDICES

Appendix		Pages
I	Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2008 rainy season	198
II	Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2009 rainy season	198
III	Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs 2010 rainy season	199
IV	Average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2008/ 2009 dry season	199
V	Average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2009/ 2010 dry season	200
VI	Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2008 rainy season.	200
VII	Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2009 rainy season	201
VIII	Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2010 rainy season	201
IX	Combined analysis of Variance for the effect of RYMV on plant height in the screenhouse from 2008 to 2010 rainy seasons . ..	202
X	Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2008/ 2009 dry season	202
XI	Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2009/ 2010 dry season.	203
XII	Combined analysis of Variance for the effect of RYMV on plant height in the screenhouse 2008/ 2009 and 2009/ 2010 dry seasons	203

XIII Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2008 rainy season 204

XIV Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2009 rainy season 204

XV Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2010 rainy season. 204

XVI Combined analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse from 2008 to 2010 rainy seasons. 205

XVII Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2008/ 2009 dry season 205

XVIII Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2009/ 2010 dry season 206

XIX Combined analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse 2008/ 2009 and 2009/ 2010 dry seasons. 206

XX Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2008 rainy season- 207

XXI Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2009 rainy season- 207

XXII Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2010 rainy season- 207

XXIII Combined analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse from 2008 to 2010 rainy seasons . 208

XXIV Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2008/ 2009 dry season. 208

XXV Analysis of Variance for the effect of RYMV on days to 50 % flowering the screenhouse during 2009/ 2010 dry season. 209

XXVI Combined analysis of variance for the effect of RYMV on days to 50 % flowering in the screenhouse 2008/ 2009 and 2009/ 2010 dry seasons. . 209

XXVII Analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse during 2008 rainy season 210

XXVIII Analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse during 2009 rainy season. 210

XXIX Analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse during 2010 rainy season 210

XXX Combined analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse from 2008 to 2010 rainy seasons. .. 211

XXXI Analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse during 2008/ 2009 dry season. 211

XXXII Analysis of Variance for the effect of RYMV on number of grains per panicle the screenhouse during 2009/ 2010 dry season. 212

XXXIII Combined analysis of Variance for the effect of RYMV on number of grain per panicle in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons. 212

XXXIV Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2008 rainy season. 213

XXXV Analysis of Variance for the effect of RYMV on the paddy yield in the screenhouse during 2009 rainy season. 213

XXXVI Analysis of Variance for the effect of RYMV on the paddy yield in the screenhouse during 2010 rainy season. 213

XXXVII Combined analysis of Variance for the effect of RYMV on paddy yield in the screenhouse from 2008 to 2010 rainy seasons. 214

XXXVIII Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2008/ 2009 dry season. 214

XXXIX Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2009/ 2010 dry season. 215

XL Combined analysis of Variance for the effect of RYMV on paddy yield in the screenhouse 2008/ 2009 and 2009/ 2010 dry seasons- 215

XLI Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2008 rainy season. 216

XLII Analysis of Variance for the effect of RYMV on the paddy yield loss in the screenhouse during 2009 rainy season- 216

XLIII Analysis of Variance for the effect of RYMV on the paddy yield loss in the screenhouse during 2010 rainy season. 216

XLIV Combined analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse from 2008 to 2010 rainy seasons 217

XLV Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2008/ 2009 dry season- 217

XLVI Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2009/ 2010 dry season 218

XLVII Combined analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse 2008/ 2009 and 2009/ 2010 dry seasons. .. 218

XLVIII Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2008 rainy season. 219

XLIX Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2009 rainy season. 219

L Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2010 rainy season.- 219

LI Combined analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse from 2008 to 2010 rainy seasons. 220

LII Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2008/ 2009 dry season 220

LIII Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2009/ 2010 dry season. 221

LIV Combined analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons. .. 221

LV Analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse during 2008 rainy season. 222

LVI Analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse during 2009 rainy season. 222

LVII Analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse during 2010 rainy season... 222

VIII Combined analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse from 2008 to 2010 rainy seasons... .. 223

LIX Analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse during 2008/ 2009 dry season 223

LX Analysis of Variance for the effect of RYMV on 1000 grain weight the screenhouse during 2009/ 2010 dry season. 224

LXI Combined analysis of Variance for the effect of RYMV on 1000 grain weight in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons. 224

LXII Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2008 rainy season 225

LXIII Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2009 rainy season. 225

LXIV Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2010 rainy season 225

LXV Combined analysis of Variance for the effect of RYMV incidence in the screenhouse from 2008 to 2010 rainy seasons. 226

LXVI Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2008/ 2009 dry season. 226

LXVII Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2009/ 2010 dry season. 227

LXVIII Combined analysis of Variance for the effect of RYMV incidence in the Screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons. 227

LXIX Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2008 rainy season. 228

LXX Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2009 rainy season. 228

LXXI Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2010 rainy season. 228

LXXII Combined analysis of Variance for the effect of RYMV severity index in the screenhouse from 2008 to 2010 rainy seasons. .. 229

LXXIII Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2008/ 2009 dry season. 229

LXXIV Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2009/ 2010 dry season. 230

LXXV Combined analysis of Variance for the effect of RYMV severity index in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons- . .. 230

LXXVI Analysis of variance of RYMV incidence 6 WAS at Bomo 2008 rainy season 231

LXXVII Analysis of variance of RYMV incidence 8 WAS at Bomo 2008 rainy season 231

LXXVIII Analysis of variance of RYMV incidence 10 WAS at Bomo 2008 rainy season 231

LXXIX Analysis of variance of RYMV incidence 12 WAS at Bomo 2008 rainy season 231

LXXX Analysis of variance of RYMV incidence 14 WAS at Bomo 2008 rainy season 232

LXXXI Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2008 rainy season.. 232

LXXXII Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2008 rainy season 232

LXXXIII Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2008 rainy season 232

LXXXIV Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2008 rainy season 233

LXXXV Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2008 rainy season 233

LXXXVI Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Bomo during 2008 rainy season 233

LXXXVII Analysis of variance of RYMV incidence 6 WAS at Bomo 2009 rainy season- 233

LXXXVIII Analysis of variance of RYMV incidence 8 WAS at Bomo 2009 rainy season 234

LXXXIX Analysis of variance of RYMV incidence 10 WAS at Bomo 2009 rainy season 234

XC Analysis of variance of RYMV incidence 12 WAS at Bomo 2009 rainy season 234

XCI Analysis of Variance of RYMV incidence 14 WAS at Bomo 2009 rainy season 234

XCII Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2009 rainy season 235

XCIII Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2009 rainy season- 235

XCIV Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2009 rainy season 235

XCV Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2009 rainy season 235

XCVI Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2009 rainy season 236

XCVII Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Bomo during 2009 rainy season 236

XCVIII Analysis of Variance of RYMV incidence 6 WAS at Bomo 2010 rainy season 236

XCIX Analysis of Variance of RYMV incidence 8 WAS at Bomo 2010 rainy season 236

C Analysis of Variance of RYMV incidence 10 WAS at Bomo 2010 rainy season 237

CI Analysis of Variance of RYMV incidence 12 WAS at Bomo 2010 rainy season 237

CII Analysis of Variance of RYMV incidence 14 WAS at Bomo 2010 season 237

CIII Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2010 rainy season 237

CIV Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2010 rainy season 238

CV Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2010 rainy season 238

CVI Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2010 rainy season 238

CVII Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2010 rainy season 238

CVIII Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Bomo during 2010 rainy season 239

CIX Analysis of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2008 rainy season 239

CX Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2008 rainy season 239

CXI Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2008 rainy season 239

CXII Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2008 rainy season 240

CXIII Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2008 rainy season 240

CXIV Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2008 rainy season 240

CXV Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2008 rainy season 240

CXVI Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2008 rainy season 241

CXVII Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2008 rainy season 241

CXVIII Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2008 rainy season 241

CXIX Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Sayen Gobirawa during 2008 rainy season 241

CXX Analysis of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2009 rainy season 242

CXXI Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2009 rainy season 242

CXXII Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2009 rainy season 242

CXXIII Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2009 rainy season 242

CXXIV Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2009 rainy season 243

CXXV Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2009 rainy season 243

CXXVI Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2009 rainy season 243

CXXVII Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2009 rainy season 243

CXXVIII Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2009 rainy season 244

CXXIX Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2009 rainy season 244

CXXX Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Sayen Gobirawa during 2009 rainy season 244

CXXXI Analysis of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2010 rainy season 244

CXXXII Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2010 rainy season. 245

CXXXIII Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2010 rainy season 245

CXXXIV Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2010 rainy season 245

CXXXV Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2010 rainy season 245

CXXXVI Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2010 rainy season 246

CXXXVIII Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2010 rainy season 246

CXXXIX Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2010 rainy season 246

CXL Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2010 rainy season 246

CXLI Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2010 rainy season 247

CXLII Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Sayen Gobirawa during 2010 rainy season 247

CXLIII Analysis of Variance of RYMV incidence 6 WAS at Nasarawan Buhari 2008/ 2009 dry season 247

CXLIV Analysis of Variance of RYMV incidence 8 WAS at Nasarawan Buhari 2008/ 2009 dry season 247

CXLV Analysis of Variance of RYMV incidence 10 WAS at Nasarawan Buhari 2008/ 2009 dry season 248

CXLVI Analysis of Variance of RYMV incidence 12 WAS at Nasarawan Buhari 2008/ 2009 dry season 248

CXLVII Analysis of Variance of RYMV incidence 14 WAS at Nasarawan Buhari 2008/ 2009 dry season 248

CXLVIII Analysis of Variance of RYMV Severity index 6 WAS at Nasaeawan Buhari 2008/ 2009 dry season 248

CXLIX Analysis of Variance of RYMV Severity index 8 WAS at Nasarawan Buhari, 2008/ 2009 dry season 249

CL Analysis of Variance of RYMV Severity index 10 WAS at Nasarawan Buhari, 2008/ 2009 dry season 249

CLI Analysis of Variance of RYMV Severity index 12 WAS at Nasarawan Buhari, 2008/ 2009 dry season 249

CLII Analysis of Variance of RYMV Severity index 14 WAS at Nasarawan Buhari, 2008/ 2009 dry season 249

CLIII Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Nasarawan Buhari during 2008/ 2009 dry season 250

CLIV Analysis of Variance of RYMV incidence 6 WAS at Nasarawan Buhari, 2009/2010 dry season 250

CLV Analysis of Variance of RYMV incidence 8 WAS at Nasarawan Buhari, 2009/ 2010 dry season 250

CLVI Analysis of Variance of RYMV incidence 10 WAS at Nasarawan Buhari, 2009/ 2010 dry season 250

CLVII Analysis of Variance of RYMV incidence 12 WAS at Nasarawan Buhari, 2009/ 2010 dry season 251

CLVIII Analysis of Variance of RYMV incidence 14 WAS at Nasarawan Buhari, 2009/ 2010 dry season 251

CLIX Analysis of Variance of RYMV Severity index 6 WAS at Nasarawan Buhari during 2009/ 2010 dry season 251

CLX Analysis of Variance of RYMV Severity index 8 WAS at Nasarawan Buhari, 2009/ 2010 dry season 251

CLXI Analysis of Variance of RYMV Severity index 10 WAS at Nasarawan Buhari, 2009/ 2010 dry season 252

CLXII Analysis of Variance of RYMV Severity index 12 WAS at Nasarawan Buhari during 2009/ 2010 dry season 252

CLXIII Analysis of Variance of RYMV Severity index 14 WAS at Nasarawan Buhari, 2009/ 2010 dry season 252

CLXIV Analysis of Variance for the effect of RYMV on paddy yield of rice cultivar at Nasarawan Buhari during 2009/ 2010 dry season 252

CLXV Correlation coefficient for the screenhouse experiment in 2008 rainy season 253

CLXVI Correlation coefficient for the screenhouse experiment in 2009 rainy season 254

CLXVII Correlation coefficient for the screenhouse experiment in 2010 rainy season 255

CLXVIII Correlation coefficient for the screenhouse experiment in 2008, 2009 and 2010 rainy seasons combined analysis 256

CLXIX Correlation coefficient for the screenhouse experiment in 2008/2009 dry season 257

CLXX Correlation coefficient for the screenhouse experiment in 2009/2010 dry season 258

CLXXI Correlation coefficient for the screenhouse experiment in 2008/2009 and 2009/2010 dry season combined analysis 259

CLXXII Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Bomo from 2008 to 2010 rainy seasons 260

CLXXIII Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Sayen Gobirawa from 2008 to 2010 rainy seasons 260

CLXXIV Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Nasarawan Buhari for 2008/2009 and 2009/ 2010 dry seasons 261

CLXXV Phosphate Buffer 261

CLXXVI Phosphate Buffered Saline 261

CLXXVII Phosphate Buffered Saline Tween 262

CLXXVIII Sample Extraction Buffer 262

CLXXIX Conjugate or Antibody Buffer 262

CLXXX Carbonate Buffer or Coating Buffer 263

CLXXXI Substrate Buffer or Diethanolamine Buffer 263

SYMBOLS

Symbol	Description
mm	Millimetre
cm	Centimetre
m	Metre
g	Gram
kg/ha	Kilogramme per hectare
%	Percentage
µl	Microlitre
^{o}C	Degree celsius

ABBREVIATIONS

bp	Base pair
CP	Coat protein
DAS-ELISA	Double antibody sandwich- Enzyme Linked Immunosorbent Assay
DNA	Deoxyribonucleic acid
dNTPs	Deoxynucleotide triphosphate
EDTA	Ethylene Diamine Tetreacetic acid
et al	and others
FAO	Food and Agricultural Organization
mM	Micromole
ORF	Open reading frame
P	Probability
PCR	Polymerase chain reaction
RAM-AP	Rabbit anti- mouse (Polyclonal antibody) Alkaline phosphatase labelled
RNA	Ribonucleic acid
RT- PCR	Reverse Transcriptase - Polymerase Chain Reaction
RYMV	Rice yellow mottle virus
TAS-ELISA	Triple antibody sandwich- Enzyme Linked Immunosorbent Assay
VPg	Viral protein genome-linked
WAS	Weeks after sowing
WARDA	West Africa Rice Development Association

CHAPTER 1

1.0 INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for about one half of people in the world and is mainly harvested and consumed in Asia and Africa (Anonymous, 2005; Sun *et al.,* 2006). In many regions it is eaten with every meal and provides more calories than any other single food (Hynes, 2007). It is not only consumed by humans and fed to livestock as it is also useful industrially for processing into acetic acid, glucose and starch. Rice straw and stems are used by local farmers as bedding for animals and for weaving roofs, hats, baskets and sandals. The inedible rice hull is used as fuel, fertilizer and insulation (Schalbroeck, 2001; Gao *et al.,* 2004; Hynes, 2007).

Rice is produced in about 10% of all cropland (144 million hactares) in over 110 countries (Luth, 1980). It has the ability to adapt to diverse environmental conditions and is therefore, grown in varied climatic conditions ranging from Sahel to the Rainforest ecological zones (Luth, 1980) in every country in West Africa (WARDA, 1995).The main production ecologies are rainfed lowland, rainfed upland, irrigated lowland, deep water/flooding and mangrove swamp (Onyishi *et al.*, 2010). Nigeria cultivated 2.191 million hectares of land with rice paddy production of 3.28 million metric tonnes in 1999 while land area under rice production increased by 0.4 % with 3.30 metric tonnes in 2000 (Anonymous, 2001). The potential land area for rice production in Nigeria is between 4.6 and 4.9 million hectares (Nwilene *et al.,* 2009a). Despite the continuous increase in the land area that is cultivated with rice, Nigeria still imports rice annually (FAO, 2010). It was reported in order to meet local demand, Nigeria imported 1.7 and 1.8, million tonnes of rice in 2008/ 2009 and 2009/ 2010, respectively (FAO, 2010). Post-forecast Nigeria's rice imports in 2010/ 2011 is to grow to 1.9 million tonnes (FAO, 2010).

Rice is the primary and secondary host of many viruses (Koklu and Yilmaz, 2004) but the most important is the rice yellow mottle virus (RYMV) genus Sobemovirus (Awoderu, 1991a; Fargette

et al., 2002). It is endemic in Africa and became important after the introduction of new high yielding exotic varieties that are susceptible to the virus (Rossel and Thottappilly, 1988), availability of water through irrigation, which allows for sequential planting and maintenance of higher crop intensity without dry season gaps (IITA, 1981, 1982; Rossel *et al.*, 1982a; Thresh, 1989). The pathogen was first noticed in 1966 in Kenya (Bakker, 1970). However, it has since spread to other parts of Africa (Koklu and Yilmaz, 2004). The virus is characterized by high genetic variability due to its intrinsic high rates of mutation which is evident from the detection of several strains of the pathogen (N'Guessan *et al.,* 2001; Pinel- Galzi and Fargette, 2006). Six strains of the virus have been reported so far: S1, S2 and S3 in West and Central Africa, S4, S5 and S6 in East Africa (Pinel *et al.,* 2000; Fargette *et al.,* 2002; Banwo *et al.,* 2004a). Both virulent and avirulent isolates were found among the strains, indicating that phytopathological traits of an isolate are not hereditary or confined to a specific strain or a particular region, but occurs naturally in different lineages in different parts of Africa (Sorha *et al.,* 2005). The emergence of several strains of the virus is due to its high replication, as well as intensification of rice cultivation in most countries of Africa (Awoderu, 1991a; Traore *et al.,* 2005).

Generally, RYMV infection is characterized by mottle and yellowing symptoms of varying intensities, depending on rice genotype and age at infection (Bakker, 1970; Thottappilly and Rossel, 1993a), as well as the virulence of the invading virus strain. Other symptoms include wilting, streaking of the leaves, stunting of the plant, grain discolouration, malformation and partial emergence of the panicles, non – synchronous flowering, brown to dark brown discolouration of panicles and grain, sterility and death of infected plants (Bakker 1971; 1974; Fauquet and Thouvenel, 1977; Thottappilly and Rossel, 1993b). Symptoms occur at any stage from transplanting to booting (Abo *et al.,* 1998).

RYMV is environmentally stable and is transmitted mechanically from rice to rice (Bakker, 1971; Fauquet and Thouvenel, 1977). The virus can be spread mechanically through contact between healthy and infected plants, contaminated hands, cow dung and soil containing undecomposed infected plant materials, debris, gestation fluid, irrigation water and harvesting tool such as sickle (Bakker, 1974; Reckhaus and Andriamasintseheno, 1995; Tsuboi *et al.,* 1995; Abo, 1998; Sarra et *al.,* 2004; Traore *et al.,* 2006; Traore *et al*., 2008). It is also transmitted by insect vectors belonging to the families Chrysomelidae (*Chaetocnema* spp., *Dactylispa* spp., *Hispa unsambarica* Weise, *Sesselia pusilla* Gartucker, *Trichispa sericea* Guerin); Tettigonidae (*Conocephalus longipennis* de Haan, *C. merumontamus* Sjostedt)) and Coccinelidae (*Chnootriba similis* Thunberg) (Bakker, 1971; Reckhaus and Adamou, 1986 and Abo, 1998).

RYMV disease has become a major limiting factor to rice production for lowland and irrigation ecosystems in Africa. It is now found in virtually all rice growing countries in Sub-Saharan Africa (Fomba, 1990; Aworedu *et al.,* 1991a) and on the islands of Zanzibar and Madagascar (Kouassi, *et al.,* 2005). According to Traore *et al.* (2005), RYMV occurs in diverse cultivated rice system (rainfed, irrigated lowland and mangrove), in all kinds of ecosystems (forest, woodland Savanna, grass Savanna up to the Sahelian region as well as upland Savanna), in countries where rice is either a main or a minor crop and also where epidemics are widespread or localized. Diversification and spread of RYMV has been concommitant with an extension of rice cultivation in Africa since the 19th century. This major agro- ecological change increased the encounter between primary hosts of RYMV and the cultivated rice; it also modified the landscape ecology in ways that facilitated virus spread (Traore *et al*., 2009). It is known to be naturally very destructive and therefore threatening the rice production in the African continent on a large scale (Banwo *et al.,* 2004b) rapidly spreading among and within the major rice growing areas (Ali, 1999) and cause severe yield losses ranging from 25 to 100% depending on the date and time of infection as well as

type of rice variety (Rossel *et al.,* 1982b; Taylor *et al.,* 1990; Sy, 1994; Konate *et al.,* 1997). Crop abandonment due to the infection of rice field by RYMV was also reported in Zamfara state of Nigeria (Alegbejo *et al.,* 2006).

1.1 JUSTIFICATION

RYMV remains one of the major constraints to rice production in rainfed lowland and irrigated ecosystems in Africa. In Nigeria management of RYMV has been largely concentrated on the identification and development of resistant materials without success to develop cultivar with durable resistance to the disease, rice production is undermined and yield is always made uncertain by the occurrence of RYMV. Although, some work has been carried out on yield loss due to this virus, yet none has related the effect of the virus to the growth stages or established the stage of the plant growth at which virus infection is most detrimental to growth and yield attributes Therefore, more research is needed to assess the crop loss at different stages of the plant growth due to RYMV incidence and severity, hence the need to identify the critical stage of the plant growth when the disease has high effect on the yield components or suggest previously unrecognized associations between risk time factor and the disease.

Just like there is no information on responses of rice cultivars to RYMV infection stages in the country, hence there is need to concentrate on filling in the gaps in existing knowledge of the virus epidemiology with a view to gathering more information on the virus epidemics under the prevailing weather conditions in the country. Despite the strong influence that the local environmental condition may have on the spread of the disease, individual climatic factors with respect to epidemiological knowledge has still received little attention from researchers. It is probably the reason why research is yet to come up with efficient methods to manage the disesase. Therefore, the impact of specific climatic factors on the incidence and severity of the virus,

population density of insect vector and responses of the host plant was initiated so that progress in designing intervention strategies that are sustainable are recommended for disease management.

There is scanty information on the alternative hosts where the virus population survive during off season as only a few weed species have been reported in Nigeria, resulting in their role in RYMV epidemiology being poorly understood. This is a major research challenge which would broaden the existing knowledge of the disease epidemiology with a view to developing management strategies of RYMV in the country.

Although RYMV is probably present every where rice is grown in Nigeria and poses serious threats to rice production. There is limited information on the different serotypes of RYMV in Nigeria. The existence of different RYMV serotypes in the field that cause different kinds of diseases is a matter of considerable practical importance. Therefore, more research is needed for distinguishing and identifying those serotypes. Knowledge of the serological relationship between RYMV isolates is valuable in diagnostic work and may prove to be important in epidemiological research and in breeding for RYMV resistant programmes.

Considering the several strains of RYMV and its rapid spread within and between states in Nigeria, information on the nature of variability and assessing the molecular characteristics of the virus, is indispensable in understanding RYMV biology and inherent variability as well as shifts in pathogen population. Obtaining such information of RYMV will be greatly useful for understanding how the virus strains changed and evolved from a common ancestor. Therefore, more study is needed to understand the molecular characteristics of the virus, to provide more accurate and rapid identification of the pathogen, and may contribute to the development of methods of management of the virus in the study area.

1.2 OBJECTIVES

The objectives of the study are to:

i. Quantify yield losses due to RYMV in selected rice cultivars

ii. Determine the influence of weather factors on the vectors populations and RYMV incidence and severity

iii. Identify the alternative hosts of the virus

iv. Identify the serotypes of RYMV and their distribution in northern Nigeria, and

v. Molecular characterization of strains of the virus.

CHAPTER 2

LITERATURE REVIEW

2.1 RICE

Rice plant is an annual grass belonging to the genus Oryzea in the family Poaceae. It can grow for more than a year under favourable conditions and are well adapted to acquatic habitats. Two species of rice were domesticated; *Oryza sativa* L. and *O. glaberrima* Steud. Cultivar of the rice species O. *sativa* is widely grown in Asia, whereas *O. glaberrima* have been grown for ages in Africa (Sarra, 2005). In the last century several O. *glaberrima* cultivars were replaced by higher yielding O. *sativa* cultivars in Africa (Pinto *et al*., 1999). This resulted in the emergence of RYMV (Abo *et al*., 1998) causing a highly infectious disease in most rice growing regions with epidemics proportions in irrigated and lowland cultivated rice in the 1990s (Konate *et al*., 2002).

2.2. IMPORTANCE OF RICE YELLOW MOTTLE VIRUS GENUS SOBEMOVIRUS (RYMV*)*

The increasing incidence and importance of RYMV in East and West Africa is attributed to the cultivation of new highly susceptible exotic rice varieties (mostly from Asia) and the availability of water (through irrigation) which allows for sequential planting and maintenance of higher crop intensity without dry season gaps (IITA, 1981, 1982; Rossel *et al.,* 1982b). In Africa four viruses, *Rice necrosis stripe* (RNSV) genus Furovirus*, Maize streak virus* (MSV) genus Mastrevirus*,,* Rice crinkle disease and *Rice yellow mottle virus (*RYMV) genus Sobemovirus (Harder and Bakker, 1973; Bakker, 1975) have been reported to infect rice. RYMV is the only economically important virus disease of rice (Rossel and Thottappilly, 1985). The disease is fast becoming a major limiting factor to rice production for lowland and irrigated ecosystems in Africa. It is now found in virtually all rice growing countries in Eastern, Western and Southern Africa (Fomba, 1990; Awoderu *et al.,* 1991b; Banwo *et al.,* 2004a). It has reached epidemics proportions in some African countries and is

spreading fast in others (Reckhaus and Adamou, 1986; John *et al.,* 1984*;* Sy, 1994; Abo *et al.,* 1998).

Losses caused by RYMV in paddy fields have reached alarming proportions and some farmers have suffered complete crop failure (Yaboue, 1989; Alegbejo *et al*., 2006). RYMV causes a severe disease of rice in most rice growing countries in Africa and yield loss ranges from 25 to 100 % depending on the stage and time of infection as well as type of variety (Rossel *et al.,* 1982b; Taylor *et al.,* 1990; Sy, 1994; Konate *et al.,* 1997). Yield losses of 58-67 % were reported in Niger (Reckhaus and Adamou, 1986); 54-97 % in Sierra Leone (Taylor, 1989); 20-45 % in Burkina Faso (Sere, 1991); 67-84 % in Cote d'Ivoire and of 64-100 % in Mali (Sy *et al.,* 1993). In Kenya the yield reduction of variety Sindano was estimated at 50 % (Nwilene *et al*., 2009a). In Tanzania it was reported that some farmers could not harvest any rice while others completely abandoned their fields (Banwo *et al.,* 2004a). Crop abandonment due to the infection of rice fields by RYMV was also reported in Zamfara state of Nigeria (Alegbejo *et al.,* 2006). RYMV causes no damage at all in some years but then reach epidemic proportions when climatic conditions are exactly right for disease development (Nwilene *et al*., 2009a).

2.3. DISTRIBUTION OF RYMV

Incidence of RYMV was first reported in 1966 in Kenya (Bakker, 1970) but has now been reported in many different countries in Central, East and West Africa. It was reported in 1976 in Liberia, Sierra Leone and Tanzania (Raymundo and Buddengan, 1976; Rossel *et al*., 1982b). In 1977 it was reported in Cote d'Ivoire (Fauquet and Thouvenel, 1977) and in 1980 in Ghana and Guinea (Raymundo and Konteh, 1980). By 1984 it was identified in Burkina

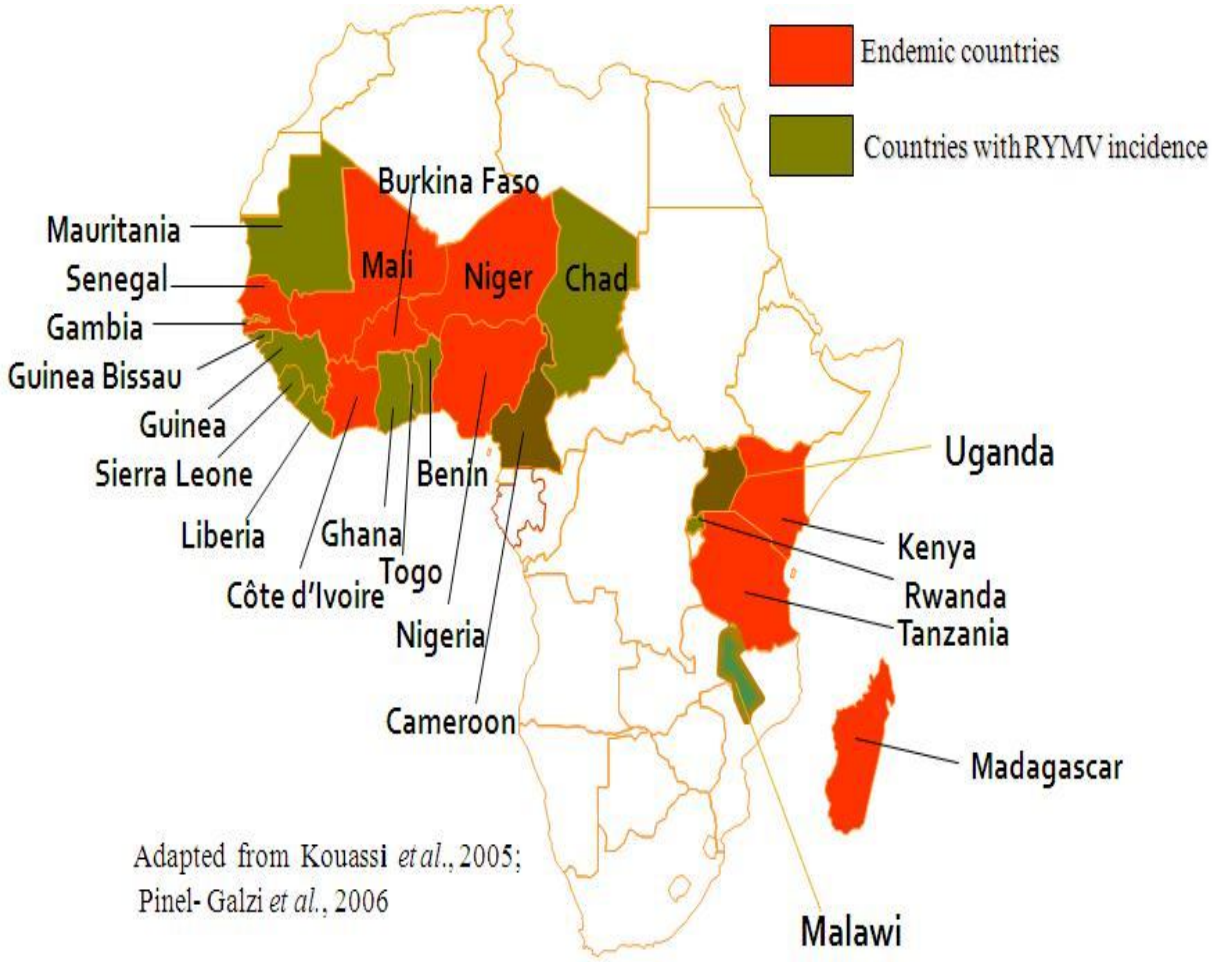


Figure 1: Distribution of RYMV in Africa

Faso, Malawi, Mali, Niger and Senegal (John *et al*., 1984) and in Rwanda in 1987 (Awoderu *et al*., 1987). Later in 1989 it was described in Madagascar (Reckhaus and Randrianangaly, 1990). In 2001 it was noticed in Cameroun and Chad (Traore *et al.*, 2001).

The first incidence of RYMV in Nigeria was reported in Niger and Oyo states in 1975 (Raymundo and Buddengan, 1976). The virus was later found in Anambara and Imo states (Awoderu, 1991b), Akwa Ibom, Ebonyi and Sokoto states (Singh *et al*., 1997), Zamfara state (Alegbejo *et al*., 2006), Bauchi, Gombe and Kano states (Abo *et al*., 2002b).

2.4. SYMPTOMS OF RYMV

The characteristic symptoms of RYMV are leaf mottling and yellowing, grain discoloration, grain or spikelet sterility and stunting of the plants (Bakker, 1974; Raymundo and Bunddenhagen, 1976; Fauquet and Thouvenel, 1977; Rossel *et al.,* 1982a; IITA, 1983; John *et al.,* 1984; Rossel and Thottappilly, 1985; Taylor *et al.,* 1990; Thottappilly and Rossel, 1993b). Raymundo and Buddenhagen (1976) stated that infected plants had pale yellow mottle leaves, conspicuous bronze or orange colouration, rolling of leaf margins, leaf desiccation, stunting, reduced tillering, non-synchronous flowering, poor panicle exertion and malformation, spikelet discolouration and sterility, erect panicles, compact appearance of spikelet, brown to dark-brown discolouration of grains a consequence of secondary infection by fungi and crinkling of new growth.

Infected rice plants are found first near the bunds and thereafter whole fields may be infected (Bakker, 1975). Also Fauquet and Thouvenel (1977) reported that the disease appeared as a yellow and green mottle at the leaf tip. In an infected field, yellow-orange discolourations of leaves were seen on plants scattered throughout the field but such plants were more prevalent

Some common symptoms of RYMV



Plate I: Yellowing, Stunted growth and reduced tillering of rice



Plate II: Mottling, yellowing and reddening of rice leaves (Nwilene *et al.*, 2009b)



Plate III: Poor panicle development and sterility in rice

at field margins. Leaf mottling and yellowing symptoms of varying intensities may be developed depending on the genotype. It could be mistaken for iron or nitrogen-deficiency (Thottappilly and Rossel, 1993b) as well as iron toxicity damage (Bakker, 1975). Bakker (1974) reported yellowish leaves on cultivar Sindano, mild yellowish green on cultivar Basmati 217 or orange on IR8. Raymundo and Buddenhagen (1976) stated that some varieties continued to produce relatively green leaves with faint, hardly discernable streaking and mottling but with conspicuous stunting, others with narrow and very chlorotic leaves and severe stunting, and still some showed pronounced chlorosis but minimal stunting. Other varieties developed conspicuous bronze or orange pigmentation followed by rolling of leaf margins and subsequent leaf desiccation, malformation and incomplete emergence of panicles and sterility. Symptoms occur at any stage from transplanting to booting (Fauquet and Thouvenel, 1977; Nwilene *et al*., 2009b) and are more pronounced on ratoons (Raymundo *et al.,* 1979). In severe cases, affected plants may die (Bakker, 1974; Ou, 1985; Fomba, 1988; Thottappilly and Rossel, 1993b).

Symptom expression of RYMV may be strongly influenced by light intensity, day length, humidity, temperature, growth stage of plant, nutrient status, among other factors (Bakker, 1974; Albar *et al.,* 1995; Nwilene *et al*., 2009a). According to Bakker (1974) "Sindano" variety at the 3 – 4 leaf stage showed at high temperature (30 ^{0}C or more) the first systemic symptoms after 4 – 5 days, at 25 ^{0}C the symptoms were noticed after 6 days, and at 20 ^{0}C after 7 – 8 days. During prolonged periods of temperatures below 20 ^{0}C, the yellow dots enlarged more slowly parallel to the veins than at 25 ^{0}C, while at higher temperatures the period in which only yellow dots were seen was very short. Inoculation of "Sindano" at increasing age delayed symptom appearance and the symptoms were more pronounced and necrotic in the glass-house than in the field (Bakker, 1974). Awoderu, (1991a) and Albar *et al*. (2005) stated that temperature affected symptom expression differently in host plant. At low temperature RYMV show only mild symptom while at

high temperature severe symptom developed and also greater expression of RYMV symptoms when the relative humidity was low.

2.5. MOLECULAR CHARACTERISTICS AND SEROTYPES OF RYMV

RYMV belongs to the genus Sobemovirus (Seghal, 1981; Hull, 1988). It is a single stranded positive sense RNA and a distinctive spherical virus measuring about 28 $\pm$ 3 nm in diameter (Bakker, 1974; Rossel *et al.,* 1982b; Rossel and Thottappilly, 1985; Fauquet and Thouvenel, 1987). Sobemoviruses are characterized by being mechanically transmissible (except Blueberry shoestring virus BSSV), having relatively narrow host ranges, and isometric particles that sediment between 110-120 S and form one band in $CSCl_2$ (Some form several bands in CS_2 SO_2), and having a single viral coat protein species of molecular weight of about 30,000 (30 kb) (Hull, 1988). Most Sobemoviruses lack immunological reactions with other Sobemoviruses (Thottappilly *et al.,* 1992). Most of them occur at relatively high concentrations in infected plant and the particles are found in the cell cytoplasm (Edwardson *et al.,* 1966; Hartman *et al.,* 1973; Bakker, 1974; Mohammed and Mossop, 1981; Hull, 1988) and in the nuclei (Mohammed and Mossop, 1981; Fracki *et al.,* 1985).

The percentage of nucleic acid is estimated to be about 18% RNA while the molecular weight of the coat protein is 28 $\pm$ 1 kd (Fauquet and Thouvenel, 1987). The percentage of nucleic acid in the infective virus particle is estimated to be 23.6 $\pm$ 0.5 % (Bakker, 1974).The genome is a single stranded RNA (ssRNA) of molecular weight of about 1.4 x 10^6 daltons (about 4,500 nucleotides) and has a plus or messenger sense polarity (Hull, 1988). Furthermore, according to Brugidou *et al.* (1995), the genomic RNA consists of 4,550 nucleotides and is not polyadenylated. It also consists of 4 open reading frames (ORFs). ORF I (nt. 80 to 553) encode a protein called P1 of 17.8 Kd and presumed to be the movement protein of the virus. ORF 2 (nt. 608 to 3607) encodes for a polyprotein of 110 Kd and contains a putative linked protein (VPg), helicase, protease and

polymerase. ORF 3 (nt. 2092 to 2467) encodes a small protein of an unknown function. The ORF 4 (nt.3477 to 4116) codes for the coat protein (CP) of 26 Kd.

RYMV variability has been studied in several countries of Africa (Pinel *et al.,* 2000; Traore *et al.,* 2005). Six major strains (S1 – S6) were found and phylogenetic separation was apparent among strains from East, Central and West Africa (Abubakar *et al.,* 2003). Considerable genetic divergence across a narrow geographical range occurred in East Africa, whereas shallow genetic differences were found across larger distances in west and central Africa (Traore *et al.,* 2005). Pinel *et al.* (2000) and Fargette *et al.* (2002) carried out molecular assays of coat protein gene sequences of 40 and 52 isolates of RYMV in Africa, respectively. In all, they differentiated five major strains, three (S1, S2 and S3) from Central and West Africa and two (S4 and S5) from East Africa, with a spatial overlap of strains within each of these two regions showing that geographical isolation alone cannot explain the genetic diversity of RYMV. In a comparison of isolates from Central, East and West Africa and Madagascar, Fargette *et al.* (2002) reported four isolates from West and Central Africa showed similarities to the six from Madagascar one from Kenya (S4). In evaluation of some molecular characteristics of RYMV isolates occurring on rice in Tanzania, Banwo *et al.* (2002b) reported a completely new group/strain of RYMV referred to as S6. Pinel *et al.* (2000) and Fargette *et al.* (2002) reported that in general, variability was two fold and higher among the East African isolates. Fargette *et al.* (2002) reported that East African strains S4 and S5 were more distantly related to each other and to the Central/West African strains (S1 – S3) with an average nucleotide divergence of about 11%. Isolates collected from a few kilometres apart in the same country could belong to different strains as it was observed in both West and East Africa (Pinel *et al.,* 2000; Banwo *et al.,* 2002b). Three strains are now known to exist in both West Africa (S1 – S3) and East Africa (S4, S5 and S6) (Fargette *et al.,* 2002; Banwo *et al.,* 2002b). Different serotypes (Sere *et al*., 2007) and pathotypes (Ochola and Tuslime, 2011b) of RYMV isolate are known to exist.

Serological study using 20 RYMV isolates revealed two major Nigeria serogroup (NSg1 and NSg2) and four subgroup (NSg1a, NSg1b, NSg2a and NSg2b) in Southwest Nigeria (Onasanya *et al*., 2011). Similarly, RYMV serotypes SA and SB were found in Northern Nigeria (Salaudeen *et al.*, 2008b).

2.6. TRANSMISSION OF RYMV

Rice is known to be attacked by more than 80 species of insects (Alam *et al.,* 1984). The insects infest rice at all stages and feed on all parts of the plant (Banwo *et al.,* 2004a). RYMV is transmitted by insects with biting and chewing mouthparts (Hull, 1988). A few insects belonging mainly to the family Chrysomelidae have been found to transmit RYMV in East Africa (Bakker, 1971, 1975) and Madagascar (Reckhaus and Andriamasintsheneno, 1995). These insects include *Trichisp*a *sericea* Guerin., *Sesselia pussila, Dicladispa* spp., *Chaetocnema* spp. and those in the genus Apophylia (Bakker, 1974, 1975). *T. sericea*. is identified as the major vector in Niger and Mali (Reckhaus and Adamou, 1986; Sy, 1994), and *Chaetocnema* spp. were suggested by Raymundo and Buddenhagen (1976), Raymundo (1980), Fomba (1990) to be responsible for the spread of RYMV in West Africa. Nwilene *et al*. (2009a) reported new insect vectors of RYMV including; *Zonocerus variegatus, Paratettix sp. Cheilomenes lunata, Euscyrtus sp., Cofana spectra, Cofana unimaculata and Locris rubra*. The long horned grasshopper (*Conocephalus merumontame* Syostedt) (Tettigonnidae) and mites from the families Eriophydidae and Tarsonemidae have been indicated as transmitting the virus in Kenya at low levels but possible contamination of the plant by these vectors was not over-ruled (Bakker, 1974).

RYMV can also be transmitted through other sources. The virus is transmitted mechanically through sap (Bakker, 1974, 1975; Fauquet and Thouvenel, 1977). It could also be transmitted by farm implements such as the sickle used in harvesting rice, hoe and through the cultural practice of trimming shoots of rice seedlings at transplanting (Tsuboi *et al.,* 1995), through leaf contact in closely spaced plants, by contaminated hands, rice stubbles incorporated into the soil, and through

rice roots inter-twined together (Abo, 1998; Nwilene *et al*., 2009b). Cow dung and soil containing insufficiently decomposed plant materials can also contribute to infection with RYMV (Reckhaus and Andriamasintseheno, 1995).

The virus was found in leaf debris and empty rice spikelets *(*Abo and Sy*,* 1988). RYMV could then be transported in rice sacks containing contaminated and partially winnowed rice seeds to new areas far from its origin and spread there. In Mali 100% infections were reported to occur in transplanted rice fields but not in directly seeded fields thus indicating a possible connection with the infection from the nursery (Sy, 1994). RYMV could also be transmitted through guttation fluid and in the irrigation water of heavily infected rice fields, cow dung, rice straw, rice ratoons, weeds and wild rice (Bakker, 1974; Ou, 1985; Nwilene *et al*., 2009b). Most likely where insects feed and caused injury to the plants and their dead bodies might have contaminated the water with virus particles (Banwo *et al.,* 2004a).

2.7. HOST RANGE OF RYMV

Host range is narrow, outside the genus *Oryza.* Some Graminaceous species particularly in the tribe Eragrostideae were found to be systemic hosts of RYMV (Bakker, 1974, 1975; Ou, 1985). The grass species reported as diagnostic hosts include *Eleusine indica* Gaertiner, *Echinochloa crus-galli* L.P. Beak, *Dinebra retroflexa,* (Wahl)*,* Ponzer, *Eragrostis tenifolia,* (*A.* Rich) Steud*., Panicum maximum* Jacq (Bakker, 1974, 1975; Raymundo *et al.,* 1979; Okiome *et al.,* 1983; Taylor *et al.,* 1986; Awoderu, 1991a; Nwilene *et al*., 2009a). Abo (1998) found systemic infection of RYMV on rice only and infections of localized nature was obtained with *O. longistaminata, Eragrostis ciliaris, (L) R.* Br*., Echinochloa crus-pavonis* Scultes and *E. Pyramidalis* Hiche *&* Chase. RYMV was also found in *O longistaminata* A. Chev. and Roehr. growing in marshy areas and rice fields in Niger and Mali (John *et al.,* 1984; Sy, 1994, Hamadoun *et al.,* 1995), Senegal (Mbodj *et al.,* 1984), and Burkina faso (Konate, 1995). Sy (1994) reported that RYMV – like symptoms were observed

visually on *O. longistaminata, O. glaberrina* and I*mperata* sp. in lowland in Mali. *Cynodon dactylon, Cyprus esculentus* L., *C. rotundus* L., *Eleocharis complanata*, *Eleusine indica, E. cofana, Fuirena umbellata, Imperata cylindrica, Kyllinga pumila* and *Paspalum vaginatum* were reported by Salaudeen *et al*. (2008c) as weed hosts of RYMV in Nigeria.

No infection was obtained with cultivated cereals such as *Sorghum bicolor* (L) Moench, *Zea mays* L., *Pennisetum americanum (L.)* Lecke *and Triticum aestinum* L., neither with some sedges and broad leaved weeds (Abo, 1998). Konate *et al.* (1997) and Nwilene *et al.* (2009a) reported that most of the field samples were from *Oryza* species and New rice for Africa (NERICA) progenies and from the wild grasses belonging to the Poaceae family. Thus it is evident that the host range of RYMV is narrow.

RYMV is highly stable in crude, dry and frozen leaves and highly infectious (Bakker, 1974; Fauquet and Thouvenel, 1977). Sap derived from young infected rice leaves (2 – 3 weeks old) is still infective at a dilution of 10^{-11}; however, the dilution end point varies with the origin of the inoculum (Fauquet and Thouvenel, 1987). The virus remains infective for 35 days at 27 ^{0}C to 29 ^{0}C but when stored at 9 ^{0}C, the sap remains infective for 71 days (Bakker, 1970, 1974) and at 4 ^{0}C for 84 days (Fauquet and Thouvenel, 1987). However, the inoculation progressively looses its capacity for infection from 55 ^{0}C to 70 ^{0}C, although in crude sap the virus remains viable for at least 34 days at 27 ^{0}C (Fauquet and Thouvenel, 1987). It can replicate at a surprisingly rapid rate (Fauquet *et al.,* 1995).

2.8. EPIDEMIOLOGY OF RYMV

Many factors influence the development of epidemics and it is simplistic to assume that there can be any single underlying cause of the serious epidemics of diseases (Thresh, 1989). Onasanya *et al*.

(2012) reported that for epidemics of RYMV in natural conditions, insect vectors played a significant role in disease epidemics as they were able to transfer RYMV from surrounding infected fields and contaminated weeds to the new rice fields. Many cultural practices favour RYMV epidemics: uprooting and bundling of seedlings from nurseries to permanent field provides a means of transmission through contact between healthy and diseased seedlings (Sarra, 2005; Traoré *et al*., 2006); farmers own livestock and after harvesting, they allow cattle to graze on regenerating stubbles so that the dung deposited adds manure to fertilise the subsequent crops; this enhances the virus build-up for cattle, beetles, donkeys and grass rats which all contribute to the epidemics of the virus (Absa, 2010); harvesting using sickles without distinguishing the healthy from the diseased plants, increases the incidence of disease in the subsequent rice regrowth from the remaining stubbles and thus build-up RYMV inoculum reservoir (Sarra, 2005); Traoré *et al*. (2009) reported that most epidemics occur in areas where irrigated rice is grown and also to a lesser extent when water is available for several months during the rainy season where lowland rice is grown. The worst epidemics of RYMV disease were experienced in Niger (Reckhaus and Adamou, 1986; John *et al.,* 1986), Mali (Sy, 1994) and Madagascar (Reckhaus and Andriamassintseheno, 1995). The disease was also severe in Cote d'Ivoire (Singh, 1995). It is increasing in other countries of Africa (Abo *et al.,* 1995). The disease has come to the foreground due to intensification and modification of rice culture which has led to major epidemics of rice viruses revealed by growing susceptible varieties, fertilizer and pesticides uses (Buddenhagen, 1983; Thresh, 1989). It is on record that any country where RYMV disease is a serious problem has one or more highly susceptible varieties on a large acreage. For example, Sindano, Basmati 217 and IR 22 in East Africa, BG 90-2 in Mali, Bouake 189 in Cote d'ivoire, IR 1529-680-3 in Niger, Jaya in Senegal, ITA 123 in Burkina Faso, ITA 212 (FARO 35) and FARO 29 (BG 90-2) in Nigeria and IR8 and IR20 in Madagascar (Bakker, 1974; Singh, 1995). Disease outbreaks have been reported mainly from irrigated and rainfed lowland production systems. Also it does occur in both the highly susceptible exotic and indigenous varieties under rainfed upland production ecosystems (Awoderu, 1991b). It is gradually building up in other

countries of Africa (Abo *et al.,* 1995; Anno-Nyako and Twumasi, 1995; Singh, 1995). Bakker (1974) stated that expression of the virus is strongly influenced by light intensity, day length, humidity, temperature, growth stage of the plant and other environmental factors. The area originally affected in Kenya by RYMV was part of a new irrigation project which had led to an increase in rice cultivation due to availability of water throughout the year. Similar circumstances have been associated with high incidence of RYMV in other parts of Africa (Rossel *et al.,* 1982b). The increased use of fertilizer and irrigation have influenced plant growth in favour of pest population build up, survival and perennation of pathogens by leading to enhanced growth and greater continuity of weed hosts, rice stubble/ratoons, and seedlings volunteers (Abo and Sy, 1998).

Climatic factor such as rainfall, relative humidity, temperature and sunshine hours play important part in outbreaks of epidemics of virus diseases (Shaner, 1981). Many diseases are favoured by humid or rainy weather and may be more common and severe in years favouring good crop production (Moore, 1993). Similarly, the incidence and development of all the insect vectors are much dependent upon the prevailing environmental factors such as temperature, relative humidity and precipitation (Aheer *et al*., 1994). Most emerging infections appear to be caused by pathogens already present in the environment, brought out of obscurity or given a selective advantage by changing conditions and afforded an opportunity to infect new host populations (Moore, 1993).Variation in incidence and severity of RYMV depending on climatic zones and the local environment in which rice is grown (Awoderu, 1991a). Some rice cultivar planted in the rainy season suffers most from RYMV while rice cultivar grown mainly under irrigation is the most productive (Reckhaus and Andriamasintsebeno, 1997). Many and often contradictory results were generated most probably because of the use of different virus isolates and infection conditions. Awoderu (1991a) reported higher RYMV incidence in areas poorer in rainfalls and in areas with

low relative humidity while Heinrichs *et al*. (1997) reported no correlations between RYMV and both windspeed and rainfall.

The comparative epidemiology of rice virus diseases showed that the *Oryza sativa* Japonica type varieties are very susceptible to rice viruses from Asia, Americas and the Caribbean while the *O. sativa* indica type varieties are either resistant or tolerant of the viruses (Buddenhagen, 1983; Chen, 1991). On the other hand the *O. sativa* indica type varieties are very susceptible to the Africa specific RYMV and the *O. sativa* Japonica types are either resistant or tolerant of the virus (Abo and Sy, 1998). For example IR8 and IR20, which are resistant to *Rice stripe virus (*RSTV*) Genus Tenuivirus* in Asia (Chiu *et al.,* 1986) are highly susceptible to RYMV in Africa and the neighbouring islands (Bakker, 1974; Thottappilly and Rossel, 1993; Reckhaus and Andriamasintsheheno, 1995).

A survey of incidence and severity of RYMV carried out in four rice growing environments and vegetation zones between 1983 and 1986 in West Africa showed that the incidence was 75% in tropical rainforest, while lowland rice environment had higher incidence than the upland environments (Awoderu, 1991a). Epidemics caused by virus on any varieties of crop plant in the field are influenced not only by the genetic background of host varieties, but also by initial disease intensity and weather (Luo and Zeng, 1995). Poor understanding of the epidemiology and transmission of the disease was reported to have increased the incidence and severity levels at an alarming rate from the late sixties to the nineties, predominantly affecting rice in the lowland ecosystems (Pinto, 2000).

2.9 VARIETAL REACTIONS AND YIELD LOSS ASSESSMENT

Studies conducted at IITA on the reaction of hundreds of *O. glaberrima* Steud, shows that they have higher levels of resistance than *O. sativa* L. (Alam, 1988; Ng, 1988). Screening of *Oryza* germplasm to identify the potential sources of resistance to the virus that could be used in breeding programmes for resistance to the virus. These sources of resistance are mainly from *O. glaberrima, O. longistaminata,* and *O. barthi* as well as traditional African upland Japonica varieties that are highly tolerant, resistant or immune to the virus. Good progress has been made in identifying valuable sources of tolerant/resistant germplasm (Abo and Sy, 1998). So far immunity to RYMV was only reported in *O. barthi* and *O. longistaminata* accessions (IITA, 1984; Rossel and Thottappilly, 1985).

Screening for RYMV resistance which started in the late 70's at Rokupr, Sierra Leone and IITA, Ibadan, Nigeria indicated the following upland tropical japonica cultivars as resistant: 0S6, LAC 23, Moroberekan. Iguape, Cateto, 63-83, IRAT 13, NSO2 Gbongosy, Taminahum, marlie and many traditional farmer' landrace. Raymundo *et al.* (1979) reported infection of ADT 32, ITA 212, ARC 1175, FARO 15, Americana, and other traditional rice varieties on farmer's lowland fields in Nigeria. Varietal reactions in field and greenhouse tests confirmed high level of susceptibility to RYMV in BG 90-2, Bouake 189, Jaya, IR 1529-680-3, IR5, IR29, ITA 212, Gambiaka, ITA 123, FARO 15, IR46, and ROK5 among others (Sy and Akator, 1993). Varieties found resistant to RYMV in West Africa include IRAT 133, IRAT 156, IR 47686-15051-1, WABIS 18, FARO 300 and ITA 305 (Awoderu, 1991a). In East Africa, the resistant varieties include IR47686 -15–1–1, Gigante, IR 53734-27, FARO 300, TGR 78, ITA 305, IRAT 302, CT 7244-9-1-52, Supa SSD 1 and Supa SSD 5 (Luzi-Kihupi, 2001). Also reported to be resistant to RYMV are FARO 11, ITA 235, IRAT 133, FARO 399 and ITA 195 (Kanyeka *et al.,* 1996). In Nigeria, field experiment showed

that BOUAKE 189, FARO 29, FARO 35, FARO 44, FARO 52, FARO 54 and GIGANTE were moderately resistant (Salaudeen, 2007).

A study of yield reduction from inoculated and naturally infected rice plants showed a yield reduction rate of 84 % for Bouaké 189, 67% for BG 90-2 and 4 % for Moroberakan (Sy *et al.,* 1993). Yield losses of 58-67% were reported in Niger (Reckhaus and Adamou, 1986), of 54-97 % of Sierra Leone (Taylor, 1989) of 20-45 % in Burkina Faso (Sere, 1991). In Tanzania, the yield loss estimates ranged from 25 – 100 % (Luzi-Kihupi, 2001). Yield losses of 17-100 % were obtained under screenhouse conditions in Nigeria (Onwughala *et al*., 2011). Under natural infection by RYMV disease, Bakker (1974) reported yield reduction of 50 % in Kenya. While Taylor *et al.* (1990) reported 82 % yield reduction in Sierra Leone. During a special monitoring tour of the West Africa rice development association (WARDA) constituted Rice Integrated Pest Management Task Force (IPM-TF) - estimated yield losses on BG 90-2 was as high as 60 % under farmers' conditions in Niger (Sy, 1994).

2.10. MANAGEMENT STRATEGIES 0F RYMV

The prospects for reducing the threat of RYMV as an increasingly serious disease of rice in rice growing areas of Africa have been investigated (Singh, 1995; Abo *et al*., 1998). Resistant cultivar, cultural practice, and application of insecticides have been widely used for RYMV control (Ndjiondjop *et al*., 1999; Kouassi *et al*., 2005; Sorho *et al*., 2005). Breeeding for resistance is the most promising mechanism of limiting infection and yield losses caused by RYMV (Sorho *et al*., 2005; Wopereis *et al*., 2008; Zhang, *et al*., 2009). Several improved lines obtained from the introgression of *rymv1-2* resistant gene from cultivar Gigante were developed by Biotechnology Unit of Africa Rice Centre and evaluated in the field for RYMV resistance (Absa, 2010). Control of the disease through the development of transgenic plants has been investigated and some transgenic

lines with high levels of RYMV resistance have been obtained (Pinto *et al*., 1999). Some rare accessions of African cultivated *O. sativa* (Gigante) and traditional rice species *O. glaberrima* (Tog) were found to be highly resistant to RYMV (Ndjiondjop *et al*., 1999). In lowland ecosystems, Moroberekan variety, of Japonica type, appeared to be highly resistant whereas WITA 9 and WAT 316 varieties, of Indica type, were resistant (Zouzou *et al*., 2008). In Nigeria, the rice cultivars FARO 11, 37, 38, 50, IDSA 10, 25, LAC 23, ITA 150, IRAT 144, Moroberekan and Gigante are resistant to the virus (Abo *et al.,* 2001). Resistance was also observed in Moroberekan and NERICA-L42 under both mechanical and natural viral infection (Onwuaghalu *et al*., 2011), moderate resistance was found in Gigante, WAB 189 838HB, WAB 450 38HB and WAB 450 160HB under screenhouse conditions (Saluadeen *et al*., 2008b). In addition, genomic studies with combined transcriptome and proteome approaches were developed to identify plant genes and proteins involved in the virus cycle (Kouassi *et al*., 2005). Control by genetic engineering was applied to widely grown, RYMV-susceptible varieties; Bouake 189, ITA 212, BG90-2 have been transformed with contract encoding a fragement of the RNA-dependent RNA polymerase of RYMV (Kouassi *et al*., 2005). Deployment of resistant varieties as replacement of the known susceptible local varieties, based on cultivar resistance ranking, three *O. sativa* subspecies japonica (NERICA 6, ITA 257 and ITA 325) and two *O. sativa* subspecies indica (WAC 116 and WAC 117) were identified as the potential sources of resistance for improving susceptible local varieties (Ochola and Tuslime, 2011a). The confirmed resistance breakdown in Gigante (Traore *et al*., 2006) has important implications for plant breeding and disease control strategies. Therefore, pyramiding different sources of resistance is recommended for enhanced durability of resistance. In addition, the use of sufficient pre-release challenge by the combination of isolates with different levels of aggressiveness will delay the rise of susceptibility in deployed resistant cultivars (Ochola and Tuslime, 2011a).

Several cultural practices have been recommended by WARDA's Integrated Pest Management Task Force (IPM- TF) involving international and national rice scientists and farmers in combating the disease among countries affected by the virus. Namely, destruction of rice residues after harvest and ratoons that harbour the virus and insect vectors (Reckhaus and Adamous, 1986), diversification of varieties on a single plot, change of site for the next nursery beds, change the mode of sowing from wet to dry seeding (raising nurseries under rainfed conditions in lieu of irrigation), flooding of tilled plots until transplanting is carried out in order to limit the spread of the disease, early transplanting before the outbreak of *T. sericea* and reduction of plant spacing, rouging of infected plants and immediate replanting, early and double weeding to reduce the weed reservoir of the virus and insect vectors, withholding irrigation between planting to provide a rice free period and to restrict the build-up of the virus infection and insect population, and reduction of fertilizer application (e.g urea) on infected plants (Reckhaus and Adamous, 1986: Thresh, 1991; Coulibaly,1995; Reckhaus and Andriamasintsebeno, 1997; Abo *et al.*, 1998 ; Nwilene *et al.*, 2009b).

Different insecticides such as Malathion, Decis, Carbaryl, have been used to control rice insect vectors population (Abo and Sy, 1998). Usually when the insect population is low, chemical control of the vectors reduces virus disease incidence effectively, but when the population is very high the use of an insecticide may not give any control of the disease (Kissimoto, 1969). According to Breniere (1983) spreading a light layer of insecticides or petrol on the surface of water and thus causing insects to drop on it, as well as using granulated insecticides in water of the paddy against the larvae are effective strategies for the control of hispid beetles.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 EXPERIMENT I: EFFECT OF RYMV ON PLANT GROWTH AND YIELD LOSS ASSESSMENT OF RICE CULTIVARS

A screenhouse study was conducted to determine the effect of different infection timing on rice yield. In the Department of Crop Protection, Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, Nigeria.Ten rice cultivars which include FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 46, FARO 52, FARO 57, MOROBEREKAN (resistant check) and BOUAKE (189 (susceptible) check (IITA, 1986; WARDA, 2000) were used.

The treatments consisted of the following:

1. Control uninoculated treatment
2. Test rice plants artificially inoculated at 4 weeks after sowing (WAS)
3. Test rice plants artificially inoculated at 6 WAS
4. Test rice plants artificially inoculated at 8 WAS
5. Test rice plants artificially inoculated at 10 WAS

The experiment was laid out in a strip plot design and replicated three times, with the ten rice cultivars in the vertical factors (main plot) and four inoculation regimes of RYMV (extract) at 4, 6, 8 and 10 (WAS) and un-inoculated control, was in the horizontal factors (sub- plot). Each treatment consisted of 3 pots with 3 plants per pot. The rice seeds were obtained from the germplasm of National Cereal Research Institute, Badeggi, Niger state, Nigeria.

3.1.1. Data Collection and Analyses

3.1.1 1. RYMV Disease Assessment

RYMV Disease incidence:

RYMV incidence was computed as the number of infected plants expressed as percentage of the total number of plants assessed as follows:

$$\text{RYMV incidence \%} = \frac{\text{Number of symptomatic plants}}{\text{Total number of plants}} \times 100$$

Disease severity was monitored and recorded weekly starting from 4 to 14 WAS. Disease severity was rated using a visual assessment scale of 1-9 based on Standard Evaluation System (SES) (IRRI, 1988, 1996) for field test at growth stages from 4 weeks and above.

1 - No symptoms

3 - Leaves green, but with sparse dots or streaks and less than 5 % of height reduction

5 - Leaves green or pale green with mottling and 6 to 25 % of height reduction, flowering slightly delayed.

7 - Leaves pale yellow or yellow and 26-75 % of height reduction flowering delayed

9 - Leaves turn yellow or orange, more than 75 % of height reduction, no flowering or some plants dead.

RYMV Disease Severity Index:

The disease severity index for each treatment was computed using the formula below.

$$\text{Disease severity index (\%)} = \frac{\sum n \times 100}{N \times 9}$$

Where ;

$\sum n$ = summation of individual rating

N = Total number of plants assessed

9 = Highest score on severity scale.

Plant height:

Plant height was measured from the ground level to the tip of the uppermost leaf using a measurement ruler (cm).

Reduction in plant height

Reduction in plant height was calculated from the following formula

$$\text{Reduction in plant height (\%)} = \left[\frac{H_2 - H_1}{H_2}\right] \times 100$$

Where:–

H_2 = mean height of control plants

H1 = mean height of test plants

Number of tillers per plant:

This was done by counting the number of tillers produced by each test plant

Reduction in the number of tillers per plant

It was calculated from the following formula:

$$\text{Reduction in the number of tillers (\%)} = \left[\frac{T_2 - T_1}{T_2}\right] X 100$$

Where:

T_2 = mean number of tillers of control plants

T_1 = mean number of tillers of test plants

Days to 50 % flowering:

Increase in days to 50 % flowering was determined by counting from the date of sowing to the number of days taken by half of the entire plant population of each test plant to flower.

Increase in days to 50 % flowering

This was determined from the following formula:

Increase in days to 50 % heading = D □ D1

Where:

D = the mean number of days taken by half of the infected plant population of each test cultivar to flower

D1 = the mean number of days taken by half of the control plant population of each test cultivar to flower

Number of grains per panicle:

The number of grains per panicle was determined by counting the total number of grains on the panicle per test plant.

Paddy yield:

The Paddy yield was determined by weighing the quantity of paddy rice produced at harvest, by each test plant.

Paddy yield loss:

The Paddy yield loss was estimated from the following formula:

$$\text{Yield loss (\%)} = \left[\frac{Y_2 - Y_1}{Y_2}\right] \times 100$$

Where

Y_1 = mean paddy yield of test plants

Y_2 = mean paddy yield of control plant.

Threshing percentage:

Threshing percentage was calculated from the harvested grain of each test plant, the threshed grain weight was expressed as percentage of the un-threshed grain weight using the following formula:

$$\text{Threshing percentage (\%)} = \frac{\text{Weight of threshed grain}}{\text{Weight of un-threshed grain}} \times 100$$

One thousand (1,000) grain weight:

This was determined by randomly hand picking 1,000 grains in each treatment. These were then weighted for each treatment.

Data Analysis

Data obtained were subjected to analyses of variance using package of Statistical Analysis System (SAS, 1999) and significant differences between means determined using Duncan's Multiple Range Test (DMRT) at 1 and 5 % level of probability (Gomez and Gomez, 1984). Correlation analyses were also carried out.

3.2. EXPERIMENT II: EPIDEMIOLOGY OF RYMV

The experiment was conducted during the wet seasons of 2008, 2009 and 2010 at Bomo (latitude 11^0 07′N, longitude 07^0 41′E and Sayen Gobirawa (latitude 11^0 06′N, longitude 07^0 44′E (upland) and dry seasons of 2008/ 2009 and 2009/ 2010 at Nasarawan Buhari (latitude 11^0 07′N, longitude 07^0 39′E (lowland) all in Zaria environs. These locations are in Northern Guinea Savanna Zone of Nigeria where natural sources of RYMV are prevalent, high incidence of the virus had been observed (Salaudeen *et al*., 2008a) and its vectors are abundant

The experiment was conducted to evaluate the responses of ten (10) selected rice cultivars. These were FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 46, FARO 52, FARO 57, MOROBEREKAN (resistant check) and BOUAKE 189 (susceptible check) (IITA, 1986; Singh, 1995; WARDA, 2000; Onasanya *et al*., 2004).

The trial was laid out in a randomized complete block design (RCBD) with three replicates. Each test cultivar was seeded on a separate plot at an inter and intra-row spacing of 0.20 m (N'Guessan *et al*., 2001) and each plot consisted of 10×10 rows. Rice seedlings were thinned to three per stand, to give a total number of 100 stands in each plot and 300 plants. Each plot was 3 m wide and 3 m long. The plots were 0.5 m apart while replicates were separated by a border zone of 1 m.

Weeding was done manually using hoe and hand pulling when necessary. Fertilizer was applied at the rate of 60 kg /N/ ha, 30 kg $P_2$05/ ha and 30 kg $K_2$0/ ha at 4 and 8 Weeks after germination

(IITA, 1986). Harvesting was done manually with a sickle, when the plants were fully matured and the paddy colour turned yellow.

3.2.1 Sampling and Identification of Insect Vectors of RYMV associated with Rice Plants

Insect sampling was made at weekly intervals between the hours of 7.00 and 8.30 am (6 and 7.30 GMT) (when their movement was sluggish) in each plot starting from four weeks after germination till the end of the experiment. Sweep net was used to sample the inner rows. Five sweeps were made per plot. The insects sampled were immobilized using chloroform in a piece of cotton swab in a bottle and kept in the refrigerator for sorting out later. Identification was carried out in the Insect Museum of the Department of Crop Protection, Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, Nigeria (Musa, I. P. pers. commun.)

3.2.2. Transmission test of Insect associated with Rice plants in the Fields

For the transmission test, adult insects found in and around the experimental fields, within 3 to 14 WAS and RYMV insect vectors reported by other researchers were collected, using sweep nets and kept in closed bottle with perforated cover before being used for the transmission tests. Adult insects were caged on RYMV infected Bouake 189 cultivar for 24 hours for acquisition access feeding (Nwilene *et al*., 2009b). Later a single adult insect was removed after acquiring the virus and caged to feed on healthy seedlings of RYMV susceptible rice cultivar, Bouake 189 at the 2 to 3 leaf stage, because rice plants are most susceptible to RYMV at this stage (Bakker, 1974). A camel hair brush was used to collect and transfer insects from plants and from cages (Banwo *et al*., 2002a). Inoculation access feeding for 24 hours was carried out by caging viruliferous insects into test plant with tubes (PVC insect rearing tube) measuring 23 cm by 10 cm and covered with netting. Three potted plants were used per cage and the experiment was replicated nine times. At the end of 24 hours, the insects were removed from the cage and killed by exposure to freezing

temperature. The plants exposed to the insects were kept for 4 weeks in the screenhouse at the Department of Crop Protection IAR/ABU, Zaria, Nigeria for symptom development. To verify the presence or absence of RYMV infection, plants were evaluated by Double antibodies sandwich - Enzyme- Linked Immunosorbent Assay (DAS-ELISA).

Transmission rate was calculated from the number of plant infected expressed as percentage of the total number of plant tested using the following formula:

$$\text{Rate of transmission (\%)} = \frac{\text{Number of plant infected}}{\text{Total number of plant tested}} \times 100$$

3.2.3. Relative abundance of Insect Vectors Associated with Rice in Relation to Weather factors and RYMV Incidence

Insect vectors of RYMV were sampled weekly and related to various weather factors. RYMV infected plants were also monitored weekly starting from 4 to 14 WAS. Insect sampling and observations on RYMV incidence were made on the same day. Insect vectors caught in each plot were counted separately. Weekly mean weather factors of temperature, relative humidity, sunshine hours and rainfall were obtained from the Agroclimatological Unit of the Institute for Agricultural Research, ABU, Samaru, Zaria and related to the incidence of the virus and to the population of insect vectors.

The plants were assessed for disease severity index, plant height, number of tillers per plant, days to 50 % flowering, number of grains per panicle, paddy yield, threshing percentage and 1,000 grain weight. The data obtained were subjected to analyses of variance using software package of Statistical Analysis System (SAS, 1999)) and significant difference between means was determined by the techniques of Student Newman Keuls (SNK) test at 1 and 5% level of probability. The difference in average insect vector caught and RYMV infected plants per plot were determined. Correlation analyses were also carried out between climatic factors and the number of insect

vectors caught per week; RYMV incidence, severity index, paddy yield and age of plant (in weeks).

3.3. EXPERIMENT III: IDENTIFICATION OF WEED HOSTS OF RYMV

3.3.1 Field Survey and Sampling

Field surveys were carried out during the wet and dry seasons for rice in the year 2007 to 2010. Seven states (Borno, Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara) were surveyed for the distribution of RYMV and its weed hosts. Hotspots and epidemics areas within those states were surveyed. The surveys were carried out at the tillering and panicle initiation stages (Abo *et al.,* 2002). In each field surveyed, three quadrants, 4×4 m^2 in size were randomly chosen (Alegbejo and Kashina, 2000). Infected rice and weed species leaves with and without RYMV- liked symptoms were randomly sampled on the edges of the field, within the rice field and in the vicinity of the RYMV-infected rice plants using the visual diagnostic symptoms of RYMV (IRRI, 1996). Samples were collected using separate polyethylene bags, labelled, kept in ice box and transported to the Virology laboratory, Department Crop Protection, ABU, Zaria. Thereafter, the weed plants were identified in the Herbarium of the Department of Biological Sciences, ABU, Zaria, Nigeria. The weed species identified and the rice samples collected were kept in the refrigerator for further serological test.

3.3.2. Double Antibody Sandwich Enzyme- Linked Immunosorbent Assay (DAS-ELISA)

Leaves of weed species collected from RYMV hotspots and epidemics areas in different parts of Northern Nigeria were subjected to the direct double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) method as described by Clark and Adams (1977). Purified coating antibody (lgG 0074), RYMV polyclonal antiserum obtained from plant virus collection centre, DSMZ (German collections of Microorganism and cell cultures) Braunschweig, Germany, was diluted in coating buffer to give the recommended dilution ratio of 1:1,000. One hundred microlitres (100 µl) of the solution was dispensed into each well of the ELISA plate. Healthy rice

leaves were ground and used as control. The plate was covered with another plate and wrapped with nylon bag and incubated at 37 ^{0}C for 4 hours. The microtitre plate was then removed and washed with PBS-T three times; allowing 3 minutes at each wash and tap the plate on tissue paper to dry. The designated well of microtitre plate was then blocked by adding one hundred microlitres (100 µl) of 2 % egg-albumin dissolved in PBS-T. Incubated at 37 ^{0}C for 1 hour, thereafter, the plate was inverted and allowed to drain. Again the plate was washed three times as stated above. One gram (1 g) of leaf tissue of each isolate sample was ground in 10 ml of 0.1 M phosphate buffer (pH 7.4). One hundred microlitres (100 µl) of the supernatant was dispensed into each well of the antibody coated microtitre ELISA plate and refrigerated (4 ^{0}C) overnight. Healthy rice leaves were ground and used as control. The plate was removed and washed with PBS-T thrice, allowing 3 minutes at each wash before pouring the solution, the microtrite plates were tapped dry on tissue paper. Conjugate buffer was mixed with the antivirus conjugate (AS 0074 lgG AP) to give a dilution ratio of 1:1,000. One hundred microlitres (100 µl) of the solution was dispensed to each well of the test sample and incubated at 37 ^{0}C for 4 hours. Again the plate was removed and washed three times as stated above. Finally phosphate tablets (p-nitrophenyl phosphate (Sigma 104-105) was dissolved in substrate buffer (1mg/ml) One hundred microlitres (100 µl) of the solution was added to the wells coated with test samples. The plate was then incubated at room temperature for 30 minutes. Colour change was measured with ELISA microreader (GF. M3000 Microplate reader, B. Bran Scientific & Instrument Company, England). Absorbance value (A.405 nm) was accepted as positive (+) when the reading was greater than twice the mean absorbance value of the virus free control sample.The positive value was also visualized when the colourless substrate p-nitrophenyl phosphate give rise to a yellow p-nitrophenol product.

3.4. EXPERIMENT IV: DETERMINATION OF SEROTYPES OF RYMV

Samples of rice plant tillers showing symptoms of RYMV were collected from RYMV epidemics and hotspot rice growing areas of Northern Nigeria. All the samples were collected during the vegetative stage of the crop, twice a year during dry and wet seasons. The leaf samples were preserved in the freezer, at the Department of Crop Protection, Ahmadu Bello University, Zaria, Nigeria.

The virus was recovered from the infected samples by back inoculation to the highly susceptible rice cultivars Bouake 189 (Onasanya *et al.,* 2004). For inoculation tests, leaves from each specimen plant were pooled and then ground with a sterilized pestle and mortar, 1g of the infected leaves in 10 ml (Sarra *et al.,* 2004*)* of 0.1M phosphate buffer (pH 7.4) (Luzi-Kihupi *et al.,* 2000*)*, containing carborundum powder (600 mesh) to act as an abrasive to facilitate virus entry into the plant. The extracts were used in inoculating 5 seedlings of Bouake 189 cultivar, planted in plastic pot filled with, sterilized soil to each isolate by mechanical (sap) inoculation. The test plants were kept for 3 weeks in the screenhouse and monitored for symptom(s) expression. Leaves of the test plants showing symptoms of RYMV were harvested and later used as sources of inocula during the serotyping and molecular characterization.

3.4.1. Serological Characterazation of RYMV Isolates

The Triple Antibody Sandwich Enzyme Linked Immunosorbent Assay (TAS-ELISA) as outlined by Clark and Adams (1977) was used in the determination of serotypes of RYMV at the Virology Laboratory, Department of Crop Protection, Ahmadu Bello University, Zaria, Nigeria.

3.4.1.1. *TAS-ELISA*

Four DSMZ monoclonal antibodies (AS-0478/11, AS-0478/12, AS-0478/21 and AS- 0478/22) obtained from plant virus collection centre, DSMZ (German collections of Microorganism and cell cultures) Braunschweig, Germany were used. The purified coating antibody (AS-0074 IgG) was

diluted in a coating buffer to give a dilution ratio of 1:1,000. The wells were then coated with one hundred microlitres (100 µl) of the solution and covered with another microtitre plate, wrapped in a nylon bag and then incubated for 4 hours at 37 ^{0}C. The plate was later removed and washed with PBS-T, three times, allowing 3 minutes before each wash and tapped dried the plate on tissue paper. The designated well of plate was then blocked by adding one hundred microlitres (100 µl) of 2 % egg-albumin dissolved in PBS-T. Incubated at 37 ^{0}C for 1 hour, thereafter, the plate was inverted and allowed to drain. Again the plate was washed three times as stated above. Leaf sample of each isolate were then ground in 0.01 M phosphate buffer. One hundred microlitres (100 µl) aliquots of each sample was dispensed into each designated well of the antibody coated plate and kept in a refrigerator overnight at 4 ^{0}C. Healthy leaves of rice plant were ground and used as control. The plate was removed and washed thrice with PBS-T as described previously. One hundred microlitres (100 µl) of monoclonal antibody (AS- 0478/11, AS- 0478/12, AS- 0478/21 and AS- 0478/22) diluted at 1:50 in conjugated buffer was added to the designated wells. The healthy control wells were filled with one hundred microlitres (100 µl) of polyclonal antibody (AS-0074 IgG).The plate was again incubated at 37 ^{0}C for 4 hours. The plate was removed and washed three times as discussed earlier. RAM-AP was dissolved in a conjugate buffer to give the recommended dilution ratio of 1:1,000. One hundred microlitres (100 µl) of the solution was added to each well of the plate and incubated at 37 ^{0}C for 2 hours. The plates were removed and washed as previously described. Finally, P-nitrophenyl- phosphate tablet was dissolved in substrate buffer at the rate of 1mg/ml. One hundred microlitres (100 µl) of the solution was added to the wells and incubated at room temperature for 30 minutes. Colour change was measured with ELISA microreader (GF. M3000 Microplate reader, B.Bran Scientific & Instrument Company, England). Absorbance value (A.405 nm) was accepted as positive (+) when the reading was greater than twice the mean absorbance value of the virus free control sample. The positive value were visualized when the colourless substrate p-nitrophenyl phosphate give rise to a yellow p-nitro phenol product.

Hierarchical cluster dendrogram analysis was also generated from the data obtained with the four monoclonal antibodies reactivity from the TAS ELISA results. Using average linkage between isolates by rescaled distance cluster combine analysis (Graph pad instat statistical analysis package software).

3.5. EXPERIMENT V: MOLECULAR CHARACTERISATION OF RYMV ISOLATES

Polymerase chain reaction (PCR) techniques was used in detecting the different RYMV isolates sampled from different locations in Northern Nigeria at the Genetic Engineering Laboratory, Centre for Biotechnology Research and Training, Ahmadu Bello University, Zaria, Nigeria.

3.5.1. RNA Extraction Protocol (Fermentas Life Science, South Africa).

One gram of harvested leaves (frozen) of samples of each isolate was ground to a fine powder using a sterilized mortar and pestle. 100 mg fine powder of each ground sample was transferred into a ZR Bashing Bead lysis tube, and 800 µl RNA lysis buffer was added to the sample. The samples were then secured in a bead beater fitted with a 2 ml tube holder assembly and shaken for 30- 60 seconds. The ZR Bashing bead lysis tubes were centrifuged at 12,000 × g for 1 minute. 400 µl of the supernatant was transferred into a Zymo- spin III C column in a collection tube and centrifuged at 8,000 × g for 30 seconds, thereafter, the flow through were save and 320 µl of ethanol (95- 100 %) was added into the collection tube, mixed well and vortexed briefly. The mixture was transferred into a Zymo-spin ll C column in a collection tube and centrifuge at 12,000 × g for 30 seconds. The flow through was discarded, 400 µl RNA prep- buffer was added into the column, and centrifuged at 12,000 × g for 1 minute. Again, the flow through was discarded and the Zymo-spin ll C columns were placed back into the collection tube. The washing step with 400 µl RNA wash buffer was repeated, and the Zymo-spin ll C column was centrifuged at 12,000 × g for 2 minutes in an emptied collection tube to ensure complete removal of the wash buffer. The Zymo-spin ll C column was carefully removed from the collection tube and placed into a DNase/RNase

free tube. Then 25 µl DNase/RNase free water was added directly to the column matrix and left to stand for 1 minute. Again, the column was centrifuged for 10,000 × g for 30 seconds to elute the RNA from the column. Finally the eluted RNA sample was transferred into a prepared Zymo- spin IV- HRC Spin filter in a DNase/RNase free tube and centrifuged at 8,000 × g for 1 minute. The filtered RNA obtained was used for reverse transcriptase - polymerase chain reaction (RT- PCR) RNA template for cDNA synthesis.

3.5.2 Reverse Transcriptase - Polymerase Chain Reaction (RT- PCR)

3.5.2.1 *First Strand- cDNA synthesis*

The first Strand cDNA synthesis was done according to the manufacturer's instruction using RevertAid premium first strand cDNA synthesis kit (Fermentas Life Science, South Africa).

The mixture per reaction contained the following:

Total RNA	1µl
Gene- specific primer (forward)	1µl
Deoxynucleotide triphosphate (dNTPs) 10 mM (2.5 mM µl each of dATP, dCTP, dGTP &dTTP) (0.5 mM final concentration)	1 µl
Nuclease free water	12 µl

The above reagents were added into a sterile Rnase free tube on ice and gently mixed, centrifuged briefly and incubated at 65 ^{0}C for 5 minutes, chilled on ice, briefly centrifuged again and placed on ice. The following components were added:

5×RT buffer	4 µl
RevertAid premium Enzyme mix	1 µl

The mixture was incubated for 30 minutes at 60 ^{0}C, and then the reaction was terminated by heating at 85 ^{0}C for 5 minutes. The reaction product (the first Strand cDNA synthesis) was used directly in PCR as template for subsequent PCR assay.

Primer

Two pairs of gene- specific primers (AI and B1, A2 and B2) (Pinel *et al.*, 2000) targeting West Africa RYMV strains (S1 and S2) and random hexamer primer (Anonymous, 1997; Kwaga, 2006) were used to transcribe and amplify the coat protein (CP) gene.

Primer	Sequence	Location
A1	5'-GTGAGTGCAACTCCTCACGTAG-3' (forward)	4300-4321
B1	5'-CCAGGAAGGGCAAGAAAA-3' (reverse)	3451-3468
A2	5'-CTCCCCCACCCATCCCGAGAATT-3' (forward)	4428-4450
B2	5'-CAAAGATGGCCAGGAA-3' (reverse)	3442-3457

The forward primers A1 and A2 were used in the RT-PCR to transcribe and amplify genome fragments containing the CP gene (nt 4428 to 4450 and nt 4300-4321) (Pinel *et al.*, 2000).

3.5 3. Polymerase Chain Reaction (PCR)

The PCR amplification of the RT-PCR products was done using the primers A1 and B1, A2 and B2, (Pinel *et al.*, 2000), and random hexamer primer (5′-GTTCTACACGAGTCACTGCAGNNNNNNTGGC-3′) for samples that are difficult to copy with specific primers (Anonymous, 1997).

3.5.3.1 *PCR Cocktail*

The PCR reactions were carried out in a volume of 50 µl sample in an eppendorf tube. The reaction mixture contained the following;

Sample cDNA	5 µl
Virus forward primer	1 µl
Virus reverse primer	1 µl
Mastermix	25µl

(Deoxynucleotide triphosphate (dNTP) 10 mM

(2.5 mM µl each of dATP, dCTP, dGTP and dTTP)

RNase/DNase free water buffer 18 µl

The thermocycler (Techne TC 315) was programmed for initial denaturation at 94 °C for 5 minutes followed by 30 cycles with denaturation for 3 minutes at 94 ^{o}C, annealing for 1 minute at 55 ^{o}C, and extension for 1 minute at 72 ^{o}C with a final extension at 72 ^{o}C for 10 minutes (Pinel *et al*., 2000). The PCR reaction products were kept at 4 ^{o}C until when electrophoresis was done.

3.5.4 Agarose gel electrophoresis of PCR products

The agarose gel was prepared by dissolving 1g agarose in 100 ml Tris acetate EDTA (ethylene diamine tetra acetic acid) TAE buffer and heated in a microwave oven for 2 minutes. After cooling down to a hand touch (about 40-50 ^{oC}), the agarose was then stained with 5 µl of ethidium bromide and poured carefully into the gel electrophoresis tank that was fitted with one or two combs. After the gel had solidified it was immersed into the electrophoresis chamber containing TAE buffer. The combs were then lifted to expose the wells formed. The PCR products were loaded into the well of the gel. 25 µl of each sample was pipetted into a separate well, 5 µl of DNA marker or ladder (1 Kb) was also loaded in the wells, before the first sample and healthy control after the last sample. Electrophoresis was performed at 100 V for 30 minutes (Pinel *et al*., 2000). The DNA bands were observed under UV light and their position in relation to the DNA ladder used. They were than Photographed and documented using computer software system (Unipro).

CHAPTER 4

4.0 RESULTS

4.1 SCREENHOUSE EXPERIMENTS

4.1.1. Effect of inoculation regime of RYMV on plant height of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

There were significant ($P \leq 0.01$) variation in plant height among the inoculation regimes. Control treatment had significantly taller plants, followed by inoculation regimes at 10 WAS, while the lowest was in the inoculation regimes at 4 WAS in all trials conducted. There were significant ($P \leq 0.01$) variations in plant height among the rice cultivars. The highest plant height was recorded in FARO 46 in 2008, though not significantly different from that of MOROBEREKAN. The shortest plant was obtained in FARO 36, though it was statistically similar to FARO 44 (Table 4.1). However, in both 2009 and 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons, also in the combined mean for each season the tallest plant was obtained with MOROBEREKAN while the shortest plant was BOUAKE 189, though it was statistically insignificant to those of FARO 35, FARO 36, FARO 37 and FARO 44 during the 2010 rainy season (Table 4.1). The mean plant height was higher during the rainy season than the dry seasons. The effect of interactions of inoculation regimes and cultivars on plant height was significantly higher ($P \leq 0.01$)) among the treatments in both rainy and dry season experiments (Table 4.1).

4.1.2. Interaction of rice cultivars and inoculation regimes of RYMV on plant height in the screenhouse (combine analysis).

Combined analysis of the three years data under rainy season condition in the screenhouse showed that rice cultivar MOROBEREKAN under control treatment gave significantly taller plant than the remaining treatment. The lowest plant height was recorded on the test cultivar

Table 4.1: Effect of inoculation regimes of RYMV on plant height of rice cultivars in the Screenhouse

	Rainy season (June – October)				Dry season (December –April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	73.47^{e}	67.70^{e}	75.00^{e}	72.06^{e}	72.43^{e}	71.43^{e}	71.93^{e}
6 WAS	83.33^{d}	74.57^{d}	79.63^{d}	79.18^{d}	76.63^{d}	76.73^{d}	76.68^{d}
8 WAS	93.63^{c}	91.30^{c}	88.77^{c}	91.23^{c}	91.57^{c}	90.10^{c}	90.83^{c}
10 WAS	102.67^{b}	100.80^{b}	100.33^{b}	101.27^{b}	101.53^{b}	100.90^{b}	101.98^{b}
Control	107.53^{a}	108.50^{a}	116.23^{a}	110.76^{a}	111.67^{a}	112.30^{a}	111.90^{a}
Mean	92.13	88.57	91.99	90.89	90.77	90.29	90.53
SE+	0.50	0.57	1.54	1.01	0.66	0.59	0.63
	**	**	**	**	**	**	**
Cultivar							
FARO 11	117.13^{b}	97.87^{b}	96.47^{bc}	104.49^{c}	91.60^{c}	89.27^{d}	90.43^{d}
FARO 35	75.87^{g}	80.20^{e}	88.60^{de}	81.56^{e}	85.73^{e}	86.13^{e}	85.93^{f}
FARO 36	70.13^{h}	87.40^{d}	88.67^{de}	82.07^{e}	88.00^{de}	86.93^{d}	87.47^{ef}
FARO 37	86.73^{d}	92.73^{c}	87.13^{de}	88.87^{d}	90.07^{cd}	88.93^{d}	89.50^{d}
FARO 44	77.53^{fg}	81.80^{e}	83.87^{e}	81.07^{e}	88.87^{cd}	89.20^{d}	89.03^{de}
FARO 46	120.00^{a}	94.33^{c}	102.13^{b}	107.16^{b}	96.07^{b}	96.06^{b}	96.07^{b}
FARO 52	80.87^{e}	92.40^{c}	91.07^{cd}	88.11^{d}	95.13^{b}	92.80^{c}	93.97^{c}
FARO 57	90.20^{c}	77.07^{f}	75.87^{f}	81.04^{e}	78.47^{f}	76.40^{f}	77.43^{g}
MOROBEREKAN	119.20^{ab}	111.87^{a}	123.93^{a}	117.67^{a}	120.73^{a}	123.20^{a}	121.97^{a}
BOUAKE 189	78.60^{f}	70.07^{g}	82.20^{e}	76.96^{f}	73.00^{g}	74.00^{g}	73.50^{h}
Mean	92.13	88.57	91.99	90.89	90.77	90.29	90.53
SE $\pm$	0.71	0.80	2.18	1.43	0.94	0.85	0.88
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 %, using Duncan's multiple range test (DMRT). ** = significant at P =0.01 %,

Table 4.2: Interaction of rice cultivars and inoculation regimes of RYMV on the plant height in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons

	Rainy season (June – October 2008 -2010)					Dry season (December – April 2008/ 2009- 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	85.44^{s}	92.22^{pq}	104.44^{hi}	113.33^{ef}	127.00^{b}	77.00^{mn}	79.17^{m}	91.33^{j}	98.67^{h}	106.00^{ef}
FARO 35	65.11^{z}	72.11^{vwx}	84.22^{s}	89.77^{q}	96.56^{mko}	70.00^{pq}	72.83^{op}	87.83^{kl}	95.17^{i}	104.00^{f}
FARO 36	63.22^{z}	69.11^{xyz}	86.55^{rs}	94.00^{op}	96.44^{no}	69.50^{q}	75.50.^{no}	84.83^{l}	98.16^{h}	109.33^{e}
FARO 37	68.55^{yz}	75.33^{v}	90.44^{q}	93.80^{op}	116.11^{e}	69.17^{qr}	74.83^{no}	88.83^{jk}	99.83^{gh}	114.83^{d}
FARO 44	60.55^{z}	67.44^{z}	80.77^{u}	94.11^{op}	102.44^{ijk}	66.00^{rs}	71.00^{pq}	86.00^{kl}	103.16^{f}	119.00^{c}
FARO 46	89.56^{qr}	99.77^{klm}	107.44^{gh}	115.67^{e}	123.44^{c}	73.00^{op}	76.67^{mn}	95.33^{ij}	110.00^{de}	125.33^{b}
FARO 52	67.33^{z}	75.11^{v}	86.00^{s}	100.77^{jkl}	111.33^{ef}	70.00^{pq}	72.00^{op}	95.33^{ij}	109.33^{e}	123.16^{b}
FARO 57	63.22^{z}	72.44^{vw}	81.44^{tu}	90.00g	98.11l^{mn}	61.17^{t}	63.67st	78.50^{m}	86.00^{kl}	97.83^{hi}
MOROBEREKAN	101.56^{ik}	108.11^{g}	120.11^{d}	127.22^{b}	131.33^{a}	104.00^{f}	118.00^{cd}	125.00^{b}	129.83^{a}	133.00^{a}
BOUAKE 189	65.00^{z}	60.11^{z}	70.88^{wx}	93.88^{op}	103.88^{ij}	59.50^{t}	63.17st	75.33^{no}	82.17^{lm}	87.33^{kl}
SE ±			3.21					1.99		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

BOUAKE 189, though not significantly different from most of the cultivar at 4 WAS inoculation regimes, with the exception of MOROBEREKAN, FARO 11 and FARO 46 at 4 WAS inoculation regime. It was further observed that there were no significant differences in the plant height among BOUAKE 189, FARO 36 and FARO 44 at 4 and 6 WAS inoculation regimes (Table 4.2).

Similarly, combined analysis of the two years dry season trials in the screenhouse, showed that MOROBEREKAN cultivar under control treatment had significantly taller plants than the other interaction treatments except for plant height recorded with MOROBEREKAN at 10 WAS inoculation regimes (Table 4.2). Also, the lowest plant height was recorded on BOUAKE 189 at 4 WAS. However, this was not significantly different from FARO 57, inoculated at 4 WAS and BOUAKE 189 and FARO 57 inoculated at 5 WAS, respectively (Table 4.2).

4.1.3. Effect of inoculation regime of RYMV on number of tillers per rice cultivar in the screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

There were significant ($P \leq 0.01$) differences in number of tillers per plant among the inoculated plants. Control treatment had significantly higher number of tillers per plant than the inoculated plants. The lowest number of tillers per plant was recorded on inoculation regimes at 4 WAS in all the trials (Table 4.3).

Among the rice cultivars, significantly highest number of tillers per plant was recorded on BOUAKE 189 in both rainy and dry season experiments and when the data was combined for each season. However, the lowest number of tillers per plant was recorded on FARO 36, MOROBEREKAN and FARO 37 in 2008, 2009 and 2010 wet seasons, respectively (Table 4.3).

Table 4.3: Effect of inoculation regimes of RYMV on the number of tillers per rice cultivars in the Screenhouse

	Rainy season (June – October)				Dry season (December – April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	4.93^{e}	6.97^{e}	6.73^{e}	6.21^{e}	7.73^{e}	6.96^{e}	7.15^{e}
6 WAS	5.40^{d}	7.63^{d}	7.56^{d}	6.87^{d}	8.47^{d}	7.83^{d}	8.15^{d}
8 WAS	7.00^{c}	8.77^{c}	8.63^{c}	8.13^{c}	9.57^{c}	9.00^{c}	9.28^{c}
10 WAS	8.03^{b}	10.07^{b}	9.93^{b}	9.34^{b}	10.33^{b}	10.27^{b}	10.30^{b}
Control	9.27^{a}	11.13^{a}	11.46^{a}	10.62^{a}	11.13^{a}	11.27^{a}	11.20^{a}
Mean	6.93	8.91	8.87	8.23	9.36	9.07	9.23
SE+	0.11	0.10	0.10	0.03	0.11	0.10	0.10
	**	**	**	**	**	**	**
Cultivar							
FARO 11	6.40^{cd}	9.13^{b}	8.80^{bc}	8.11^{c}	9.00^{de}	8.60^{d}	8.80^{de}
FARO 35	7.20^{ab}	8.93^{b}	8.47^{c}	8.20^{bc}	8.60^{e}	8.60^{d}	8.60^{e}
FARO 36	6.13^{d}	8.73^{b}	9.00^{b}	7.96^{c}	9.40^{bcd}	9,20^{b}	9.30^{b}
FARO 37	7.13^{ab}	8.73^{b}	8.40^{c}	8.09^{c}	9.06^{cde}	9.13^{b}	9.10^{bcd}
FARO 44	6.67^{c}	9.13^{b}	8.60^{bc}	8.13^{c}	9.53^{bc}	9.00^{bcd}	9.26^{bc}
FARO 46	6.80^{bc}	8.93^{b}	8.93^{b}	8.22^{bc}	9.73^{b}	9.06^{bc}	9.40^{b}
FARO 52	7.40^{a}	9.07^{b}	8.93^{b}	8.47^{b}	9.46^{bcd}	9.26^{b}	9.36^{b}
FARO 57	6.53^{cd}	8.73^{b}	9.00^{b}	8.09^{c}	9.26^{bcd}	8.93^{bcd}	9.10^{bcd}
MOROBEREKAN	7.40^{a}	8.06^{c}	8.93^{bc}	8.07^{c}	9.26^{bcd}	8.67^{cd}	8.96^{cd}
BOUAKE 189	7.60^{a}	9.67^{a}	9.80^{a}	9.02^{a}	10.33^{a}	10.20^{a}	10.26^{a}
Mean	6.93	8.91	8.87	8.23	9.36	9.07	9.23
SE $\pm$	0.15	0.14	0.14	0.04	0.16	0.14	0.14
	**	**	**	**	**	**	**
Interaction	**	*	**	*	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 %, using Duncan's multiple range test (DMRT). * = Significant at 0.05, **= Significant at 0.01 %

Table 4.4: Interaction of rice cultivars and inoculation regimes of RYMV on the number of tillers per plant in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.

Cultivar	Rainy season (June – October 2008 -2010)					Dry season (December- April 2008/2009 – 2009/2010)				
	4 WAS	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	6.11^{op}	6.67^{l-p}	7.89^{i-m}	9.78^{c-f}	10.11^{b-f}	6.67^{tu}	7.67^{p-t}	9.00^{i-o}	10.00^{r-j}	10.67^{c-f}
FARO 35	5.78^{p}	$6.88l^{-p}$	7.67^{j-n}	9.44^{d-g}	11.22^{ab}	6.67^{tu}	7.67^{p-t}	8.00^{n-s}	9.83^{e-k}	10.83^{cde}
FARO 36	6.44^{nop}	6.44^{nop}	7.89^{i-m}	8.88^{f-g}	10.11^{b-f}	7.50^{q-t}	7.83^{o-t}	9.17^{h-n}	10.50^{c-g}	11.50^{bc}
FARO 37	6.22^{op}	6.77^{nop}	8.00^{h-l}	9.00^{f-j}	10.44^{b-e}	7.33^{rst}	8.00^{n-s}	9.17^{h-n}	10.00^{e-j}	11.00^{b-e}
FARO 44	5.77^{p}	6.44^{nop}	8.00^{h-l}	9.33^{d-h}	11.11^{abc}	6.00^{u}	8.00^{n-s}	10.17^{d-i}	10.67^{c-f}	11.50^{bc}
FARO 46	6.44^{nop}	7.00^{k-o}	8.00^{h-l}	9.11^{e-i}	10.56^{b-d}	7.33^{rst}	8.50^{l-r}	9.50^{f-l}	10.33^{c-h}	11.33^{bcd}
FARO 52	6.55^{op}	7.33^{l-p}	8.56^{f-k}	9.33^{d-h}	10.56^{b-d}	7.67^{p-t}	8.17^{m-r}	9.50^{f-l}	10.17^{d-i}	11.33^{bcd}
FARO 57	$6.11l^{op}$	6.78^{l-o}	8.11^{g-l}	9.11^{e-f}	10.33^{b-d}	7.33^{rst}	8.17^{m-r}	9.50^{f-l}	10.00^{e-j}	10.50^{c-g}
MOROBEREKAN	6.88^{l-p}	7.22^{l-o}	7.89^{i-m}	$8.78f^{k}$	9.55^{def}	8.17^{m-r}	8.67^{k-q}	8.67^{k-q}	9.33^{g-m}	10.00^{e-j}
BOUAKE 189	5.77^{p}	7.11^{l-p}	9.33^{d-h}	10.67^{bd}	12.22^{a}	6.83^{stu}	8.83^{j-p}	10.17^{d-i}	12.17^{ab}	13.33^{a}
SE $\pm$			0.35					0.33		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

The number of tillers produced per rice cultivars were statistically insignificant among FARO 35, FARO 37, FARO 52, MOROBEREKAN and BOUAKE 189 in 2008, Similarly, among FARO 11, FARO 35, FARO 36,, FARO 37, FARO 44, FARO 46, FARO 52 and FARO 57 in 2009 and also among FARO 11, FARO 36, FARO 37, FARO 44, FARO 46, FARO 52, FARO 57 and MOROBEREKAN in 2010 rainy seasons, respectively (Table 4.3). Combined analysis of the rainy season's data showed that the lowest number of tillers per plant was recoded on FARO 36, though it was statistically similar to those of FARO 11, FARO 35, FARO 37, FARO 44, FARO 46, FARO 57 and MOROBEREKAN. Similarly the lowest number of tillers per plant was recorded on FARO 35 and FARO 11 in 2008/ 2009 and 2009/ 2010 dry seasons, respectively. However, there were no significant differences among FARO 11, FARO 36, FARO 37, FARO 44 FARO 52, FARO 57 and MOROBEREKAN in 2008/2009 and also among FARO 11, FARO 35, FARO 44, FARO 57 and MOROBEREKAN in 2009/ 2010 dry seasons (Table 4.3). Combined analysis of the dry season's data showed that the lowest number of tillers per plant was recorded on FARO 35 though it was statistically similar to FARO 11. The results obtained in the combined analysis of the dry seasons, showed that there were no significant differences among FARO 35, FARO 37, FARO 44, FARO 46, FARO 52 and FARO 57. The mean number of tillers per plant was higher during the dry season than the rainy season. The effect of interactions of inoculation regimes and cultivars on number of tillers per plant was significantly higher ($P \leq 0.05$)) among the treatments in both rainy and dry season experiments (Table 4.3).

4.1.4. Interaction of rice cultivars and inoculation regimes of RYMV on number of tillers produced per plant in the Screenhouse (combine analysis).

The number of tillers produced per cultivar during the rainy seasons showed that control treatment of rice cultivar of BOUAKE 189 recorded significantly ($P \leq 0.01$) higher tiller number per plant than the other treatments except for rice cultivar FARO 35 and FARO 44

at the control treatment. Similarly the lowest tiller production per plant was recorded on FARO 44 and BOUAKE 189 at 4 WAS inoculation regimes, respectively. It was further observed that plants inoculated at 4 and 6 WAS inoculation regimes were statistically similar (Table 4.4).

Similarly, during the dry seasons control treatment of cultivar BOUAKE 189 recorded significantly ($P \leq 0.01$) higher tiller number per plant than the other treatments except for BOUAKE 189 inoculated at 10 WAS. The lowest tillers production was obtained on FARO 44 at 4 WAS inoculation regimes though it was not significantly different from those of FARO 11, FARO 35 and BOUAKE 189 at the same inoculation regime (Table 4.4).

4.1.5. Effect of inoculation regime of RYMV on days to 50 % flowering of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

In both rainy and dry seasons, days to 50 % flowering varied significantly among the inoculated cultivars. Inoculated plants at 4 WAS had significantly longer days to 50 % flowering, followed by plants inoculated at 6, 8 and 10 WAS (Table 4.5).

The number of days to 50 % flowering significantly varied ($P \leq 0.05$) among the cultivars in both the rainy and dry season experiments. The longest and shortest days to 50 % flowering was recorded on MOROBEREKAN and FARO 46 throughout the trial periods. They were significantly higher and shorter than to those of the remaining cultivars. However, the number of days to 50 % flowering was statistically insignificant between FARO 11 and FARO 44 and also between FARO 52 and FARO 57 in 2008 wet season. The number of days to 50 % flowering was statistically similar between FARO 37 and FARO 44 and also between FARO 52 and FARO 57 in 2009 wet season. Furthermore, the numbers of days to 50 % flowering were statistically insignificant among FARO 11, FARO 35, FARO 37 and FARO 44 and also between FARO 52 and FARO 57 in 2010 wet season (Table 4.5).

Combined analysis of 2008, 2009 and 2010 season's results showed that the number of days to 50 % flowering were statistically insignificant among FARO 11, FARO 37 and FARO 44 and similarly between FARO 35 and FARO 36, and also between FARO 52 and FARO 57. However, there were highly significant ($P \leq 0.01$) variations in the increase in the number of days increase to 50 % flowering among the test cultivars during 2008/ 2009 and 2009/ 2010 trials, with the exception of FARO 52 and FARO 57 in 2008/ 2009 trial and FARO 11 and FARO 44, and also FARO 37 and FARO 44 in 2009/ 2010 trial (Table 4.5). Combined analysis of 2008/ 2009 and 2009/ 2010 trial results showed that the number of days to 50 % flowering were highly significant ($P \leq 0.01$) among the test cultivars. The mean number of days to 50 % flowering was higher during the wet season than the dry seasons. The effect of interactions of inoculation regimes and cultivars on number of days to 50 % flowering was significantly higher ($P \leq 0.05$)) among the treatments in both rainy and dry season experiments (Table 4.5).

4.1.6. Interaction of rice cultivars and inoculation regimes of RYMV on the days to 50 % flowering in the Screenhouse (combine analysis)

Combined analysis in the rainy showed that rice cultivar of MOROBEREKAN inoculated at 4 WAS gave significantly ($P \leq 0.01$) more days to 50 % flowering than those of other interaction. The few days to 50 % flowering was recorded with FARO 46 in the control treatment. However there were no significant differences in the days to 50 % flowering among FARO 46 inoculated at 8, 10 WAS and under uninculated control treatment (Table 4.6). Similarly, in the dry season trials rice cultivar of MOROBEREKAN inoculated at 4 WAS, recorded the least days to 50 % flowering, though not significantly different from the same cultivars inoculated at 6 and 8 WAS. The least days to 50 % flowering was recorded with FARO 46 in the control treatment, though, not significantly difference from FARO 46 inoculated at 4, 6, 8 and 10 WAS and to the remaining uninoculated control treatment (Table 4.6).

Table 4.5: Effect of inoculation regime of RYMV on the number of days to 50 % flowering of rice cultivars in Screenhouse

	Rainy season (June –October)				Dry season (December – April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	94.50[a]	93.97[a]	99.53[a]	95.58[a]	93.46[a]	95.80[a]	94.63[a]
6 WAS	92.40[b]	92.10[b]	98.27[b]	94.68[b]	91.43[b]	94.27[b]	92.85[b]
8 WAS	88.63[c]	87.90[c]	93.10[c]	89.88[c]	87.33[c]	90.23[c]	88.78[c]
10 WAS	85.73[d]	84.53[d]	88.33[d]	86.20[d]	84.07[d]	85.90[d]	84.98[d]
Control	82.10[e]	81.33[e]	83.37[d]	82.27[e]	80.86[e]	83.63[e]	92.25[e]
Mean	88.67	87.97	92.52	89.72	87.43	89.96	88.70
SE±	0.22	0.25	1.48	0.89	0.21	0.24	0.23
	**	**	**	**	NS	**	*
Cultivar							
FARO 11	83.67[d]	87.00[c]	86.53[d]	85.73[d]	85.93[d]	85.60[e]	85.76[d]
FARO 35	75.13[g]	78.80[e]	81.67[de]	78.53[e]	75.26[g]	76.13[h]	75.70[i]
FARO 36	80.53[f]	81.07[fc]	80.00[e]	80.53[e]	81.13[f]	82.00[g]	81.60[h]
FARO 37	82.53[e]	84.07[d]	87.93[d]	84.84[d]	83.13[e]	84.47[f]	83.80[f]
FARO 44	84.46[d]	84.87[d]	87.27[d]	85.53[d]	84.53[d]	85.20[ef]	84.86[e]
FARO 46	60.80[h]	62.40[h]	63.67[f]	62.29[f]	62.07[i]	62.60[i]	62.33[j]
FARO 52	102.87[b]	104.80[b]	108.47[b]	105.38[b]	104.33[b]	104.50[c]	104.50[c]
FARO 57	102.37[b]	105.60[b]	106.93[b]	104.87[b]	105.00[b]	106.60[b]	105.80[b]
MOROBEREKAN	119.07[a]	118.60[a]	126.13[a]	121.27[a]	120.13[a]	120.40[a]	120.26[a]
BOUAKE 189	95.60[c]	72.47[g]	96.60[c]	88.22[c]	72.73[h]	92.00[d]	82.37[g]
Mean	88.67	87.97	92.52	89.72	87.43	89.96	88.70
SE ±	0.32	0.35	2.11	1.25	0.29	0.33	0.33
	**	**	**	**	NS	**	**
Interaction	**	**	NS	**	NS	**	NS

Column means followed by the same letter(s) are not significantly different at P = 0.05, using Duncan's multiple range test (DMRT). NS = Not significant, *= Significant at 0.05 %
**= Significant at 0.01 %

Table 4.6: Interaction of rice cultivars and inoculation regime of RYMV on the number of days to 50 % flowering in the Screenhouse combined over 2008 to 2010 wet and 2009/ 2010 dry seasons

	Rainy season (June – October 2008-2010)					Dry season (December – April 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	92.44^{gh}	89.11^{hij}	85.78^{j-m}	$87.00l^{-q}$	79.33^{qrs}	91.50^{jk}	88.00^{l}	87.33^{lm}	83.67^{opq}	78.33^{uv}
FARO 35	83.89^{lmn}	81.78^{m-r}	78.89^{qrs}	76.22^{s}	71.89^{t}	82.50^{pqr}	78.17^{tuv}	75.33^{x}	71.83^{y}	69.67^{y}
FARO 36	83.44^{l-o}	82.89^{l-m}	80.44^{n-r}	79.56^{p-s}	76.33^{s}	85.50^{mno}	84.00^{op}	80.83^{rst}	79.67^{tu}	78.00^{uv}
FARO 37	91.11^{hi}	86.77^{jkl}	84.44^{k-m}	83.44^{l-p}	78.11^{rs}	91.00^{jk}	87.83^{l}	82.00^{qr}	80.00^{stu}	78.17^{uv}
FARO 44	89.56^{hij}	88.22^{ijk}	86.89^{jkl}	83.22^{l-o}	79.78^{n-s}	90.17^{k}	87.83^{l}	85.00^{no}	81.83^{qrs}	79.50^{tu}
FARO 46	65.00^{u}	63.78^{u}	62.11^{uv}	61.33^{l-p}	59.22^{v}	64.67^{z}	63.67^{z}	62.33^{z}	60.83^{z}	60.17^{z}
FARO 52	116.11^{cd}	115.11^{d}	105.67^{r}	97.56^{uv}	92.44^{gh}	115.67^{ef}	114.67^{f}	102.83^{l}	96.83^{i}	92.50^{j}
FARO 57	116.56^{cd}	114.78^{d}	105.22^{r}	97.00^{f}	90.78^{hi}	117.00^{de}	115.33^{ef}	106.83^{g}	98.33^{i}	91.50^{jk}
MOROBEREKAN	131.67^{a}	122.22^{b}	119.44^{bc}	117.78^{f}	115.22^{d}	121.67^{a}	121.17^{cb}	120.16^{abc}	119.50^{bc}	118.83^{cd}
BOUAKE 189	95.44^{fg}	92.67^{gh}	89.56^{hij}	83.89^{lmn}	79.56^{p-s}	86.67^{lmn}	86.83^{lmn}	85.17^{no}	77.33^{vw}	75.83^{wx}
SE ±			2.80					0.73		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05,, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.7. Effect of inoculation regime of RYMV on number of grains per panicle of rice cultivar in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons

Number of grains per panicle varied significantly ($P \leq 0.05$) among the inoculated plants. The control treatment had significantly higher number of grains per panicle than the inoculated plants. The lowest number of grains per panicle was recorded in inoculated plants at 4 WAS, followed by inoculated plants at 6, 8 and 10 WAS in increasing order compared to uninoculated treatment (Table 4.7).

In the 2008 rainy season among the rice cultivars, FARO 57 recorded significantly higher number of grains per panicle than the remaining cultivars. The lowest number of grains per panicle was recorded on FARO 52, although it was statistically similar to FARO 36, FARO 44 and BOUAKE 189 (Table 4.7). Similarly, in 2009 rainy season significantly higher number of grains per panicle was recorded on FARO 46, while the lowest was recorded on FARO 35 though it was statistically similar to FARO 36. The results obtained during 2010 rainy season showed that significantly higher number of grains per panicle was recorded on MOROBEREKAN, though it was statistically similar to FARO 46. While the lowest number of grains per panicle was recorded on FARO 44 although it was statistically similar to FARO 36. Combined analysis of the rainy season's data showed that significantly higher number of grains per panicle was recorded on MOROBEREKAN, though it was statistically similar to FARO 46. While the lowest number of grains per panicle was recorded on FARO 44 though it was statistically similar to FARO 36. Similarly, during 2008/ 2009 and 2009/ 2010 trials, significantly higher number of grains per panicle was recorded on FARO 46 compared to the other remaining test cultivars. While the lowest number of grains per panicle was recorded on FARO 36 although it was statistically similar to FARO 11, FARO

35, FARO 44 and FARO 52 in 2008/2009 trial (Table 4.7). While during the 2009/ 2010 trial the lowest number of grains per panicle was recorded on FARO 11, though it was statistically similar to FARO 35, FARO 36, FARO 44 and FARO 52. Combined analysis of the dry season's data showed that FARO 46 recorded significantly higher number of grains per panicle than the remaining cultivars. The lowest number of grains per panicle was recorded on FARO 36; however, it was statistically insignificant to FARO 11 FARO 35, FARO 44 and FARO 52. The mean number of grains per panicle was higher during the wet season than the dry seasons. The effect of interactions of inoculation regimes and cultivars on number of grains per panicle was significantly higher ($P \leq 0.05$)) among the treatment in both rainy and dry season experiments (Table 4.7).

4.1.8. Interaction of rice cultivars and inoculation regime of RYMV on the number of grains per panicle in the Screenhouse (combine analysis).

Combined analysis of the rainy season's data showed that the highest number of grains per panicle was obtained in FARO 57 at 10 WAS inoculation regimes. It was significantly ($P \leq 0.01$) higher than those of the remaining interaction treatment except for FARO 44 and FARO 57 under control and 10 WAS inoculation regimes, respectively. The lowest number of grains per panicle was recorded on FARO 44 inoculated at 4 WAS, thought not significantly different from those of FARO 36 and FARO 52 inoculated at 4 WAS (Table 4.8). However, during the dry season FARO 46 under the control treatment recorded significantly higher number of grain per panicle than the remaining interaction treatments. The lowest number of grains per panicle was obtained with FARO 35 inoculated at 4 WAS, though it was not significantly different from most of the treatments under 4 WAS inoculation regimes, with the exception of FARO 11, FARO 37, FARO 46, and FARO 57 and MOROBEREKAN cultivars (Table 4.8).

Table 4.7: Effect of inoculation regime of RYMV on the number of grains per panicle of rice cultivars in the Screenhouse

	Rainy season (June – October)				Dry season (December – April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	77.33^{e}	68.37^{e}	71.23^{e}	72.31^{e}	66.17^{e}	65.97^{e}	66.07^{e}
6 WAS	93.00^{d}	74.67^{d}	78.67^{d}	82.11^{d}	72.90^{d}	73.30^{d}	73.10^{d}
8 WAS	116.53^{c}	93.47^{c}	99.67^{c}	103.22^{c}	102.83^{c}	100.00^{c}	101.42^{c}
10 WAS	151.93^{b}	112.50^{b}	119.53^{d}	127.98^{b}	121.73^{b}	121.6^{7b}	121.70^{b}
Control	158.50^{a}	121.13^{a}	131.30^{a}	137.04^{a}	135.07^{a}	134.43^{a}	134.75^{a}
Mean	119.50	94.03	100.08	104.54	99.74	99.07	99.41
SE+	1.88	0.88	2.08	1.75	0.99	1.48	1.26
	**	**	**	**	**	**	**
Cultivar							
FARO 11	122.53^{c}	89.33^{de}	98.80^{b}	103.56^{c}	91.20^{de}	86.13^{f}	88.67^{f}
FARO 35	126.13^{bc}	80.80^{g}	103.00^{b}	103.31^{c}	90.73^{de}	90.87^{ef}	90.80^{f}
FARO 36	108.13^{d}	83.67^{fg}	86.67^{fg}	92.87^{ef}	87.93^{e}	88.73^{fd}	88.33^{f}
FARO 37	128.07^{bc}	92.67^{d}	94.27^{bc}	105.55^{c}	92.93^{d}	95.80^{ef}	94.37^{e}
FARO 44	103.73^{d}	84.67^{fc}	84.47^{d}	90.96^{f}	89.07^{dec}	90.33^{ef}	89.70^{f}
FARO 46	122.67^{c}	118.73^{a}	116.67^{a}	119.35^{ab}	132.00^{a}	130.67^{ae}	131.33^{a}
FARO 52	101.40^{d}	89.33^{de}	94.93^{bc}	95.22^{de}	89.33^{de}	88.87^{f}	89.70^{f}
FARO 57	144.20^{a}	103.60^{c}	101.47^{b}	116.67^{b}	108.93^{b}	106.33^{bc}	107.63^{c}
MOROBEREKAN	131.27^{b}	110.13^{b}	121.60^{a}	121.00^{a}	112.53^{b}	112.13^{b}	112.33^{b}
BOUAKE 189	106.13^{d}	87.33^{ef}	98.80^{b}	97.67^{d}	102.73^{c}	100.87^{cd}	101.80^{d}
Mean	119.50	94.02	100.08	104.54	99.74	99.07	99.41
SE $\pm$	2.66	1.25	2.95	2.48	1.40	2.09	1.80
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 %, using Duncan's multiple range test (DMRT). ** = significant at P = 0.01 %

Table 4 .8: Interaction of rice cultivars and inoculation regime of RYMV on the number of grains per panicle in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons

	Rainy season (June – October 2008 – 2010)					Dry season (December – April 2008/ 2009 – 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	85.88^{qr}	89.78^{pq}	103.11^{mno}	115.89^{hi}	123.11^{g}	71.00^{u}	73.33t^{u}	74.50^{t}	110.33^{lmn}	114.16^{kl}
FARO 35	77.11^{tu}	82.89^{rs}	98.78^{o}	122.56^{g}	135.44^{def}	50.67^{z}	54.17^{yz}	97.00^{rs}	121.50^{ij}	130.67^{ef}
FARO 36	48.56^{w}	62.78^{v}	99.78^{no}	121.89^{g}	131.33^{f}	53.17^{yz}	57.50^{x}	93.33^{s}	113.16^{klm}	124.50^{gh}
FARO 37	74.44^{u}	81.11^{rst}	109.67^{j-m}	124.56^{g}	135.22^{def}	61.00^{wx}	64.83^{vw}	97.3^{3rs}	117.33^{jk}	131.33^{de}
FARO 44	44.00^{w}	64.67^{v}	89.44^{pq}	119.67^{gh}	137.00^{cde}	32.17^{z}	67.67^{uv}	93.33^{s}	106.83^{nop}	128.17^{efg}
FARO 46	98.00^{o}	104.78^{l-n}	111.33^{ik}	130.67^{bcd}	144.00^{ab}	101.50^{q}	106.33^{nop}	135.83^{d}	151.67^{b}	161.33^{a}
FARO 52	46.00^{w}	63.89^{v}	92.33^{p}	132.22^{ef}	141.67^{bc}	55.17^{yz}	61.00^{wx}	93.00^{s}	110.17^{lmn}	126.17^{fgh}
FARO 57	80.00st	91.78^{p}	113.78^{ij}	147. 89^{ab}	148.67^{a}	60.67^{wx}	73.50^{t}	108.67^{mno}	142.33^{c}	153.00^{c}
MOROBEREKAN	106.56^{k-m}	107.00^{j-m}	120.67^{gh}	131.78^{ef}	137.00^{cde}	104.00^{pq}	105.50^{opq}	108.83^{mno}	120.33^{ij}	123.00^{hi}
BOUAKE 189	62.06^{v}	70.44^{u}	93.56^{p}	124.00^{g}	137.78^{cd}	51.33^{z}	67.17^{uv}	112.00l^{l-m}	123.33^{hi}	155.17^{b}
SE ±			5.55					4.01		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05 , according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.9. Effect of inoculation regimes of RYMV on paddy yield of rice cultivars in the Screenhouse during 2008 to 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

Paddy rice yield varied significantly ($P \leq 0.01$) among the inoculation regimes and the control. The results obtained showed that paddy yield were significantly higher with control treatment, while the lowest paddy yield was recorded on the inoculation regime at 4 WAS. Among the cultivars, MOROBEREKAN recorded significantly higher paddy yield than the remaining cultivars during rainy season trials. While significantly ($P \leq 0.05$) lowest paddy yield was recorded on FARO 52 than the remaining cultivars in 2008 rainy season (Table 4.9). However, BOUAKE 189 gave the lowest paddy yield compared to other cultivars in 2009 rainy season, but it was statistically similar to FARO 35 and FARO 52. Furthermore, in 2010 rainy season, the lowest paddy rice yield was recorded on FARO 35 although; it was not significantly different from FARO 36 and FARO 52. Combined analysis of the rainy seasons results indicated that MOROBEREKAN recorded highly significant ($P \leq 0.05$) different paddy yield among the test cultivars, while the lowest paddy yield was recorded on FARO 52. However, it was statistically, similar to FARO 11 and FARO 35. There were no significant differences recorded among the rice cultivars of FARO 37, FARO 44 and FARO 57, and also between FARO 36 and BOUAKE 189 (Table 4.10). The results obtained in 2008/ 2009 dry season trial showed that highest paddy yield was recorded on FARO 46, though it was statistically similar to that of MOROBEREKAN, while the lowest paddy yield was recorded on FARO 11 but it was statistically similar to that of FARO 35. However, in 2009/ 2010 dry season trial significantly ($P \leq 0.05$) highest and lowest paddy yield was recorded on MOROBEREKAN and FARO 11 compared to the other test cultivars. But there were no significant differences recorded among the rice cultivars of FARO 36, FARO 37, FARO 44 and FARO 57, and also between FARO 52 and BOUAKE 189. Combined analysis of the dry season's data showed that FARO 11 had significantly lowest paddy yield than the remaining cultivars. The highest paddy yield was recorded on MOROBEREKAN;

however, it was statistically similar to FARO 46. There were no significant differences among the rice cultivars FARO 37, FARO 44 and FARO 57, and also between FARO 36 and FARO 52. The mean paddy yield was higher during the wet season than the dry seasons. The effect of interactions of RYMV inoculation regimes and cultivars on paddy yield was significantly higher ($P \leq 0.01$) among the treatment in both rainy and dry season experiments (Table 4.9).

4.1.10. Interaction of rice cultivars and inoculation regimes of RYMV on paddy yield in the Screenhouse (combine analysis)

Combined analysis of the rainy season's data showed that significantly highest paddy yield was recorded on MOROBEREKAN cultivar under control treatment, though it was statistically insignificant to paddy yield obtained in FARO 44, FARO 46, FARO 52 and BOUAKE 189 under control treatment (Table 4.10). The lowest paddy yield was recorded on FARO 52 inoculated at 4 WAS, though it was statistically similar to FARO 11, FARO 35 and BOUAKE 189 inoculated at 4 WAS (Table 4.10).

Similarly during the dry seasons significantly ($P \leq 0.01$) higher paddy yield was recorded with FARO 46 under the control treatment. It was however, statistically similar to FARO 46 and BOUAKE 189 at 10 WAS inoculation regime and uninoculated control, respectively. The lowest paddy yield was obtained in rice cultivar of BOUAKE 189 under 4 WAS inoculation regimes, though it was statistically similar to FARO 35 and FARO 52 under the same inoculation regime (Table 4.10).

Table 4.9: Effect of inoculation regimes of RYMV on the paddy yield (g) of rice cultivars in the Screenhouse

Treatment	Rainy season (June – October)				Dry season (December –April)		
	2008	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	13.54^{e}	11.08^{e}	12.08^{e}	12.24^{e}	11.96^{e}	11.49^{e}	11.72^{e}
6 WAS	16.78^{d}	12.92^{d}	15.53^{d}	15.53^{d}	13.68^{d}	13.56^{d}	13.56^{d}
8 WAS	21.57^{c}	18.02^{c}	18.93^{c}	19.51^{c}	20.90^{c}	20.90^{c}	20.74^{c}
10 WAS	27.56^{b}	27.50^{b}	27.63^{b}	27.66^{b}	27.30^{b}	28.45^{b}	27.87^{b}
Control	31.49^{a}	31.37^{a}	31.93^{a}	31.59^{a}	31.63^{a}	31.78^{a}	31.71^{a}
Mean	22.25	20.17	21.22	21.22	21.03	21.21	21.11
SE+	0.28	0.19	0.23	0.26	0.23	0.22	0.25
	**	**	**	**	**	**	**
Cultivar							
FARO 11	20.76^{ef}	15.53^{f}	19.23^{de}	18.51^{e}	16.55^{e}	16.18^{f}	26.36^{g}
FARO 35	19.24^{g}	17.97^{de}	18.07^{f}	18.43^{e}	17.23^{e}	17.80^{e}	17.52^{f}
FARO 36	19.97^{fg}	19.93^{c}	18.87^{def}	19.59^{d}	19.60^{cd}	20.00^{c}	19.80^{cd}
FARO 37	21.58^{de}	20.20^{c}	19.87^{cd}	20.55^{c}	20.73^{bc}	20.67^{c}	20.70^{b}
FARO 44	23.71^{c}	18.60^{d}	19.53^{de}	20.61^{c}	20.98^{b}	19.80^{c}	20.37^{bc}
FARO 46	28.07^{b}	24.27^{b}	26.47^{b}	26.27^{b}	28.33^{a}	28.30^{b}	28.32^{a}
FARO 52	17.17^{h}	18.60^{de}	18.67^{ef}	17.98^{e}	19.13^{d}	19.73^{d}	19.43^{de}
FARO 57	21.96^{d}	19.73^{c}	20.73^{c}	20.81^{c}	21.07^{b}	20.67^{c}	20.87^{b}
MOROBEREKAN	29.60^{a}	29.76^{a}	30.00^{a}	30.12^{a}	27.80^{a}	30.10^{a}	29.95^{a}
BOUAKE 189	20.44^{efg}	17.67^{e}	19.80^{cd}	19.30^{d}	18.03^{d}	18.83^{d}	19.88^{e}
Mean	22.25	20.17	21.22	21.22	21.03	21.21	21.11
SE ±	0.40	0.27	0.36	0.36	0.42	0.30	0.35
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 %, using Duncan's multiple range test (DMRT). ** = significant at P = 0.01 %

Table: 4.10: I**nteraction of rice cultivars and inoculation regimes of RYMV on the paddy yield (g) in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons**

	Rainy season (June –October 2008-2010)					Dry season (December – April 2008/ 2009 – 2008/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	8.54^{rs}	13.17^{mno}	18.33^{kl}	24.56^{i}	27.94^{e-h}	8.73^{v-y}	10.50^{tuv}	13.08^{rs}	22.00^{mn}	27.50^{i-l}
FARO 35	9.69^{qr}	12.78^{no}	18.11^{kl}	24.56^{i}	26.99^{gh}	7.00^{yz}	8.42^{wxy}	17.33^{q}	25.50^{l}	29.33^{f-i}
FARO 36	10.50^{pq}	13.56^{mn}	17.56^{l}	26.33^{hi}	30.00^{de}	10.33^{t-w}	11.67^{st}	19.50^{op}	27.16^{jkl}	30.33^{e-h}
FARO 37	12.41^{nop}	15.00^{m}	19.67^{jk}	26.00^{hi}	29.67^{def}	11.17^{tu}	13.33^{r}	19.50^{op}	27.83^{ijk}	31.17^{d-g}
FARO 44	11.11^{opq}	13.22^{mn}	17.22^{l}	27.95^{e-h}	33.56^{ab}	8.83^{v-y}	12.33^{rst}	18.17^{pq}	29.17^{g-j}	33.33^{bc}
FARO 46	18.33^{kl}	21.67^{j}	25.33^{hij}	31.11^{cd}	34.89^{a}	20.17^{nop}	22.50^{m}	30.00^{e-h}	33.50^{ab}	35.42^{a}
FARO 52	7.83^{rs}	10.50^{pq}	14.33^{mn}	26.89^{gh}	30.33^{cde}	8.00^{xyz}	9.33^{u-x}	21.17^{mno}	27.33^{i-l}	31.33^{c-f}
FARO 57	10.22^{pq}	13.22^{mn}	18.00^{kl}	28.67^{efg}	33.93^{ab}	9.67^{t-x}	11.67^{st}	21.17^{mno}	29.33^{f-i}	32.50^{bcd}
MOROBEREKAN	26.56^{hi}	27.78^{fgh}	29.17^{def}	32.11^{bc}	35.00^{a}	27.00^{kl}	27.58^{ijk}	28.50^{h-k}	30.17^{e-h}	31.50^{b-e}
BOUAKE 189	7.18^{s}	9.89^{qr}	17.33^{l}	28.44^{efg}	33.67^{ab}	6.33^{z}	7.75^{xyz}	19.00^{pq}	26.67^{kl}	34.67^{a}
SE ±			0.82					0.78		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.11. Effect of inoculation regime of RYMV on paddy yield loss of rice cultivars in the Screenhouse during 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons

Percentage reduction of paddy rice yield varied significantly ($P \leq 0.01$) among the inoculated plants compared to the control. In both rainy and dry season experiments, significantly highest reduction in paddy yield was recorded on plants inoculated at 4 WAS while the lowest was recorded on plant inoculated at 6, 8 and 10 WAS in decreasing order. Among the cultivars, the lowest percentage reduction in paddy yield was recorded on MOROBEREKAN in both rainy and dry season experiments (Table 4.11). However, the highest percentage reduction in paddy yield was recorded on different rice cultivars among the seasons. In the 2008 rainy season, the highest reduction in paddy yield was recorded on FARO 52, though it was statistically similar to FARO 57 and BOUAKE 189. While during 2009 rainy season the highest reduction in paddy yield was recorded on BOUAKE 189, but it was not significantly different from that of FARO 44 (Table 4.11). Furthermore, in 2010 rainy season, the highest reduction in paddy yield was recorded on FARO 44 though it was statistically similar to FARO 52 and BOUAKE 189. Combined analysis of the rainy season data showed that significantly lowest reduction in paddy yield was recorded on MOROBEREKAN, while the highest percentage paddy yield loss was recorded on BOUAKE 189. There were no significant differences recorded between BOUAKE 189 and FARO 52, between FARO 11 and FARO 36, between FARO 35 and FARO 37 and also between FARO 57 and FARO 44. In the 2008/ 2009 and 2009/ 2010 dry seasons trials , significantly ($P \leq 0.05$) highest and lowest percentage reduction in paddy yield was recorded on BOUAKE 189 and MOROBEREKAN, respectively (Table 4.11). However, there were no significant differences recorded in percentage paddy yield loss among FARO 11, FARO 35, FARO 44 and FARO 52, in 2008/ 2009 trial. Similarly, three were no significant differences recorded among FARO 11, FARO 35 and FARO 44 in 2009/ 2010 trial.

Combined analysis of the dry season results showed that significantly lowest and highest percentage reduction in paddy yield was recorded on MOROBEREKAN and BOUAKE 189, respectively. No significant differences were recorded in paddy yield loss among FARO 11, FARO 35 and FARO 44, similarly between FARO 36 and FARO 37 and also between FARO 52 and FARO 57. The mean paddy yield loss was higher during the dry season than the rainy seasons. The effect of interactions of inoculation regimes and cultivars on paddy yield loss was significantly higher ($P \leq 0.01$) among the treatments in both dry and rainy season experiments (Table 4.11).

4.1.12. Interaction of rice cultivars and inoculation regimes of RYMV on paddy yield loss in the Screenhouse (combine analysis)

BOUAKE 189 inoculated at 4 WAS with RYMV, recorded significantly ($P \leq 0.05$) higher paddy yield loss than the other interaction combinations in the rainy season, with the exception of FARO 52 under the same inoculation regime. The lowest paddy yield loss was recorded in MOROBEREKAN inoculated at 10 WAS; it was statistically similar to FARO 35 under the same inoculation regime (Table 4.12).

Similarly in the combined analysis of dry season trials, BOUAKE 189 recorded significantly higher ($P \leq 0.01$) paddy yield loss at 4 WAS inoculation regimes. The lowest paddy yield loss was recorded on MOROBEREKAN cultivar inoculated at 10 WAS, though it was statistically similar to FARO 46 inoculated at 10 WAS (Table 4.12).

Table 4.11: Effect of inoculation regimes of RYMV on paddy yield loss (%) of rice cultivars in the Screenhouse

	Rainy season (June – October)				Dry season (December – April 2008/2009 \		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	57.71[a]	65.13[a]	62.73[a]	62.86[a]	62.14[a]	64.21[a]	63.17[a]
6 WAS	46.49[b]	58.76[b]	53.23[b]	52.82[b]	56.70[b]	58.58[b]	57.64[b]
8 WAS	31.28[c]	43.46[c]	40.89[c]	38.54[c]	35.19[c]	34.08[c]	35.08[c]
10 WAS	11.74[d]	12.16[d]	13.89[d]	12.52[d]	13.68[d]	10.46[d]	12.07[d]
Control	0.00[e]	0.00[e]	0.00[e]	0.00[e]	0.00[e]	0.00[e]	0.00[e]
Mean	29.44	35.90	34.10	33.15	33.54	33.64	33.59
SE+	1.28	0.57	0.81	0.98	0.87	0.61	0.73
	**	**	**	**	**	**	**
Cultivar							
FARO 11	29.34[b]	38.43[bc]	33.50[cd]	33.82[c]	40.08[bc]	40.60[b]	40.34[b]
FARO 35	21.86[c]	38.57[bc]	33.09[d]	31.17[d]	40.62[b]	40.07[bc]	40.34[b]
FARO 36	30.66[b]	37.29[cd]	36.47[cd]	34.81[c]	34.22[e]	34.79[ef]	34.50[ef]
FARO 37	22.84[c]	35.08[d]	36.27[cd]	31.40[d]	34.55[de]	32.65[f]	33.60[f]
FARO 44	26.36[bc]	44.74[a]	42.72[a]	37.94[b]	37.75[b-e]	40.47[b]	39.11[bc]
FARO 46	22.33[c]	27.51[e]	24.37[e]	24.37[e]	19.81[f]	20.58[g]	20.20[g]
FARO 52	43.09[a]	40.54[b]	42.11[ab]	41.92[a]	38.24[bcd]	37.74[cd]	37.99[cd]
FARO 57	38.06[a]	38.94[bc]	38..02[bc]	38.67[b]	36.55[cde]	35.87[de]	36.21[de]
MOROBEREKAN	20.73[c]	11.64[f]	11.02[f]	14.46[f]	8.35[g]	7.84[h]	8.09[h]
BOUAKE 189	38.97[a]	46.30[a]	42.46[a]	42.57[a]	45.25[a]	45.87[a]	45.56[a]
Mean	29.44	35.90	34.10	33.15	33.54	33.64	33.59
SE ±	1.81	0.82	1.45	1.39	1.24	0.86	1.03
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 % using Duncan's multiple range test (DMRT). ** = significant at P = 0.01 %

Table 4.12: Interaction of rice cultivars and inoculation regime of RYMV on paddy yield loss in the Sreenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.

	Percentage paddy yield loss(%)									
	Rainy season (June – October 2008- 2010)					Dry season (December – April 2008/ 2009- 2009/ 2010)				
Cultivar	**4 WAS**	**5 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	69.56^{bc}	51.94^{ijk}	35.63^{no}	11.99st	0.00^{v}	68.17^{fg}	62.36^{i}	51.94^{k}	19.21^{q}	0.00^{x}
FARO 35	63.41^{def}	51.62^{ijk}	32.15^{o}	8.66^{tu}	0.00^{v}	76.18^{bc}	71.29^{def}	41.06^{m}	13.15^{rs}	0.00^{x}
FARO 36	64.91^{d}	55.06^{hi}	41.65^{m}	12.43^{rst}	0.00^{v}	65.91^{gh}	60.44$_{i}$	35.72^{no}	10.44st	0.00^{x}
FARO 37	57.79^{fg}	53.15^{ij}	33.6^{9o}	12.34^{rst}	0.00^{v}	64.04^{h}	55.78^{j}	37.48^{n}	10.68st	0.00^{x}
FARO 44	63.88^{de}	60.56^{efg}	48.58^{kl}	16.66^{q}	0.00^{v}	73.57^{cde}	64.02^{h}	45.61^{l}	12.34^{rst}	0.00^{x}
FARO 46	47.57^{l}	38.02^{mn}	27.26^{p}	10.82^{t}	0.00^{v}	43.17^{lm}	36.52^{n}	15.31^{r}	5.97^{w}	0.00^{x}
FARO 52	77.45^{a}	66.20^{cd}	53.47^{ij}	12.46^{rst}	0.00^{v}	74.42^{cd}	70.25^{ef}	32.54^{o}	12.74^{rst}	0.00^{x}
FARO 57	71.38^{b}	51.52^{ijk}	46.97^{l}	15.48^{qr}	0.00^{v}	70.36^{ef}	65.18^{gh}	35.91^{no}	9.58^{t}	0.00^{x}
MOROBEREKAN	28.50^{p}	25.99^{p}	16.23^{q}	6.59^{u}	0.00^{v}	14.24^{r}	12.41^{rst}	10.15st	3.65^{w}	0.00^{x}
BOUAKE 189	79.11^{a}	66.18^{cd}	49.79^{jkl}	17.78^{q}	0.00^{v}	81.67^{a}	78.08^{b}	45.13l^{m}	22.93^{p}	0.00^{x}
SE ±			3.12					2.30		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.13. Effect of inoculation regime of RYMV on the threshing percentage of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

Threshing percentage varied significantly (P≤0.01) among the inoculation regimes. The control treatment showed significantly (P≤ 0.01) higher threshing percentage than the inoculated plants. The lowest threshing percentage was recorded with inoculation regime at 4 WAS during the rainy and dry seasons (Table 4.13). In the 2008 rainy season, FARO 37 had significantly (P≤ 0.01) higher threshing percentage than other cultivars. While the lowest threshing percentage was recorded on BOUAKE 189, though it was not significantly different from that of FARO 52. However, in 2009 rainy season significantly higher threshing percentage was recorded on cultivar MOROBEREKAN than the other cultivars. While the lowest threshing percentage was recorded on FARO 36 but it was not significantly different to those of FARO 35, FARO 44, FARO 52 and BOUAKE 189 (Table 4.13). Furthermore, in 2010 rainy, MOROBEREKAN recorded significantly (P≤ 0.05) higher threshing percentage than the other cultivars, while the lowest threshing percentage was recorded on FARO 44, though it was statistically similar to those of FARO 36 and BOUAKE 189. Combined analysis of the rainy season results showed that MOROBEREKAN recorded significantly (P≤ 0.05) higher threshing percentage than the other cultivars, while the lowest threshing percentage was recorded on FARO 36, although it was statistically similar to those of FARO 44, FARO 52 and BOUAKE 189 (Table 4.13). In 2008/ 2009 and 2009/ 2010 dry seasons significantly (P≤ 0.05) higher threshing percentage was recorded on cultivar MOROBEREKAN, while the lowest threshing percentage was recorded on BOUAKE 189. However, it was statistically similar to those of FARO 36, FARO 44 and FARO 52 during the 2008/ 2009 trial and to FARO 36 and FARO 52 during the 2009/ 2010 trial. Combined analysis of the dry season results indicated that MOROBEREKAN recorded significantly (P≤ 0.05) higher threshing percentage than the

other cultivars, while the lowest threshing percentage was recorded on BOUAKE 189 although it was statistically similar to FARO 36 and FARO 52. There were significant variations among the remaining the test cultivars. The mean threshing percentage was higher during the dry seasons than the rainy seasons. Interaction effect of inoculation regimes and cultivars on threshing percentage was significantly higher ($P \leq 0.01$) among the treatment (Table 4.13).

4.1.14. Interaction of rice cultivars and inoculation regimes of RYMV on threshing percentage in the Screenhouse (combine analysis).

The highest threshing percentage was obtained with rice cultivar MOROBEREKAN under the control treatment. However, it was not significantly different from other test cultivars, with the exception of FARO 44, FARO 52, and FARO 57. The lowest threshing percentage was recorded at 4 WAS inoculation regimes in BOUAKE 189. It was significantly different from most of the test cultivars, except FARO 36 and FARO 52 under 4 WAS inoculation regimes (Table 4.14). Similarly, FARO 37 under control treatment recorded significantly higher threshing percentage, and though it was statistically insignificant to most of the test cultivars under the control treatment except for FARO 35, FARO 44 FARO 52 and FARO 57. The lowest threshing percentage was recorded on BOUAKE 189 at 4 WAS, inoculation regimes, however, it was statistically insignificant compared with FARO 36 and FARO 52 inoculated at 4 WAS (Table 4. 14).

Table 4.13: Effect of inoculation regime of RYMV on the threshing percentage of rice cultivars in the Screenhouse

Treatment	Rainy season (June – October)				Dry season (December - April)		
	2008	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	76.32^{e}	76.56^{e}	75.63^{e}	76.17^{e}	77.73^{e}	76.87^{e}	77.30^{e}
6 WAS	77.37^{d}	77.90^{d}	78.27^{d}	77.64^{d}	78.37^{d}	77.87^{d}	78.12^{d}
8 WAS	78.50^{c}	80.30^{c}	80.13^{c}	79.64^{c}	80.27^{c}	80.20^{c}	80.23^{c}
10 WAS	88.83^{b}	87.67^{b}	89.07^{b}	88.52^{b}	89.47^{b}	89.67^{b}	89.57^{b}
Control	90.35^{a}	90.95^{a}	91.57^{a}	90.96^{a}	91.48^{a}	91.48^{a}	91.53^{a}
Mean	62.27	82.67	82.93	82.63	83.46	83.23	83.35
SE+	0.16	0.23	0.22	0.22	0.19	0.16	0.20
	**	**	**	**	**	**	**
Cultivar							
FARO 11	80.94e	81.20^{d}	80.80^{d}	80.98^{e}	84.36^{e}	82.43^{c}	83.65^{c}
FARO 35	79.26^{f}	80.33^{de}	80.27^{de}	79.95^{f}	81.00^{d}	81.40^{d}	81.20^{d}
FARO 36	79.30^{f}	79.07^{f}	79.53^{ef}	79.30^{g}	79.87^{e}	79.40^{e}	79.63^{f}
FARO 37	88.07^{a}	84.53^{c}	86.87^{b}	86.48^{c}	88.80^{b}	88..20^{b}	88.50^{b}
FARO 44	79.78^{f}	79.73^{ef}	79.00^{f}	79.50^{fg}	79.33^{e}	81.47^{d}	80.40^{e}
FARO 46	87.43^{b}	87.73^{b}	89.60^{a}	88.26^{b}	88.47^{b}	88.13^{b}	88.30^{b}
FARO 52	78.53^{g}	79.53^{ef}	80.27^{de}	79.44^{fg}	79.20^{e}	78.93^{e}	79.07^{f}
FARO 57	84.73^{d}	83.70^{c}	83.00^{c}	83.81^{d}	84.47^{c}	82.80^{c}	83.63^{c}
MOROBEREKAN	86.20^{c}	90.13^{a}	90.33^{a}	89.22^{a}	90.00^{a}	90.07^{a}	90.03^{a}
BOUAKE 189	78.80^{g}	79.80^{ef}	79.67^{ef}	79.32^{g}	79.13^{e}	79.00^{e}	79.07^{f}
Mean	82.27	82.62	82.93	82.63	83.46	83.23	83.35
SE ±	0.22	0.33	0.28	0.31	0.27	0.23	0.29
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 % using Duncan's multiple range test (DMRT). ** = significant at P = 0.01 %

Table: 4.14: Interaction of rice cultivars and inoculation regimes of RYMV on the threshing percentage in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.

Cultivar	Rainy season (June – October 2008-2010)					Dry season (December – Aprail 2008/ 2009		
	4 WAS	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**
FARO 11	72.28t^{uv}	75.43^{rs}	76.94^{pq}	88.83^{d-g}	91.40^{ab}	76.83^{pq}	78.00^{op}	81.17^{n}
FARO 35	71.94^{uv}	73.82^{stu}	76.00^{qr}	86.89^{i-l}	91.11^{abc}	74.83^{r}	74.83^{r}	75.50^{qr}
FARO 36	71.00^{vwx}	72.33^{tu}	73.89st	88.44^{c-i}	90.83^{a-d}	70.50^{uv}	71.67^{tu}	74.33r^{s}
FARO 37	81.56^{n}	83.94^{m}	86.39^{j-l}	89.22^{c-g}	91.33^{ab}	84.83^{m}	86.33^{klm}	87.50^{ijk}
FARO 44	72.55t^{uv}	73.36^{stu}	75.61^{qrs}	86.11^{klm}	89.89^{b-f}	73.17st	74.17^{rs}	77.33^{p}
FARO 46	85.77^{lm}	86.88^{i-l}	88.17^{f-j}	89.00^{d-g}	91.44^{ab}	85.33^{lm}	86.00^{klm}	87.50^{ijk}
FARO 52	71.11^{uwx}	73.22^{tuv}	75.33^{rs}	87.72^{hij}	89.83^{b-f}	70.33^{uv}	70.83^{uv}	74.83^{r}
FARO 57	78.67^{g-j}	80.33^{no}	81.89^{n}	88.11^{f-j}	90.06^{b-d}	78.67^{op}	79.50^{no}	81.00i^{n}
MOROBEREKAN	87.00^{h-l}	88.11^{f-j}	88.33^{f-j}	91.00^{abc}	91.67^{ab}	89.17^{fgh}	89.33^{e-h}	90.00^{d-}
BOUAKE 189	69.83^{x}	71.00^{vwx}	73.89st	89.89^{b-f}	92.00^{a}	69.33^{v}	70.50^{uv}	73.17st
SE ±			0.69					0.64

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05 according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

.1.15. Effect of inoculation regime of RYMV on 1,000- grain weight of rice cultivars in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/2009 and 2009/2010 dry seasons.

1,000-grains weight varied significantly ($P \leq 0.01$) among the inoculated plants in both rainy and dry seasons. The control treatment had significantly higher 1,000-grains weight than the inoculated plants. The lowest 1,000-grains weight was recorded in inoculated plants at 4 WAS, followed by inoculated plants at 6, 8 and 10 WAS in increasing order compared to uninoculated treatment (Table 4.15).

In 2008 rainy season among the rice cultivars, MOROBEREKAN and FARO 11 recorded significantly ($P \leq 0.01$) higher and lower 1,000-grains weight than the remaining test plants. There were no significant variations among the remaining test cultivars, with the exception of FARO 46. Similarly, in 2009 rainy season significantly higher 1,000-grains weight was recorded on MOROBEREKAN, while the lowest was recorded on FARO 11, though it was statistically similar to FARO 37. There were significant variations among the remaining the test cultivars, except among FARO 35, FARO 36 FARO 52 and BOUAKE 189 (Table 4.15). In 2010 rainy season significantly higher 1,000-grains weight was recorded on MOROBEREKAN, while the lowest was recorded on FARO 57, though it was statistically similar to FARO 37 and FARO 52. Combined analysis of the rainy season's results indicated that MOROBEREKAN and FARO 11 had significantly ($P \leq 0.01$) higher and lower 1,000-grains weight than the other cultivars, while the variation among FARO 36, FARO 52 and BOUAKE 189 and between FARO 37 and FARO 52 were statistically insignificant (Table 4.15). Similarly, in 2008/ 2009 and 2009/ 2010 dry seasons significantly ($P \leq 0.01$) higher 1,000-grains weight was recorded on cultivar MOROBEREKAN, while the lowest 1,000-grains weight was recorded on FARO 37 and FARO 11 in 2008/ 2009 and

2009/ 2010 dry seasons, respectively (Table 4.15). Combined analysis of the dry season's results indicated that MOROBEREKAN had significantly ($P \leq 0.05$) higher 1,000-grains weight than the other cultivars, while the lowest 1,000-grains weight was recorded on FARO 11, though it was statistically similar to FARO 37. The mean 1,000-grains weight was higher during the rainy than the dry seasons (Table 4.15).

4.1.16. Interaction of rice cultivars and inoculation regimes of RYMV on 1,000-grain weight in the Screenhouse (combine analysis).

In both rainy and dry season experiment, combined analysis of each season showed that test cultivar of MOROBEREKAN under the control treatment had significantly higher 1,000 grain weight than the other interactions treatment, with the exception of the similar test cultivar under 10 WAS inoculation regimes. Similarly, significantly lowest 1,000 grain weight was obtained in BOUAKE 189 under 4 WAS inoculation regimes in both rainy and dry season; however, it was statistically similar to FARO 11, FARO 37 and FARO 57 under 4 WAS inoculation regimes during the dry season combined analysis (Table 4.16).

Table 4.15: Effect of inoculation regimes of RYMV on the 1,000- grain weight (g) of rice cultivars in the Screenhouse.

Treatment	Rainy seaon (June – October)				Dry season (December – April)		
	2008	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	19.60^{e}	20.87^{e}	20.27^{e}	20.24^{e}	21.60^{e}	20.76^{e}	21.18^{e}
6 WAS	21.13^{d}	22.33^{d}	21.90^{d}	21.78^{d}	22.87^{d}	21.97^{d}	22.47^{d}
8 WAS	22.93^{c}	24.18^{c}	22.93^{c}	23.35^{c}	24.23^{c}	23.60^{c}	23.92^{c}
10 WAS	25.03^{b}	26.85^{b}	25.97^{b}	25.95^{b}	25.50^{b}	25.63^{b}	25.77^{b}
Control	27.40^{a}	29.08^{a}	28.00^{a}	28.16^{a}	27.62^{a}	27.72^{a}	27.67^{a}
Mean	23.22	24.66	23.81	23.89	24.44	23.94	24.19
SE+	0.12	0.15	0.18	0.17	0.18	0.14	0.17
	**	**	**	**	**	**	**
Cultivar							
FARO 11	19.87^{e}	21.20^{f}	22.07^{ef}	21.04^{g}	21.00^{e}	19.93^{f}	20.46^{g}
FARO 35	21.67^{cd}	23.76^{d}	23.27^{c}	22.90^{cd}	24.27^{cd}	22.13^{d}	23.20^{de}
FARO 36	21.73^{cd}	23.53^{d}	22.47^{ef}	22.44^{e}	24.60^{c}	23.30^{c}	23.95^{c}
FARO 37	21.40^{d}	21.50^{f}	21.47^{fg}	21.46^{f}	20.07^{f}	20.93^{e}	20.50^{g}
FARO 44	21.93^{cd}	24.43^{c}	23.13^{cd}	23.17^{c}	26.73^{b}	24.86^{b}	25.80^{b}
FARO 46	23.60^{b}	25.40^{b}	24.13^{cd}	24.38^{b}	23.80^{d}	23.87^{c}	23.83^{c}
FARO 52	22.07^{c}	23.63^{d}	21.60^{fg}	22.43^{e}	23.70^{d}	23.40^{c}	23.55^{cd}
FARO 57	21.67^{cd}	22.70^{e}	21.07^{g}	21.81^{f}	20.60^{ef}	21.87^{d}	21.23^{f}
MOROBEREKAN	36.67^{a}	36.87^{a}	36.86^{a}	36.80^{a}	35.80^{a}	37.33^{a}	36.57^{a}
BOUAKE 189	21.60^{cd}	23.60^{d}	22.47^{de}	22.56^{de}	23.87^{cd}	21.73^{d}	22.80^{e}
Mean	23.22	24.66	23.81	23.89	24.44	23.94	24.19
SE $\pm$	0.17	0.21	0.25	0.24	0.27	0.20	0.25
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 % using Duncan's multiple range test (DMRT) ** = significant at P = 0.01 %

Table 4.16: Interaction of rice cultivars and inoculation regime of RYMV on 1,000 grain weight (g) in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons .

	Rainy season (June – October 2008-2010)					Dry season (December –April 2008/ 2009 – 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	17.67^{v}	19.00^{r-v}	20.22^{n-s}	23.00^{ijk}	25.33^{d-h}	17.83^{yz}	19.17^{v-z}	19.83^{u-x}	21.83^{o-s}	23.67^{k-n}
FARO 35	19.56^{p-u}	20.78^{m-q}	23.11^{ijk}	24.89^{e-h}	26.17^{de}	20.50^{s-v}	22.40^{n-s}	23.33^{l-p}	24.50^{i-l}	25.67^{f-j}
FARO 36	19.22^{q-u}	20.56^{n-r}	22.44^{j-m}	24.00^{g-j}	26.00^{def}	21.67^{p-t}	22.50^{m-q}	23.67^{k-n}	25.33^{h-k}	26.58^{e-h}
FARO 37	18.78^{s-v}	19.89^{o-t}	21.06^{l-p}	23.11^{ijk}	24.44^{f-i}	17.50^{z}	18.33^{xyz}	23.00^{t-x}	21.83^{o-s}	24.83^{i-l}
FARO 44	18.44^{s-v}	20.33^{n-s}	22.56^{jkl}	25.89^{def}	28.61^{c}	22.50^{m-q}	23.50^{l-o}	25.50^{g-j}	27.33^{ef}	30.17^{d}
FARO 46	21.00^{l-n}	22.44^{j-m}	24.00^{g-j}	25.56^{d-g}	28.88^{c}	19.83^{u-x}	21.50^{q-u}	23.33^{l-p}	26.17^{f-i}	28.33^{de}
FARO 52	18.33^{s-v}	20.22^{n-t}	21.88^{k-n}	24.56^{e-i}	27.16^{cd}	20.33^{s-w}	21.33^{q-u}	24.00^{j-m}	25.00^{i-l}	27.08^{efg}
FARO 57	18.00^{uv}	19.78^{o-t}	21.33^{l-o}	23.72^{hij}	26.22^{de}	18.00^{yz}	19.33^{v-y}	20.67^{p-u}	23.33^{l-p}	$24.83i^{-l}$
MOROBEREKAN	35.00^{b}	36.22^{b}	35.89^{b}	37.89^{a}	38.56^{a}	35.00^{c}	36.00^{bc}	36.50^{bc}	37.00^{ab}	38.33^{a}
BOUAKE 189	16.00^{x}	18.67^{s-v}	21.00^{l-n}	26.89^{d}	30.22^{c}	18.67^{w-z}	20.50^{s-v}	22.33^{s-v}	25.33^{h-k}	27.17^{efg}
SE $\pm$			0.53					0.55		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05 according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.17. Effect of inoculation regimes and rice cultivars on the incidence of RYMV in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons

The incidence of RYMV at 9 WAS inoculation regimes were significantly ($P \leq 0.01$) lower than the other inoculation regimes in both rainy and dry seasons experiments. The results obtained in 2008 rainy season showed that the RYMV incidence at 4, 6 and 8 WAS inoculation regimes were not significantly different from each other. However, during the 2009 rainy season trial, the results obtained indicated a highly significant ($P \leq 0.01$) variation of RYMV incidence among the inoculation regimes. The highest incidence was recorded on plant inoculated at 4 WAS followed by at 6, 8 and 10 WAS in decreasing incidence rate (Table 4.17). Similarly, in 2010 rainy season RYMV incidence varied significantly ($P \leq 0.01$) among the inoculation regimes. The highest incidence was recorded on plants inoculated at 4 WAS, though it was statistically similar to plants inoculated at 6 WAS, while the lowest incidence was observed at 10 WAS. The result obtained in 2008/ 2009 dry season showed that significantly lower RYMV incidence was recorded on plants inoculated at 10 WAS, while there were no significant differences among the plants inoculated at 4, 6 and 8 WAS. However, in 2009/ 2010 dry season RYMV incidence varied significantly ($P \leq 0.05$) among the inoculation regimes. The highest incidence was recorded on plants inoculated at 4 WAS, though it was statistically similar to plants inoculated at 6 WAS, while the lowest incidence was observed at 10 WAS (Table 4.17).

In the 2008 rainy season, FARO 44 had the highest incidence of RYMV, though it was not significantly different from the remaining test cultivars, with the exception of FARO 11 and MOROBEREKAN. The results recorded in 2009 and 2010 rainy seasons showed a higher RYMV incidence occurred on BOUAKE 189, though it was statistically similar to FARO 52 in 2009 and similarly to FARO 35, FARO 36, FARO 44, FARO 52 and FARO 57 in

2010 trials, respectively. Combined analysis of the rainy season's results indicated that there were significant variations in the incidence of RYMV among the rice cultivars. MOROBEREKAN and BOUAKE 189 had significantly lowest and highest incidence of RYMV than the remaining cultivars, while there were no significant differences recorded among FARO 35, FARO 36, FARO 37, FARO 52 and FARO 57 and also between FARO 11 and FARO 46 (4.17).

In the 2008 / 2009 dry season FARO 44 had the highest incidence of RYMV, though it was not significantly different from the remaining test cultivars, with the exception of FARO 46 and MOROBEREKAN., but in the 2009/ 2010 dry season trial, disease incidence varied significantly ($P \leq 0.05$) among the test cultivars, the highest incidence was recorded on BOUAKE 189 while the lowest was observed on MOROBEREKAN (Table 4.17). Combined analysis of the dry season's results indicated that there were significant variations in the incidence of RYMV among the rice cultivars. MOROBEREKAN had significantly lower incidence of RYMV than the remaining cultivars, while the lowest incidence was observed on BOUAKE 189 though it was statistically similar to FARO 44. The mean incidence of RYMV was higher during the rainy season than the dry seasons. The effect of interaction between inoculation regimes and cultivars on the incidence of RYMV was highly significant ($P \leq 0.01$) statistically (Table 4.17).

4.1.18. Interaction of inoculation regimes and rice cultivars on the incidence of RYMV in the Screenhouse (combine analysis).

In the combined analysis of rainy season's data, one hundred percentage RYMV incidence was recorded at 4 WAS inoculation regime. Similarly, there were no significant differences in the disease incidence among the test cultivars at 4, 6 and 8 WAS inoculation regimes,

Table 4.17: Effect of inoculation regime and rice cultivar on the incidence of RYMV in the Screenhouse

	Rainy season (June – October)				Dry season (December – April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	100.00[a]	100.00[a]	100.00[a]	100.00[a]	88.67[a]	96.00[a]	92.17[a]
6 WAS	100.00[a]	97.50[b]	97.83[a]	98.44[b]	87.17[a]	95.67[a]	91.58[a]
8 WAS	98.93[a]	92.67[c]	94.67[b]	95.37[c]	84.33[a]	93.33[b]	82.83[b]
10 WAS	93.33[b]	59.17[d]	60.37[c]	70.95[d]	38.67[b]	62.23[c]	50.45[c]
Control	0.00[c]	0.00[e]	0.00[d]	0.00[e]	0.00[c]	0.00[d]	0.00[d]
Mean	78.45	69.87	70.52	72.95	59.77	69.45	64.61
SE+	0.39	0.78	0.94	0.75	1.52	0.42	1.17
	**	**	**	**	**	**	**
Cultivar							
FARO 11	77.33[b]	69.67[e]	70.33[cd]	72.22[e]	64.67[a]	72.13[c]	68.40[c]
FARO 35	78.80[b]	72.00[cde]	72.67[ad]	74.49[cd]	65.67[a]	75.00[b]	70.33[bc]
FARO 36	79.20[a]	73.00[bcd]	74.67[ab]	75.64[bc]	67.33[a]	73.33[bc]	70.33[bc]
FARO 37	78.47[ab]	70.00[de]	71.33[bcd]	73.27[cd]	65.33[a]	71.67[c]	69.50[d]
FARO 44	79.87[a]	75.33[bc]	74.67[ab]	76.62[b]	70.00[a]	75.00[a]	72.50[ab]
FARO 46	78.47[ab]	68.67[e]	68.70[d]	71.93[e]	45.33[b]	67.33[d]	56.33[d]
FARO 52	79.33[a]	76.00[ab]	73.33[abc]	76.22[bc]	69.33[a]	73.33[bc]	71.33[bc]
FARO 57	78.73[ab]	75.00[bc]	73.33[abc]	75.64[bc]	71.00[a]	74.33[b]	72.67[ab]
MOROBEREKAN	74.67[c]	41.00[f]	49.67[e]	55.11[fc]	10.33[c]	32.67[e]	21.50[e]
BOUAKE 189	79.67[a]	78.67[a]	76.67[a]	78.33[af]	68.67[a]	79.67[a]	74.17[a]
Mean	78.45	69.87	70.54	72.95	59.77	69.45	64.61
SE ±	0.56	1.11	1.33	1.06	2.16	0.59	1.65
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 % using Duncan's multiple range test (DMRT). ** = significant at P = 0.01 %

Table 4.18: Interaction of inoculation regime and rice cultivars on the incidence of RYMV in the Screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons

	Rainy season (June – October 2008-2010)					Dry season (December – April 2008/ 2009 - 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	100.00^{a}	100.00^{a}	100.00^{a}	61.11^{h}	0.00^{k}	100.00^{a}	100.00^{a}	97.50^{a}	44.50^{g}	0.00^{L}
FARO 35	100.00^{a}	100.00^{a}	99.89^{a}	72.56^{f}	0.00^{k}	100.00^{a}	100.00^{a}	98.33^{a}	53.33^{f}	0.00^{L}
FARO 36	100.00^{a}	100.00^{a}	99.78^{a}	78.44^{e}	0.00^{k}	100.00^{a}	99.17^{a}	99.17^{a}	52.50^{f}	0.00^{L}
FARO 37	100.00^{a}	100.00^{a}	99.78^{a}	66.56^{g}	0.00^{k}	100.00^{a}	100.00^{a}	99.17^{a}	44.17^{g}	0.00^{L}
FARO 44	100.00^{a}	100.00^{a}	100.00^{a}	83.11^{d}	0.00^{k}	100.00^{a}	100.00^{a}	100.00^{a}	62.50^{de}	0.00^{L}
FARO 46	100.00^{a}	98.44^{a}	97.78^{a}	61.22^{h}	0.00^{k}	87.50^{b}	85.83^{b}	76.67^{c}	31.67^{i}	0.00^{L}
FARO 52	100.00^{a}	100.00^{a}	99.89^{a}	81.22^{de}	0.00^{k}	100.00^{a}	100.00^{a}	$98..33^{a}$	58.33^{e}	0.00^{L}
FARO 57	100.00^{a}	100.00^{a}	99.78^{a}	80.89^{de}	0.00^{k}	100.00^{a}	100.00^{a}	$98..33^{a}$	65.00^{d}	0.00_{L}
MOROBEREKAN	100.00^{a}	86.67^{cd}	56.11^{i}	32.78^{j}	0.00^{k}	43.33^{g}	36.67^{h}	20.83^{j}	6.67^{k}	0.00_{L}
BOJAKE 189	100.00^{a}	100.00^{a}	100.00^{a}	91.67^{b}	0.00^{k}	100.00^{a}	100.00^{a}	100.00^{a}	85.83^{b}	0.00^{L}
SE $\pm$			2.38					3.69		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

except for cultivar MOROBEREKAN at 6 and 8 WAS inoculation regimes. The lowest disease incidence was recorded on cultivar MOROBEREKAN at 10 WAS inoculation regimes (Table 4.18). In the dry season combined analysis, irrespective of the test cultivars under 4, 6 and 8 WAS inoculation regimes, there were no significant differences in RYMV incidence recorded, except for test cultivar of FARO 46 and MOROBEREKAN, Similarly, the lowest disease incidence was recorded on cultivar MOROEREKAN at 10 WAS inoculation regimes (Table 4.18).

4.1.19. Effect of inoculation regime and rice cultivars on the severity index of RYMV in the Screenhouse during 2008, 2009 and 2010 rainy and 2008/ 2009 and 2009/ 2010 dry seasons.

There were significant ($P \leq 0.05$) differences in the disease severity index among the inoculation regime in both rainy and dry seasons experiments. The lowest severity index was recorded with inoculation regime at 10 WAS followed by at 8 WAS inoculation regime. While there was no significant difference in severity index between 4 and 6 WAS inoculation regime in 2008 and 2010 rainy seasons, but it was significantly different in 2008 rainy season. Similarly, in 2008/ 2009 and 2009/ 2010 dry season trials there were significant differences in severity index among the inoculated plants (Table 4.19).

There were significant differences in the severity index of RYMV among the test cultivars in both rainy and dry season trials. Significantly lower RYMV severity index was recorded on MOROBEREKAN irrespective of trial periods. Among the cultivars in 2008 rainy season BOUAKE 189 recorded highest severity index of RYMV, though it was not significantly different from the remaining test cultivars, with the exception of FARO 46 FARO 57 and MOROBEREKAN. The results recorded in 2009 rainy seasons showed a higher RYMV severity index on FARO 44, though it was statistically similar to FARO 52,

FARO 57 and BOUAKE 189. Furthermore, in 2010 rainy season higher RYMV severity index was recorded on FARO 44, though it was statistically similar to FARO 36, FARO 52, FARO 57 and BOUAKE 189. Combined analysis of the rainy season's results indicated that there were significant variations in the severity index of RYMV among the rice cultivars, MOROBEREKAN had significantly lower severity index than the remaining cultivars, while higher severity index was recorded on BOUAKE 189, although it was statistically similar to FARO 44 and FARO 52. There were no significant differences among FARO 11, FARO 35, FARO 36, and FARO 57 and also between FARO 11 and FARO 37 (Table 4.19).

The results obtained in 2008/ 2009 and 2009/ 2010 dry seasons indicated that there were significant differences in the severity index of RYMV among the test cultivars. MOROBEREKAN and BOUAKE 189, respectively, had significantly lower and higher severity index than the remaining cultivars, while there were no significant differences among FARO 11, FARO 35 and FARO 57 in 2008/2009 dry seasons (Table 4. 19). This is also true for FARO 35, FARO 36, FARO 44, FARO 52 and FARO 57 in 2009/ 2010 dry season. Combined analysis of the dry season's results indicated that there were significant variations in the severity index of RYMV among the rice cultivars. MOROBEREKAN and BOUAKE 189 had significantly lower and higher severity index, respectively, compared to the remaining cultivars. There were no significant differences recorded among FARO 11, FARO 35, FARO 36, and FARO 57 and also between FARO 35 and FARO 37. The mean severity index of RYMV was higher during the rainy season than the dry seasons. The interaction effect of inoculation regime and cultivar on the severity index of RYMV was significantly ($P \leq 0.05$) different among the treatment (Table 4.19).

4.1.20. Interaction of inoculation regime and rice cultivars on the severity index of RYMV in the Screenhouse (combine analysis)

In the combined analysis of rainy season data, significantly highest and lowest RYMV severity index was recorded in rice cultivars of BOUAKE 189 and MOROBEREKAN inoculated at 4 and 10 WAS, respectively. There was no significant difference in severity index of RYMV between the same cultivar at 4 and 6 WAS inoculation regimes, except for cultivar MOROBEREKAN. However, there was significant different between the same test cultivar inoculated at 6 and 8 WAS with the exception of FARO 44, MOROBEREKAN and BOUAKE 189 (Table 4.20).

Similarly, during the dry season, significantly ($P \leq 0.01$) highest disease severity index was recorded in test cultivar of BOUAKE 189 under 4 WAS inoculation regimes, while the lowest was recorded on MOROBEREKAN at 10 WAS inoculation regimes. There was no significant difference between the same test cultivar inoculated at 4 and 6 WAS, with the exception of FARO 36, FARO 44, FARO 46, FARO 52 and MOROBEREKAN (Table 4.20).

Table 4.19: Effect of inoculation regime and rice cultivars on the severity index of RYMV in the Screenhouse

	Rainy season (June – October)				Dry season (December –April)		
Treatment	**2008**	**2009**	**2010**	**Combine**	**2008/2009**	**2009/2010**	**Combine**
Inoculation regime							
4 WAS	76.43[a]	66.15[a]	73.57[a]	72.05[a]	67.16[a]	75.60[a]	71.37[a]
6 WAS	72.94[b]	63.94[a]	71.67[ab]	69.52[b]	61.50[b]	71.80[b]	66.65[b]
8 WAS	64.53[c]	55.15[b]	63.10[b]	62.92[c]	54.07[c]	69.57[c]	61.82[c]
10 WAS	45.63[d]	34.75[c]	43.58[c]	41.32[d]	27.96[d]	47.95[d]	37.95[d]
Control	0.00[e]	0.00[d]	0.00[d]	0.00[e]	0.00[e]	0.00[e]	0.00[e]
Mean	51.91	43.99	51.58	49.16	42.14	52.98	47.56
SE+	0.79	0.79	1.08	0.96	0.81	0.75	0.84
	**	**	**	**	**	**	**
Cultivar							
FARO 11	54.04[abc]	43.54[c]	52.33[b]	49.97[de]	44.94[c]	54.74[c]	49.54[c]
FARO 35	53.45[abc]	45.21[bc]	52.20[b]	50.28[cde]	42.98[cd]	56.34[bc]	49.66[cd]
FARO 36	54.83[abc]	44.70[bc]	57.04[a]	52.17[bcd]	46.42[bc]	56.20[bc]	51.35[bc]
FARO 37	51.23[ab]	43.58[c]	51.53[b]	45..78[e]	40.54[d]	54.14[c]	47.34[d]
FARO 44	55.29[ab]	50.12[a]	58.20[a]	54.54[ab]	48.87[b]	58.86[b]	53.87[b]
FARO 46	48.45[d]	43.71[c]	46.53[c]	46.23[ab]	32.64[e]	45.25[d]	38.95[e]
FARO 52	53.57[abc]	48.14[ab]	57.27[a]	52.99[ab]	48.88[b]	58.47[b]	53.68[b]
FARO 57	53.03[bc]	47.47[ab]	57.20[a]	52.56[bcd]	44.40[c]	59.03[b]	51.72[bc]
MOROBEREKAN	38.24[e]	24.16[d]	25.35[d]	29.25[g]	18.79[f]	23.52[e]	21.15[f]
BOUAKE 189	56.93[a]	49.34[a]	58.20[a]	54.82[a]	52.84[a]	63.22[a]	58.03[a]
Mean	51.91	43..99	51.58	49.16	42.14	52.98	47.56
SE ±	1.13	1.13	1.44	1.36	1.15	1.06	1.19
	**	**	**	**	**	**	**
Interaction	**	**	**	**	**	**	**

Column means followed by the same letter(s) are not significantly different at P = 0.05 % using Duncan's multiple range test (DMRT). **= Significant at 0.01 %

Table 4.20: Interaction of rice cultivar and inoculation regime on the severity index of RYMV in the screenhouse combined over 2008 to 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.

	Rainy season (June – October 2008-2010)					Dry season (December – April 2008/ 2009 – 2009/ 2010)				
Cultivar	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**	**4 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**Control**
FARO 11	73.78^{a-d}	73.02^{b-e}	64.69^{ij}	38.35^{o}	0.00^{r}	72.95^{c-f}	72.78^{def}	68.87^{ghi}	34.58^{r}	0.00^{w}
FARO 35	74.87^{anc}	73.56^{bcd}	66.42^{ghi}	44.57^{n}	0.00^{r}	72.95^{c-f}	71.51^{e-h}	67.84^{hij}	36.01^{qr}	0.00^{w}
FARO 36	74.44^{abc}	73.97^{a-d}	65.52^{hi}	46.95^{mn}	0.00^{r}	73.65^{abc}	72.78^{def}	67.68^{ij}	39.65^{pq}	0.00^{w}
FARO 37	75.03^{abc}	71.79^{c-f}	61.51^{j}	35.56^{op}	0.00^{r}	72.45^{e-g}	68.91^{ghi}	61.51^{kl}	33.84^{rs}	0.00^{w}
FARO 44	75.88^{ab}	74.13^{a-d}	70.17^{d-j}	52.50^{lm}	0.00^{r}	79.32^{a}	71.55^{e-h}	70.27^{f-i}	48.22^{n}	0.00^{w}
FARO 46	72.15^{b-f}	69.46^{e-h}	55.61^{jk}	33.92^{p}	0.00^{r}	65.00^{jk}	54.74^{m}	47.87^{n}	27.12^{t}	0.00^{w}
FARO 52	74.63^{abc}	73.69^{a-d}	69.07^{e-h}	47.56^{mn}	0.00^{r}	76.74^{ab}	74.18^{b-e}	71.55^{e-g}	45.92^{n}	0.00^{w}
FARO 57	74.63^{abc}	73.97^{a-d}	68.60^{f-i}	46.40^{mn}	0.00^{r}	75.50^{bcd}	71.71^{e-g}	66.61^{ij}	44.78^{no}	0.00^{w}
MOROBEREKAN	55.44^{k}	38.15^{o}	35.64^{op}	17.04^{q}	0.00^{r}	42.14^{op}	30.65st	21.87^{u}	11.11^{v}	0.00^{w}
BOUAKE 189	77.61^{a}	74.20^{abc}	71.98^{b-f}	50.32^{lm}	0.00^{r}	80.05^{a}	77.65^{ab}	74.15^{b-e}	58.29^{lm}	0.00^{w}
SE $\pm$			3.05					2.66		

Means and treatment under the same season followed by similar letter(s) are not significantly different at P = 0.05, according to Duncan's multiple range test (DMRT).
WAS = Weeks after sowing
SE = Standard error of the mean

4.1.21. Correlation coefficients for Screenhouse experiments in 2008, 2009 and 2010 wet and 2008/ 2009 and 2009/ 2010 dry seasons.

Under screenhouse conditions in 2008 rainy season, significantly positive correlations were recorded between disease incidence and the following parameters: reduction in number of tillers per plant (0.6609); disease severity index (0.8633). Positive correlations were also recorded between plant height and paddy yield (0.6991); increase in days to 50 % flowering and paddy yield loss (0.8017); paddy yield and 1,000 grain weight (0.7531) (Appendix CLXV). Similarly, significant negative correlations were found between the following factors: disease incidence and plant height (-0.6606), and 1,000 grain weight (-0.8140), disease severity index and plant height (-0.6562), paddy yield (-0.7399), and 1,000 grains weight (-0.9286). However, all other associations were not significant (Appendix CLXV).

During the 2009 rainy season under screenhouse condition, significantly positive correlations were observed between the following parameters: plant height and threshing percentage (0.6825), reduction in plant height and number of tillers per plant (0.6864), and paddy yield loss (0.7616), number of tillers per plant and paddy yield loss (0.8418), reduction in number of tillers per plant and paddy yield loss (0.6831), number of grain per panicle and threshing percentage (0.8947), 1,000 grain weight and threshing percentage (0.6800), disease incidence and severity index (0.9909), number of tillers per plant (0.8091), reduction in number of tillers per plant (0.6881), and paddy yield loss (0.9472). disease severity index and number of tillers per plant (0.8114), reduction in number of tillers per plant (0.6591), and paddy yield loss (0.9464) (Appendix CLXVI). Significant negative associations were found between plant height and the following parameters: number of tillers per plant (-0.7059), reduction in number of tillers per plant (-0.8115), paddy yield loss (-0.8279), disease incidence (-0.8189), and disease severity index (-0.8117). Negative

correlations were also recorded between reduction in plant height and threshing percentage (-0.6521), and 1,000 grain weight (-0.6491); number of tillers per plant and threshing percentage (-0.6900) and, 1,000 grain weight (-0.6680); reduction in number of tillers per plant and 1,000 grain weight (-0.6510); number of grain per panicle and paddy yield loss (-0.7130); paddy yield and threshing percentage(-0. 8917), and 1,000 grain weight (-0.8399); threshing percentage and disease incidence (-0.7939), and disease severity index (-0.7739); 1,000 grain weight and disease incidence (-0.9002), and disease severity index (-0.8735). All other relationships were not significant (Appendix CLXVI).

Under screenhouse conditions, during the 2010 rainy season, significantly positive correlations were recorded between plant height and the following factors: number of tillers per plant (0.7028), number of grain per panicle (0.7110), paddy yield (0.8662), threshing percentage (0.7279), and 1,000 grain weight (0.8937). Positive correlations were also recorded between reduction in plant height and increase in days to 50 % flowering (0.8251), paddy yield loss (0.8794), disease incidence (0.8693), and disease severity index (0.7851); reduction in number of tillers per plant and paddy yield loss (0.6475), disease incidence (0.7014), and disease severity index (0.7914); number of grain per panicle and paddy yield (0.8003), 1,000 grain weight (0.6978); number of grain per panicle and paddy yield loss (0.8621), threshing percentage (0.7936), and 1,000 grain weight(0.6978); paddy yield and threshing percentage (0.8621), and 1,000 grain weight(0.8643); paddy yield loss and RYMV incidence (0.9197), severity index (0.8994); threshing percentage and1,000 grain weight(0.6558); disease incidence and severity index (0.9633) (Appendix CLXVII). Similarly, significantly negative relationships were found between the following parameters: plant height and reduction in plant height (-0.7163), paddy yield loss (-0.8106), disease incidence (-0.8686), disease severity index (-0.8567); reduction in plant height and paddy

yield (-0.6791), and 1,000 grain weight (- 0.7716); reduction in number of tillers per plant and paddy yield (-0.6634), threshing percentage (-0.6471), and 1,000 grain weight (-0.6468); number of grain per panicle and paddy yield loss (-0.8738), disease incidence (-0.7663), and disease severity index (-0.7528); paddy yield and number of grain per panicle (-0.9029), disease incidence (-0.8856), disease severity index (-0.9337), and paddy yield loss (-0.9029); 1,000 grain weight and paddy yield loss (-0.8464), disease incidence (-0.9512), and disease severity index (-0.9038); threshing percentage and paddy yield loss (-0.8259), disease incidence (-0.7573), and disease severity index (-0.8273). All other correlations were not significant (Appendix CLXVII).

When data of the three rainy seasons under screenhouse condition were combined, significantly positive correlations were obtained between the following factors: disease incidence and severity index (0.9805), paddy yield loss (0.9096), reduction in plant height (0.7480), and reduction in number of tillers per plant (0.7709); disease severity index and plant height (0.6977), reduction in plant height (0.7945), reduction in number of tillers per plant (0.7364), and paddy yield loss (0.9304); plant height and number of grains per panicle (0.6511), paddy yield (0.6716), and threshing percentage (0.6690); reduction in plant height and number of tillers per plant (0.6822), and paddy yield loss (0.8366); number of grains per panicle and paddy yield (0.7553), and threshing percentage (0.8821); paddy yield and threshing percentage (0.8544), and 1,000 grain weight (0.8620); paddy yield loss and increase in days to 50 % flowering (0.6544) (Appendix CLXVIII). Similarly, significant negative associations were found between the following factors: plant height and RYMV incidence (-0.7305), reduction in plant height (-0.6580), reduction in number of tillers per plant(-0.7405), and paddy yield loss (-0.7464); reduction in plant height and 1,000 grain weight (-0.6737), and paddy yield (-0.7125); reduction in number of tillers per plant and 1,000 grain weight (-0.6699); number of grain per panicle and paddy yield loss (-0.7104),

RYMV incidence (-0.6644), and disease severity index (-0.6533); paddy yield loss and paddy yield (-0.8640), threshing percentage (-0.8073), and 1,000 grain weight (-0.8021); disease incidence and paddy yield (-0.8517),threshing percentage (-0.7322), and 1,000 grain weight (-0.9299); disease severity index and paddy yield (-0.8588), threshing percentage (-0..8065), and 1,000 grain weight (-0.8965). All other associations were not significant (Appendix CLXVIII).

Under screenhouse conditions in the 2008/2009 dry season, significantly positive correlations were obtained between the following parameters: RYMV incidence and severity index (0.9491), reduction in number of tillers per plant (0.6837), and paddy yield loss (0.8585); disease severity index and reduction in number of tillers per plant (0.7810), and paddy yield loss (0.8785); plant height and paddy yield (0.6855), and 1,000 grain weight (0.7859); number of tillers per plant and plant age (0.6842); reduction in number of tillers per plant and paddy yield loss (0.7409); number of grain per panicle and paddy yield (0.8324), and threshing percentage (0.6514); paddy yield and threshing percentage (0.6894), and 1,000 grain weight (0.6941) (Appendix CLXIX). However, during the 2008/2009 dry season, significantly negative associations were observed between the following factors: disease incidence and 1,000 grain weight (-0.8810), threshing percentage (-0.6957), paddy yield (-0.7900), and plant height (-0.8738); disease severity index and plant height (-0.8566), paddy yield (-0.8060), threshing percentage (-0.8368), and 1,000 grain weight (-0.7441); plant height and reduction in number of tillers per plant (-0.6843), and paddy yield loss (-0.7787); reduction in number of tillers per plant and number of days to50 % flowering (-0.7130), paddy yield (-0.7051), and threshing percentage (-0.6901); increase in days to 50 % flowering and 1,000 grain weight (-0.6551); paddy yield loss and number of grain per

panicle (-0.6800), paddy yield (-0.8441), threshing percentage (-0.7685), and 1,000 grain weight (-0.7002). All other relationships were not significant (Appendix CLXIX).

During the 2009/ 2010 dry season significant positive relationships were obtained between the following parameters: RYMV disease incidence and disease severity index (0.9108), paddy yield loss (0.9061), and reduction in plant height (0.8361); disease severity index and paddy yield loss (0.7332), and reduction in plant height (0.7271); paddy yield and plant height (0.6535), number of grains per panicle (0.8351), threshing percentage (0.6679), and 1,000 grain weight (0.7767); plant height and 1,000 grain weight (0.8677); reduction in plant height and paddy yield loss (0.6571); number of grains per panicle and threshing percentage (0.6538) (Appendix CLXX). However, significantly negative correlations were found between the following factors: RYMV disease incidence and plant height (-0.9176), paddy yield (-.0.7910), threshing percentage (-0.6641), and 1,000 grain weight (-0.9371); disease severity index and plant height (-0.9855), days to 50% flowering (-0.6810), and 1,000 grain weight (-0.8941); plant height and reduction in plant height (-0.7325), and paddy yield loss (-0.8007); reduction in plant height and 1,000 grain weight (- 0.7211); reduction in number of tillers per plant and days to 50 % flowering (- 0.6490); paddy yield loss and number of grains per panicle (- 0.6810), paddy yield (- 0.9421), threshing percentage (- 0.7316), and 1,000 grain weight (- 0.8182). All other relationships were not significant (Appendix CLXX).

When data of the two dry seasons under screenhouse conditions were combined, significantly positive correlations were obtained between the following parameters: disease incidence and severity index (0.9762); plant height and threshing percentage (0. 6626), and 1,000 grain weight (0. 6587); reduction in plant height and number of tillers per plant (0.6500), and disease incidence (0.6646), number of tillers per plant and paddy yield

(0.6531); reduction in number of tillers per plant and paddy yield loss (0.7766), disease incidence (0.7427), and disease severity index (0.7707); number of grain per panicle and threshing percentage (0.6542); paddy yield loss and disease incidence (0.9247), and disease severity index (0.9614) (Appendix CLXXI). However, significantly negative correlations were recorded between the following factors; disease incidence and plant height (- 0.9138), and threshing percentage (- 0.7163); disease severity index and plant height (- 0.9071), and threshing percentage (- 0.8174); plant height and reduction in number of tillers per plant (- 0.7105), paddy yield loss (- 0.8690); reduction in plant height and age of plant (in weeks) (-0.9747); paddy yield loss and number of grain per panicle (- 0.6716); paddy yield (-0.6882), and threshing percentage (- 0.8009), while other relationships were not significant (Appendix CLXXI).

4.2 FIELD EXPERIMENTS

4.2.1. Incidence of RYMV insec*t* vectors during the 2008, 2009 and 2010 rainy seasons at Bomo

During the 2008 rainy season, the RYMV insect vectors caught were *Oxya* sp*., Locris rubra, Chaetocnema sp., Chnootriba similis,* and *Trichispa sericea* in order of abundance (Figure 2). The most prevalent insect vectors caught were *Oxya* sp. and L. *rubra* throughout the season. C. *similis* was also found in the rice field mostly though at low population density. *Chaetocnema* sp. and *T. sericea* were caught at the early stage of the plant growth and their population were very low. There were significant ($P \leq 0.05$) differences among the insect vectors caught in the season, except between the mean number of *Chaetocnema* sp. and *C. similis* sampled during the season (Figure 2).

Similarly, during the 2009 rainy season, the type of RYMV insect vectors caught included: *L. rubra, Oxya.* sp., *Cheilomenes* sp*., Conocephalus* sp*., Chaetocnema* sp. and *C. similis* and

T. sericea in order of abundance under field conditions (Figure 2). There were significant ($P \leq 0.05$) variation among the insect vectors caught in the season. Higher population density of *L. rubra* was recorded in the season compared to the other insect vectors encountered under the field condition (Figure 2).

During the 2010 rainy season population abundance of RYMV insect vectors caught included the following: *L. rubra, C. similis, Chaetocnema* sp., *Oxya* sp, *Cheilomenes* sp., *Zonocerus variegatus* and *Conocephalus* sp. There were variations among the insect vectors caught in the season. Higher and lower population density of *L.rubra* and *Conocephalus* sp. were recorded in the season compared to the other insect vectors encountered under the field condition, respectively. However, the population density of C*heilomenes, Z. variegatus* and *Conocephalus* sp. were statistically similar under the field condition during the season. The mean population densities of RYMV insect vectors were higher in 2009 than during the 2008 and 2010 rainy seasons (Figure 2).

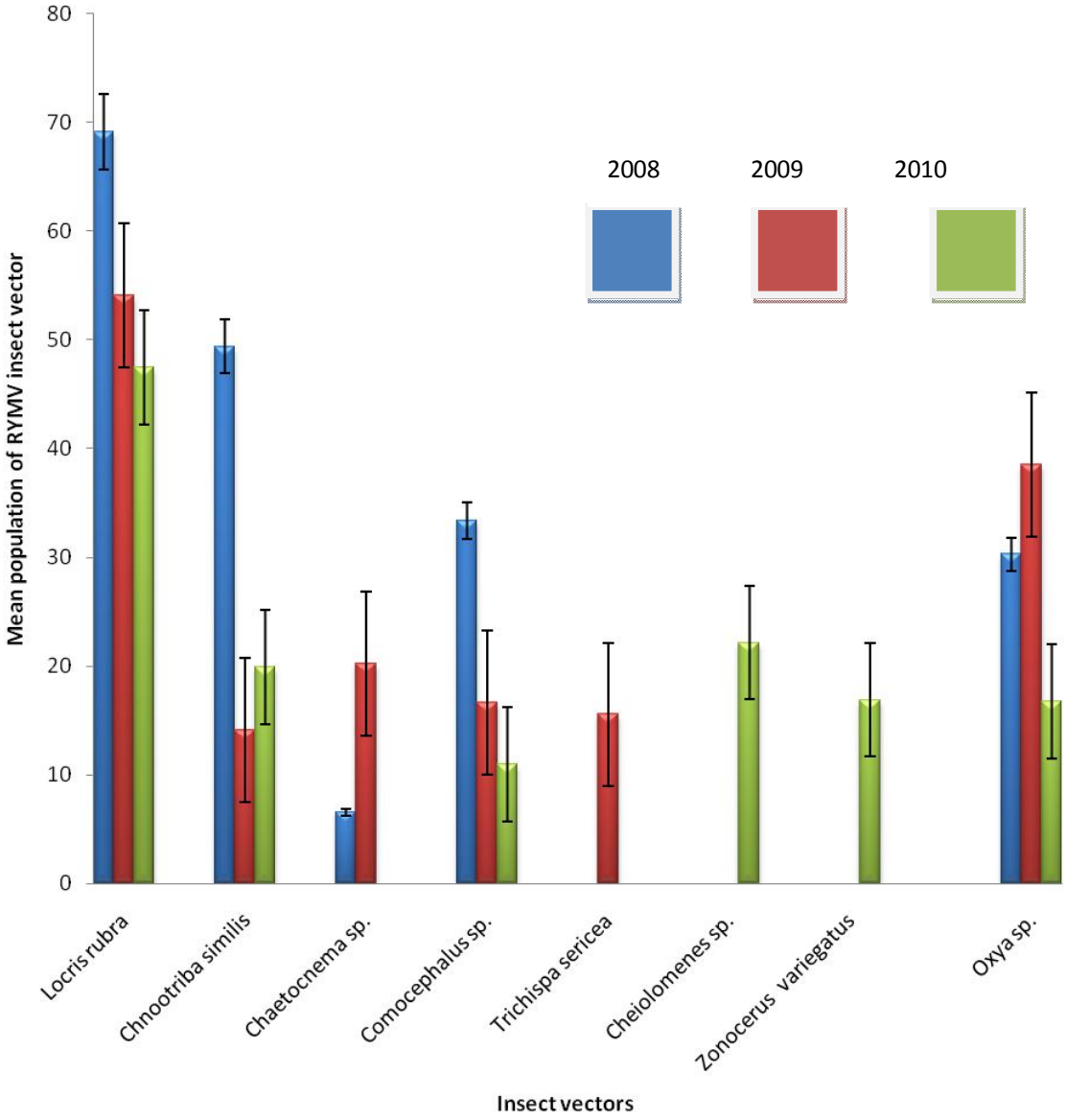


Figure 2: Mean number of insect vectors caught from June to October during the 2008 , 2009 and 2010 rainy seasons at Bomo

Bar represent ± Stardard error of the mean.

4.2.2. Incidence of RYMV insect vectors during the 2008, 2009 and 2010 rainy seasons at Sayen Gobirawa.

During the 2008 rainy season the mean number of RYMV insect vectors caught included the following: *L. rubra, C. similis, Conocephalus* sp., *Oxya* sp. and *Chaetocnema* sp. in order of abundance (Figure 3). There were significant differences ($P \leq 0.05$) in the mean population abundance of insect vectors in the season. The mean population density of *L. rubra* was significantly higher ($P \leq 0.05$) than other insect vectors, while least number of *Chaetocnema* sp. was recorded at early stage of the plant growth compared to the remaining insect vectors (Figure 3).

Similarly, during the 2009 rainy season at Sayen Gobirawa, the number of RYMV insect vectors encountered in the field included the following: *L. rubra, Oxya* sp., *Chaetocnema* sp, *Conocephalus* sp., and *T. sericea and C. similis* in order of abundance (Figure 3). The mean population density of *L. rubra* was significantly higher ($P \leq 0.05$) compared to the other insect vectors, recorded on the field. While there were no significant differences recorded in the mean population density among *Conocephalus* sp., *T. sericea and C. similis* during the sampling period (Figure 3).

In the 2010 rainy season at Sayen Gobirawa the number of RYMV insect vectors caught included the following: *L. rubra, Cheilomenes* sp, *C. similis*, *Z. variegatus*, *Oxya* sp. and *Conocephalus* sp. in order of abundance (Figure 3). There were significant ($P \leq 0.05$) variations in the mean population density of RYMV insect vectors, caught during the season. *L. rubra,* was most prevalent during the season compared to the other vectors (Figure 3).

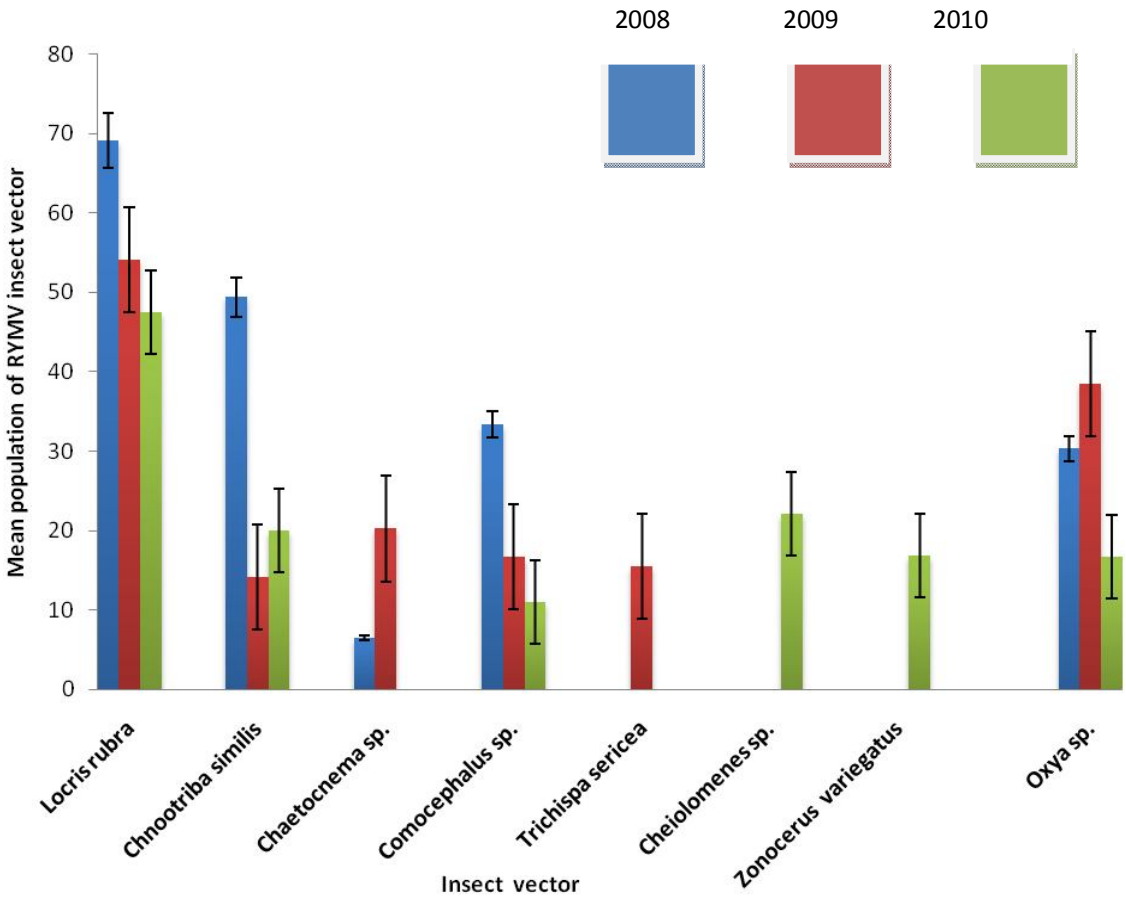


Figure 3: Mean number of insect vectors caught from June to October during the 2008, 2009 and 2010 rainy seasons at Sayen Gobirawa

Bar represent ± Stardard error of the mean.

The mean population densities of RYMV insect vectors were higher in 2008 than during the 2009 and 2010 rainy seasons. Although more numbers of RYMV insect vectors were recorded in both 2009 and 2010 seasons, respectively (Figure 3).

4.2.3. Incidence of RYMV insect vectors during the 2008/ 2009 and 2009/ 2010 dry seasons at Nasarawan Buhari.

During 2008/ 2009 dry season the mean number of RYMV insect vectors caught in the field included the following: *L. rubra, Cheilomenes* sp., *Z. variegatus*, *Parattetix sp., C. similis*, *Oxya* sp*, and Conocephalus* sp. in order of abundance (Figure 4). Generally, there were significant differences in the mean population density among the insect vectors collected in the field. Significantly higher population density of *L. rubra* was encountered in the season during the sampling period compared to the other insect vectors. However, *C. similis,* and *Cheilomemes* sp. were also prevalent, but at lower density (Figure 4).

Similarly, during the 2009/ 2010 dry season the RYMV insect vectors caught were L. *rubra, Cheilomenes* sp*., Oxya* sp., *Z. variegatus, C. similis, Conocephalus* sp. and *Chaetocnema* sp. in order of abundance. There were significant variations in the population density of insect vectors sampled during the season (Figure 4). However, there were no significant differences in the number of O*xya* sp., *Cheilomenes* sp. and *C. similis,* caught during the season. Similarly, no significant difference in the population density of *Chaetocnema* sp. and *Conocephalus* sp. was recorded on the field during the season. The mean population densities of RYMV insect vectors were higher in 2008/ 2009 than during the 2009/ 2010 dry seasons (Figure 4).

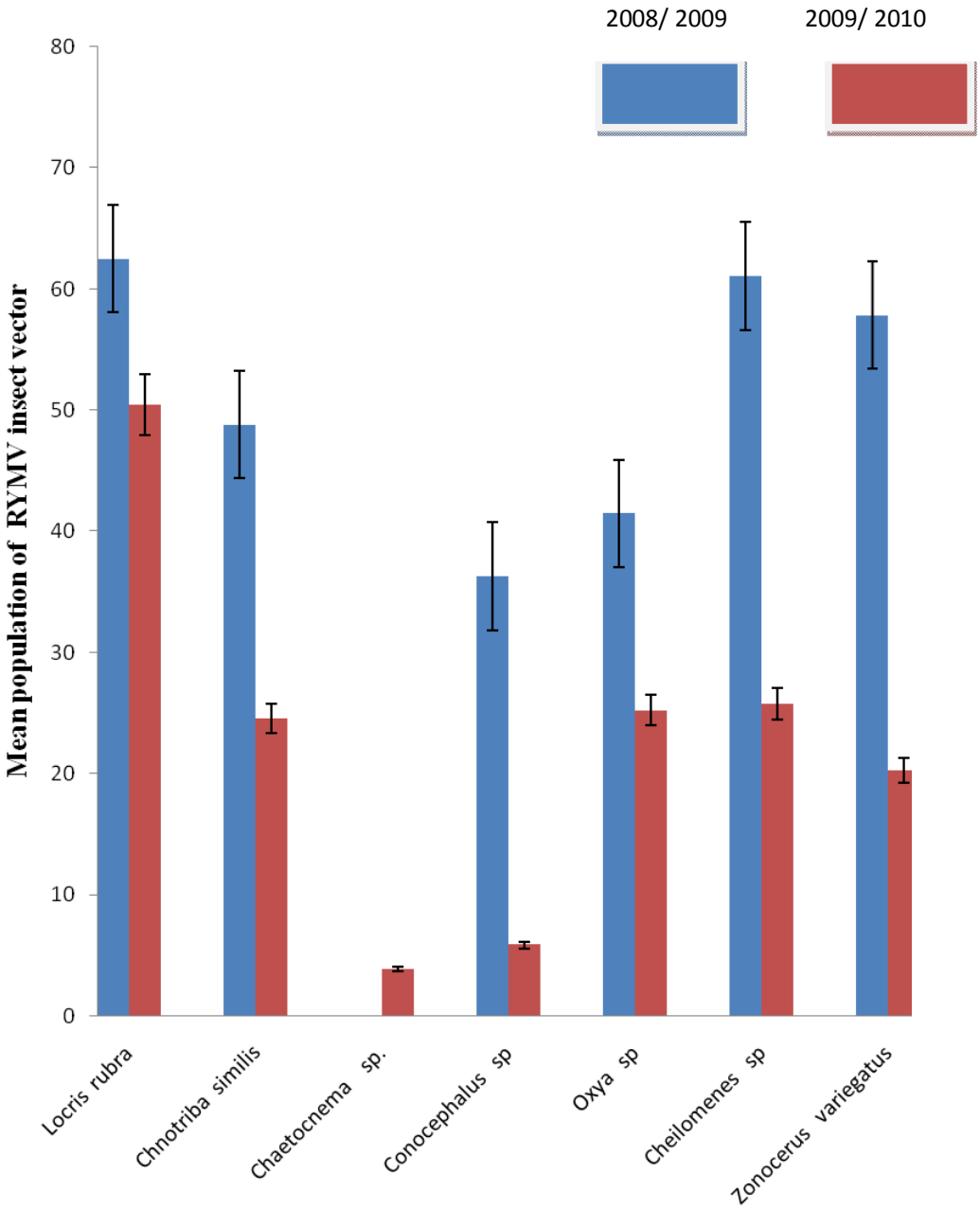


Figure 4: Mean number of insect vectors caught from December to April during the 2008/ 2009 and 2009/ 2010 dry seasons, at Nasarawan Buhari, respectively

Bar represent ± Stardard error of the mean.

4.2.4. Effect of Weather factors on Insect Vector Population, RYMV Incidence and Severity index at Bomo from 2008-2010 Rainy seasons

The trends of the population of insect vectors caught shows statistically significant differences (P≤ 0.05) during the three years of the investigation. There was significant (P≤ 0.05) differences in the mean population of *L. rubra* caught in the seasons. The highest number of *L. .rubra* was caught in 2009 followed by 2008 and least in 2010. Whereas *Oxya* sp. population trends show statistically significant differences (P≤ 0.05) in the three years trial, with the vector population highest in 2008, followed by 2009 and least in 2010, rainy seasons, respectively. Similarly, the trends of the population density of *C. simili*s and *Chaetocnem*a sp. recorded during the trial period showed significant differences (P≤ 0.05) in the number of vectors caught per season, with a highest vector population in 2010 followed by 2009 and least in 2008 rainy season, respectively. Also, statistically highest number of *Cheilomenes* sp. and *Conocephalus* sp. were caught in 2009 followed by 2010 rainy seasons, while none was recorded during the 2008 experimental period, respectively. Significant differences (P≤ 0.05) in *T. sericea* population were observed during the investigation periods, with the vector population higher in 2009, followed by 2008, and none was recorded in 2010 rainy seasons, respectively. Whereas*, Z.. variegatus* was only recorded in 2010 rainy season and none was observed in the other seasons. The result of RYMV incidence and severity index values across the years indicated that there was no significant (P≤0.05) difference between 2008 and 2010 rainy seasons. However, significantly highest (P ≤ 0.05) RYMV incidence was recorded in 2009, followed by 2008 and least in 2010 whereas, severity index value was significantly lowest in 2009 followed by 2010 and highest in 2008 (Table 4.21).

Table 4.21: Effect of weather factors on insect vector population density, Rice yellow mottle virus incidence and severity index at Bomo from 2008-2010 rainy seasons

Year	Mean number of insect vectors caught per season								RYMV incidence (%)	RYMV severity index (%)	Weather factors during the observation period (June to October)			
	LR	CH	CL	CO	CS	TR	OX	ZV			Mean temperature (^{o}C)	Mean relative humidity (%)	Mean rainfall (mm)	Mean Sunshine hours
2008	50.49^{b}	10.20^{c}	00.0^{c}	00.0^{c}	12.96^{c}	3.0^{b}	58.8^{a}	00.0^{b}	64.58^{b}	68.77^{a}	26.07^{a}	79.09^{b}	62.67^{c}	5.92^{a}
2009	57.74^{a}	15.87^{b}	28.57^{a}	22.21^{a}	15.37^{b}	11.4^{a}	46.13^{a}	00.0^{b}	67.34^{a}	60.37^{b}	25.67^{a}	75.73^{c}	76.41b	6.73^{a}
2010	41.43^{c}	19.34^{a}	14.40^{b}	10.16^{b}	22.72^{a}	00.0^{c}	16.50^{c}	10.29^{a}	64.33^{b}	68.14^{a}	23.50^{b}	90.67^{a}	97.80a	6.34^{a}
Mean	49.87	14.87	14.32	10.75	17.01	4.80	40.47	3.43	65.42	65.76	25.07	81.90	78.69	6.33
SE±	4.67	2.64	8.25	6.38	2.94	3.41	12.53	3.43	0.96	2.70	0.79	4.60	10.22	NS

Column mean under the same parameter(s) followed by the same letter are not significant different at p = 0.05 accrding to Student Newman Keul (SNK) test. NS = Not significant

Locris rubra = LR,, *Chaetocnema* sp. = CH, *Cheilomene*s sp. = CL,. *Conocephalu*s sp., = CO,, *Chnootriba simili*s = CS,, *Trichispa seracea* =TR,, *Oxya* sp. = 0X and, *Zonocerus variegatus* = ZV

Mean rainfall and relative humidity were statistically (P≤ 0.05) higher in 2010 followed by 2009 and less in 2008. Average temperature was significantly (P ≤ 0.05) highest in 2008 followed by 2009 and less in 2010. Mean sunshine hours was highest in 2009 followed by 2010 and least in 2008 However, sunshine hours recorded across the years were statistically similar (Table 4.21).

4.2.5. Effect of Weather factors on Insect Vector Population, RYMV Incidence and Severity index at Sayen Gobirawa from 2008-2010 Rainy seasons

The population density of vectors recorded across the three years trial, show statistically significant differences (P≤ 0.05) in the number of the insect vectors caught per season. Insect vectors caught included the following*: L. rubra, Oxya sp., C. similis, Conocephalus sp., Chaetocnema sp., Cheilomenes sp., Z. variegatus* and *T. sericea* in order of abundance. The highest number of *L. rubra* was caught in 2008 followed by 2009 and least in 2010. Significantly highest (P≤ 0.05) number of *C similis* was recorded in 2008 followed by 2010 and least in 2009. Similarly the highest number of *Conocephalus* sp. was caught in 2008 followed by 2009 and least in 2010. However, the population density of the grasshopper recorded was statistically similar in 2009 and 2010 rainy seasons. The highest number of *Chaetocnema* sp. was caught in 2009, followed by 2008 while none was recorded in the 2010 rainy season. However, across the three years, it was only in the 2010 rainy season that *Cheilomenes* sp. and Z. *variegatus* were recorded at Sayen Gobirawa. Similarly *T. sericea* was recorded only in 2009. There were significant (P≤ 0.05) differences in the incidence of RYMV across the trial periods. The results showed that the highest incidence of RYMV was observed in 2008 followed by 2010 and least in 2009 (Table 4.22).

Table 4.22: Effect of weather factors on insect vector population density, Rice yellow mottle virus incidence and severity index at Sayen Gobirawa from 2008-2010 rainy seasons

Year	Mean number of insect vectors caught per season								RYMV incidence (%)	RYMV severity index (%)	Weather factors during the observation period (June to October)			
	LR	CH	CL	CO	CS	TR	OX	ZV			Mean temperature (^{o}C)	Mean relative humidity (%)	Mean rainfall (mm)	Mean Sunshine hours
2008	69.00^{a}	6.53^{b}	0.00^{b}	33.40^{a}	49.00^{a}	0.00^{b}	30.30^{b}	0.0^{b}	73.67^{a}	61.48^{a}	26.07^{a}	79.09^{b}	62.67^{c}	5.92^{a}
2009	54.41^{b}	20.29^{a}	0.00^{b}	11.67^{b}	14.14^{c}	15.64^{a}	38.00^{a}	0.0^{b}	51.52^{c}	60.45^{b}	25.65^{a}	75.73^{c}	76.41^{b}	6.73^{a}
2010	47.49^{c}	0.00^{a}	22.16^{a}	10.97^{b}	19.94^{b}	0.00^{b}	16.73^{c}	16.90^{a}	60.17^{b}	62.96^{a}	23.50^{b}	90.67^{a}	97.80^{a}	6.34^{a}
Mean	56.46	28.34	8.94	27.09	18.48	5.21	7.38	5.63	61.78	62.29	25.07	81.90	78.86	6.33
SE±	6.34	5.98	7.38	7.36	10.78	5.21	6.22	5.63	6.45	0.43	0.79	4.60	10.22	NS

Column mean under the same parameter(s) followed by the same letter are not significant different at p = 0.05 accrding to Student Newman Keuls (SNK) test. NS = Not significant

Locris rubra = LR, *Chaetocnema* sp. = CH, *Cheilomene*s sp. = CL, *Conocephalu*s sp. = CO, *Chnootriba simili*s = CS, *Trichispa seracea* =TR,, *Oxya* sp. =0X and *Zonocerus variegatus* =ZV

However, no significant differences were observed across the years in disease severity index values, but the highest severity index was recorded in 2010, followed by 2009 and least in 2008. Average temperature was significantly higher in 2008, followed by 2009 and least in 2010. Mean sunshine hours was higher in 2009, followed by 2010 and least in 2008, although the sunshine hours recorded across the years were statistically similar. Furthermore, mean rainfall and relative humidity were significantly ($P \leq 0.05$) higher in 2010, followed by 2009 and least in 2008 (Table 4.22).

4.2.6. Effect of Weather factors on the Insect vector population, RYMV Incidence and Severity index at Nasarawan Buhari in 2008/ 2009 and 2009/ 2010 dry seasons

In the 2008/ 2009 and 2009/ 2010 dry seasons experiments the population densities of insect vectors recorded show statistically significant ($P \leq 0.05$) differences between the seasons. Higher numbers of insect vectors were caught in 2008/ 2009 compared to 2009/ 2010 dry season. RYMV insect vectors caught included *L. rubra*, *Z. variegatus*, *C.simlis, Oxya* sp., *Conocephalus* sp. and *Chaetocnema* sp. in order of abundance. The incidence and severity index values of RYMV were significantly lower in 2008/ 2009 than in the 2009/ 2010 dry season. A similar trend was observed in weather factors: average temperature and sunshine hours were lower in 2008/ 2009 compared to 2009/ 2010 dry season, but mean relative humidity was higher in 2008/ 2009 compared to 2009/ 2010 dry season (Table 4.23).

Table 4.23: Effect of weather factors on insect vector population density, Rice yellow mottle virus incidence and severity index at Nasarawan Buhari (2008/ 2009 and 2009/ 2010).

Year	Mean number of insect vectors caught per season							RYMV incidence (%)	RYMV severity index (%)	Weather factors during the observation period (December to April)		
	LR	CH	CL	CO	CS	OX	ZV			Mean temperature (^{o}C)	Mean relative humidity (%)	Mean Sunshine hours
2008/09	62.51^{a}	0.00^{b}	61.07^{a}	36.27^{a}	48.81^{a}	41.47^{a}	57.83^{a}	50.50^{b}	61.40^{b}	26.44^{b}	16.46^{a}	8.27^{a}
2009/10	50.45^{b}	3.96^{a}	25.78^{b}	5.83^{b}	24.53^{b}	25.22^{b}	20.23^{b}	89.66^{a}	65.59^{a}	28.22^{a}	13.30^{b}	9.10^{a}
Mean	56.48	1.98	43.43	21.05	36.67	33.35	39.03	70.08	63.49	27.39	14.88	8.68
SE±	6.03	1.98	17.65	15.22	12.14	18.75	18.20	19.58	2.09	0.95	1.58	0.42

Column mean under the same parameter followed by the same letter are not significantly different at p = 0.05 accrding to Student Newman Keul (SNK) test.

Locris rubra = LR, *Chaetocnema* sp. = CH, *Cheilomene*s sp. = CL, *Conocephalu*s sp. = CO, *Chnootriba simili*s = CS, *Oxya* sp. = 0X and *Zonocerus variegatus* = ZV.

4.2.7. Effect of RYMV incidence and severity index on paddy yield during the 2008 rainy seasons at Bomo.

In 2008, RYMV incidence recorded among the treatments were statistically significant even at 6 WAS., although symptom was only recorded on FARO 35, FARO 36, FARO 44 and BOUAKE 189. At 8 WAS, 50 % of the cultivars were already infected (Table 4.24). The highest incidence was observed on BOUAKE 189 followed by FARO 36, FARO 52 , FARO 35 and FARO 44 , while there were no visible RYMV symptoms on FARO 11, FARO 37, FARO 46, FARO 57 and MOROBEREKAN, respectively. At 10 WAS, all the rice cultivars were infected, although the incidence on FARO 37, FARO 46, FARO 57 and MOROBEREKAN was less than 2%. There were significant ($P \leq 0.05$) differences, in disease incidence among the treatments. The highest incidence was on BOUAKE 189 while the lowest incidence was observed on FARO 37, FARO 46 and MOROBEREKAN. There was no significant difference in the disease incidence observed between FARO 35 and FARO 44 and between FARO 36 and FARO 52. At 12 WAS, there were significant differences in the incidence of RYMV among the treatments (Table 4.24). BOUAKE 189 had significantly higher disease incidence than the other cultivars. The lowest disease incidence was on MOROBEREKAN, though it was statistically similar to FARO 35, FARO 46, and FARO 57. At 12 WAS, the results of the mean separation of the number of infected plants per individual cultivars, was statistically significant in cultivars FARO 11, FARO 36, FARO 37, FARO 46, FARO 52, FARO 57, MOROBEREKAN and BOUAKE 189 compared with the results of incidence from 8 to 12 WAS, except for cultivars FARO 35 and FARO 44. At 14 WAS, all the cultivars used had at least 50 % RYMV infection with the exception of MOROBEREKAN and FARO 46, which recorded 45 % and 48.33 %, respectively (Table 4.24).

There was significant variation in disease severity index at Bomo in 2008 throughout the assessment period, although the level of disease severity increase was gradual. At 6 WAS only 40 % of the test cultivars had recorded 11.1 % RYMV severity index (FARO 36, FARO 44, FARO 52 and BOUAKE 189). At 8 WAS, there were significant ($P \leq 0.05$) differences in disease severity indices among the cultivars (ranged from 11.1 % to 48.1 %). However, disease severity was statistically similar among FARO 37, FARO 57 and MOROBEREKAN. Also, there were no significant differences among the rice cultivars FARO 36, FARO 44, FARO 52 and BOUAKE 189. At 10 WAS, significantly lowest and highest disease severity index was recorded on MOROBEREKAN and BOUAKE 189, respectively. However, disease severity was statistically similar between FARO 35 and FARO 44, and between FARO 37 and FARO 57, and also between FARO 36 and FARO 52. At 12 WAS, disease severity index varied from 44.40 to 77.70% among the test cultivars. Significantly lowest disease severity index was recorded on MOROBEREKAN while the highest was recorded on BOUAKE 189. The disease severity index varied significantly among the test cultivars, except between FARO 44 and FARO 52. At 14 WAS, the disease severity index increased to 51.8 % on MOROBEREKAN. However, disease severity indices were statistically similar among FARO 11, FARO 37 and FARO 52 and similarly among BOUAKE 189, FARO 36, FARO 44 and FARO 57, also between FARO 35 and FARO 46. Except for the above mentioned cases, the cultivars significantly differed in their responses to RYMV severity index (Table 4.24).

Results on the effects of RYMV on paddy yield are also shown in Table 4.24. There was a highly significant ($P \leq 0.05$) cultivar difference, during the wet seasons of 2008, at Bomo. Significantly highest paddy yield was produced in the seasons by cultivar MOROBEREKAN while the lowest paddy yield was obtained on FARO 35. However,

paddy yield produced were statistically similar among rice cultivar of FARO 11, FARO 35, FARO 36, FARO 37, FARO 52, FARO 57 and BOUAKE 189. Similarly between FARO 46 and MOROBEREKAN (Table 4.24).

4.2.8. Effect of RYMV incidence and severity index on paddy yield during the 2009 rainy seasons at Bomo

In 2009 at Bomo, the effect of the disease incidence among the treatments was highly significant (P≤ 0.05) at 6 WAS. The highest disease incidence was observed on BOUAKE 189 followed by FARO 44, while there was no visible RYMV symptoms observed on FARO 46 and MOROBEREKAN. At 8 WAS, the effect of disease incidence was significant (P≤ 0.05). The highest and lowest number of infected plants was recorded on BOUAKE 189 (35 %) and MOROBEREKAN (5 %), respectively. There was no significant difference in the disease incidence observed on FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 52, FARO 57 and BOUAKE 189, similarly between MOROBEREKAN and FARO 46. At 10 WAS there were significant differences (P≤ 0.05) in the incidence of RYMV among the treatments. BOUAKE 189 and FARO 52 had significantly higher disease incidence than the other cultivars, though it was statistically similar to FARO 44 and FARO 57. The lowest incidence was recorded on MOROBEREKAN. At 12 WAS, there were significant differences (P≤ 0.05) among the rice cultivars. FARO 44 and FARO 52 had recorded disease incidence of 60 %, though it was statistically similar to FARO 57 and BOUAKE 189. The lowest incidence of 20 % was recorded on MOROBEREKAN. However, there were no significant differences in the disease incidence observed on FARO 11, FARO 35, FARO 36, FARO 37 and FARO 46. At 14 WAS, all the rice cultivars had RYMV incidence more than 50 %, except cultivar FARO 46 (48.33 %) and MOROBEREKAN (35 %). There were significant (P≤ 0.05) differences in disease

incidence among the treatments. The highest incidence was recorded on BOUAKE 189 while the lowest was on MOROBEREKAN (Table 4.25).

Results of the disease severity index at Bomo during the 2009 rainy season are presented in Table 4.25. Generally, there was increase in severity imdex of RYMV in most of the rice cultivars compared to the results of 2008 wet season. At 6 WAS the highest disease incidence was observed on FARO 52 (33.33 %) while the lowest was on FARO 37 (10 %), but no visible RYMV symptom was observed on MOROBEREKAN. At 8 WAS, the highest and lowest severity index was on FARO 44 and MOROBEREKAN, respectively. However disease severity index was statistically similar among FARO 11, FARO 35, FARO 36, FARO 44, FARO 52, FARO 52, FARO 57 and BOUAKE 189. At 10 WAS disease severity index varied from 20.97 to 65.43 % among the test cultivars. Significantly lowest and highest disease severity index was obtained on cultivars of MOROBEREKAN and BOUAKE 189, respectively. However, severity index was statistically similar among FARO 35, FARO 44, FARO 52, FARO 57 and BOUAKE 189, also among FARO 37, FARO 46 and MOROBEREKAN. At 12 WAS, the impact of RYMV severity was highly significant ($P \leq 0.05$) among the treatments. Significantly lowest and highest severity index was recorded on MOROBEREKAN and BOUAKE 189, respectively. But disease severity index was statistically similar among cultivars FARO 35, FARO 36, FARO 44, FARO 52, FARO 57 and BOUAKE 189. At 14 WAS disease severity index varied from 30.85 to 70.36 %. RYMV severity index was significantly ($P \leq 0.01$) lowest on the rice cultivar MOROBEREKAN compared to other treatments. Although BOUAKE 189 had the highest disease severity index it was statistically similar to FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 52 and FARO 57 (Table 4.25).

Table 4.24: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2008 rainy season

Cultivar	RYMV incidence					RYMV severity index					Paddy yield
	6WAS	8 WAS	10 WAS	12WAS	14 WAS	6 WAS	8 WAS	10 WAS	12 WAS	14 WAS	Kg/ha
FARO 11	0.00^{c}	3.67^{d}	5.45^{f}	11.18^{ef}	52.00^{e}	0.00^{b}	22.20^{e}	44.40^{e}	51.80^{f}	59.20^{c}	1746.7^{bc}
FARO 35	1.67^{b}	6.00^{c}	7.86^{de}	10.85^{ef}	50.00^{f}	0.00^{b}	29.6^{0c}	55.50^{c}	70.30^{c}	74.00^{b}	1593.3^{c}
FARO 36	1.67^{b}	8.33^{b}	11.33^{c}	19.00^{c}	75.00^{d}	11.10^{a}	48.10^{a}	59.20^{b}	74.00^{b}	77.70^{a}	1883.0^{bc}
FARO 37	0.00^{c}	1.00^{e}	5.45^{f}	11.66^{e}	51.67^{e}	0.00^{b}	11.10^{f}	40.70^{f}	51.80^{f}	59.20^{c}	1766.7^{bc}
FARO 44	2.00^{b}	8.67^{b}	11.85^{c}	17.00^{d}	90.00^{b}	11.10^{a}	44.40^{b}	55.50^{c}	74.00^{b}	77.70^{a}	2333.3^{b}
FARO 46	0.00^{c}	1.00^{e}	8.52^{d}	10.95^{e}	49.00^{f}	0.00^{b}	25.90^{d}	48.10^{d}	55.50^{e}	59.20^{c}	2499.7^{ab}
FARO 52	0.00^{c}	6.67^{c}	14.05^{b}	20.67^{b}	86.67^{c}	11.10^{a}	44.40^{b}	59.20^{b}	74.00^{b}	77.70^{a}	1760.0^{bc}
FARO 57	0.00^{c}	1.67^{e}	6.64^{ef}	10.95^{ef}	50.00^{f}	0.00^{b}	11.10^{f}	40.70^{f}	66.60^{d}	74.00^{b}	1883.3^{bc}
MOROBEREKAN	0.00^{c}	1.00^{e}	5.45^{f}	9.43^{f}	45.00^{g}	0.00^{b}	11.10^{f}	33.33^{g}	44.40^{g}	51.80^{d}	2883.3^{a}
BOJAKE 189	3.67^{a}	10.00^{a}	18.28^{a}	28.33^{a}	99.00^{a}	11.10^{a}	48.10^{a}	66.60^{a}	77.70^{a}	77.70^{a}	2066.7^{bc}
Mean	0.90	4.80	9.48	15.0	64.83	4.44	29.60	50.32	64.10	68.82	2042.0
SE $\pm$	0.41	1.12	1.36	1.93	6.50	1.81	4.96	3.32	3.78	3.23	128.82

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keul (SNK) test. WAS = Weeks after sowing SE=Standard error of the mean

Table 4. 25: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2009 rainy season

Cultivars	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
	.6 WAS	8 WAS	10 WAS	12 WAS	14 WAS	6 WAS	8 WAS	10 WAS	12 WAS	14 WAS	Kg/ha
FARO 11	1.70^{c}	23.33^{a}	35.00^{bc}	41.20^{b}	63.33^{bc}	10.00^{e}	28.52^{ab}	38.27^{bcd}	49.48^{b}	58.02^{ab}	1767.0^{cd}
FARO 35	13.33^{ab}	25.00^{a}	33.33^{bc}	41.70^{b}	68.33^{ab}	21.22^{c}	30.99^{ab}	47.48^{ab}	60.49^{ab}	70.34^{a}	1471.7^{d}
FARO 36	16.70^{ab}	28.33^{a}	38.33^{b}	45.00^{b}	70.00^{ab}	22.22^{c}	33.46^{a}	37.60^{bcd}	55.08^{ab}	62.96^{ab}	2031.1^{c}
FARO 37	1.70^{c}	20.00^{a}	28.33^{c}	36.67^{b}	63.33^{bc}	6.30^{f}	16.31^{bc}	33.33^{bcd}	44.74^{bc}	57.55^{ab}	1916.3^{cd}
FARO 44	20.00^{a}	35.00^{a}	50.00^{a}	60.00^{a}	81.70^{a}	22.22^{c}	42.54^{a}	52.42^{ab}	62.96^{ab}	70.23^{a}	2271.0^{c}
FARO 46	0.00^{d}	8.33^{b}	21.07^{d}	33.33^{b}	48.33^{c}	11.11^{d}	13.71^{c}	28.39^{cd}	37.60^{c}	49.67^{b}	2733.7^{b}
FARO 52	15.00^{ab}	34.00^{a}	53.33^{a}	60.00^{a}	78.33^{ab}	33.33^{a}	38.27^{a}	49.28^{abc}	62.96^{ab}	67.89^{a}	1986.0^{c}
FARO 57	10.00^{b}	28.33^{a}	46.70^{a}	58.00^{a}	78.33^{ab}	30.00^{b}	40.07^{a}	51.75^{abc}	62.96^{ab}	67.90^{a}	2027.0^{c}
MOROBEREKAN	0.00^{d}	5.00^{b}	11.70^{e}	20.00^{c}	35.00^{d}	0.00^{g}	7.41^{c}	20.97^{d}	26.05^{d}	30.85^{c}	3353.3^{a}
BOUAKE 189	21.67^{a}	35.00^{a}	53.33^{a}	58.33^{a}	86.70^{a}	30.00^{b}	38.27^{a}	65.43^{a}	67.90^{a}	70.36^{a}	1763.3^{cd}
Mean	10.01	23.83	37.17	45.17	67.34	18.63	28.95	42.40	53.02	60.37	2132.10
SE ±	2.70	3.23	4.43	4.19	5.02	3.55	3.89	4.17	4.25	4.03	172.14

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keul (SNK)test. WAS = Weeks after sowing SE=Standard error of the mean

In the 2009 rainy season at Bomo cultivar MOROBEREKAN recorded significantly ($P \leq 0.01$) higher paddy yield than the remaining cultivars.The lowest paddy yield was recordrd on FARO 35, although it was statistically similar to FARO 11, FARO 37 and BOUAKE 189.Similarly, there were no significant differences in paddy yield recorded among the rice cultivars of FARO 11, FARO 36, FARO 37, FARO 44, FARO 52, FARO 57 and BOUAKE 189 (Table 4.25.).

4.2.9. Effect of RYMV incidence and severity index on paddy yield during the 2010 rainy seasons at Bomo

In 2010 at Bomo, the effect of the disease incidence among the treatments was significant ($P \leq 0.05$). From 6 to 12 WAS, there were significant variations of RYMV incidence among the test cultivars. Significantly highest incidence was observed on BOUAKE 189 while lowest was observed on MOROBEREKAN. At 10 WAS though the number of RYMV infected plants on cultivar MOROBEREKAN was statistically similar to FARO 46. Similarly, at 12 WAS the number of RYMV infected plants recorded on rice cultivar BOUAKE 189 was statistically similar to FARO 44. At 14 WAS there were significant variations ($P \leq 0.01$) in the incidence of RYMV among the test cultivars. The highest number of RYMV infected plants was recorded on BOUAKE 189, though it was statistically similar to FARO 36, FARO 44, FARO 52 and FARO 57, while the lowest incidence was recorded on MOROBEREKAN (Table 4.26).

Result of the disease severity index at Bomo during the 2010 rainy season is also presented in Table 4.26. There were significant variations in disease severity index throughout the observation period. At 6 WAS ninety percent of the test cultivars had disease severity index of 11.11 to 33.33 %, with the exception of cultivar MOROBEREKAN. At

Table 4. 26: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Bomo during 2010 rainy season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
Cultivar	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**Kg/ha**
FARO 11	3.33^{c}	20.00^{cd}	30.00^{cd}	40.00^{d}	53.33^{de}	22.22^{c}	40.74^{d}	62.96^{c}	70.36^{e}	70.36^{e}	1800.3^{c}
FARO 35	3.33^{c}	25.00^{bc}	36.67^{bc}	43.33^{cd}	66.67^{bc}	22.22^{c}	48.14^{c}	70.36^{b}	77.77^{c}	77.77^{c}	1430.0^{d}
FARO 36	5.00^{b}	26.67^{bc}	40.00^{bc}	50.00^{b}	76.67^{ab}	25.92^{b}	48.14^{c}	70.36^{b}	77.77^{c}	77.77^{c}	1997.7^{c}
FARO 37	1.67^{d}	13.33^{de}	25.00^{d}	36.67^{d}	58.33^{cd}	11.11^{d}	33.33^{e}	55.55^{d}	77.77^{c}	77.77^{c}	1946.3^{c}
FARO 44	6.67^{b}	31.67^{b}	46.67^{b}	58.33^{ab}	78.33^{ab}	33.33^{a}	55.55^{b}	77.77^{a}	85.18^{b}	85.18^{b}	2133.0^{c}
FARO 46	1.67^{d}	15.00^{de}	21.67^{de}	33.33^{d}	45.00^{e}	11.11^{d}	33.33^{e}	48.14^{e}	70.36^{e}	70.36^{e}	2510.3^{b}
FARO 52	5.00^{b}	21.67^{cd}	41.67^{b}	51.67^{b}	71.67^{b}	25.92^{b}	48.14^{c}	77.77^{a}	85.18^{b}	85.18^{b}	1940.3^{c}
FARO 57	3.33^{c}	33.33^{b}	43.33^{b}	53.33^{bc}	76.67^{ab}	22.22^{c}	55.55^{b}	77.77^{a}	85.18^{b}	85.18^{b}	2010.0^{c}
MOROBEREKAN	0.00^{e}	8.33^{c}	13.33^{e}	23.33^{e}	33.33^{f}	0.00^{e}	33.33^{e}	40.74^{f}	48.14^{f}	48.14^{f}	3244.7^{a}
BOJAKE 189	8.33^{a}	41.67^{a}	56.67^{a}	65.00^{a}	83.33^{a}	33.33^{a}	62.96^{a}	77.77^{a}	92.59^{a}	92.59^{a}	1716.7^{c}
Mean	3.83	23.67	35.50	45.49	64.33	20.74	45.92	65.92	77.03	77.03	2072.9
SE ±	0.79	3.21	4.11	3.97	5.18	3.32	3.32	4.30	3.89	3.89	157.26

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test.
WAS = Weeks after sowing
SE=Standard error of the mean

8 and 10 WAS, the impact of RYMV severity was highly significant (P≤ 0.01) among the treatments. Significantly lowest and highest severity index were recorded on MOROBEREKAN and BOUAKE 189, respectively. Significantly (P≤ 0.01) higher disease severity index values ranging from 48.14 to 92.59 % among the test cultivars in the season was observed at 12 WAS. However, the RYMV severity index values among the test cultivars dropped from 48, 01 to 77.77 % at 14 WAS in the season (Table 4.26).

Results of the paddy yield produced per rice cultivar at Bomo during the 2010 rainy season are presented in Table 4.26. Significantly lowest and highest paddy yield was recorded on MOROBEREKAN and FARO 35, respectively. But the effect of the virus on paddy yield were not significantly different among the cultivars FARO 11, FARO 36, FARO 37, FARO 44, FARO 52, FARO 57 and BOUAKE 189 (Table 4.26).

4.2.10. Effect of RYMV incidence and severity index on paddy yield during the 2008 rainy seasons at Sayen Gobirawa.

In the 2008 rainy season at Sayen Gobirawa, there were significant variations of RYMV incidence throughout the assessment period, although the rate of infection was gradual from 6 to 8 WAS. At 6 WAS, disease incidence of 1.67 % and 3.33 % was recorded on FARO 36, FARO 44 FARO 52 and BOUAKE 189, while no visible symptom of was observed on the cultivars FARO 11, FARO 35, FARO 37, FARO 46, FARO 57 and MOROBEREKAN. At 8 WAS, disease incidence of 5 %, 8.33 % and 10 % were recorded on FARO 35 and FARO 44, FARO 36 and FARO 52, and BOUAKE 189, respectively. No visible symptom was observed on the cultivars FARO 11, FARO 37, FARO 46, FARO 57 and MOROBEREKAN. At 10 WAS, there were high significant (P≤ 0.01) variations in the incidence among the treatments. The highest number of RYMV infected plant was on FARO 44 and BOUAKE 189 while the lowest incidence was recorded on

MOROBEREKAN. At 12 WAS, the highest RYMV incidence was observed on BOUAKE 189, while the lowest was observed on MOROBEREKAN. The number of infected plants recorded on cultivars FARO 11 and FARO 46 were statistically similar. At 14 WAS, there were high significant ($P \leq 0.01$) differences in the level of RYMV incidence among the test cultivars. The highest and lowest incidence of RYMV was recorded on cultivar BOUAKE 189 and MOROBEREKAN, respectively. However, the disease incidence was statistically similar between rice cultivars FARO 37 and FARO 46 (Table 4.27).

Results of the disease severity index in the 2008 rainy season at Sayen Gobirawa are also presented in Table 4.27. Similarly, the disease severity within and across the weeks showed that cultivars differ significantly on their responses to RYMV severity. There were significant variations in disease severity index throughout the assessment period, although the level of disease severity index increased gradually. At 6 WAS only 40 % of the test cultivars had recorded 11.1 % RYMV severity index (FARO 36, FARO 44, FARO 52 and BOUAKE 189). Similarly at 8 WAS disease severity index values of of 22.22 % were recorded on FARO 44, FARO 52 and BOUAKE 189, respectively, while there was no symptoms of RYMV on the remaining test cultivars. At 10 WAS, disease severity index ranged from 22.2 – 48.1 among the cultivars. However, disease severity index was statistically similar between FARO 36, and FARO 44, among FARO 11, FARO 35, FARO 52 and FARO 57, and also among FARO 37, FARO 46 and MOROBEREKAN. The highest severity occurred on BOUAKE 189. At 12 WAS, disease severity varied from 33.3 – 62.9 %. Severity was significantly lower on the rice cultivars MOROBEREKAN and FARO 11. However, there were observable increases in the severity indices of RYMV in all the rice cultivars, except MOROBEREKAN and FARO 11, from 10 – 12 WAS. Disease severity

indices were statistically similar among FARO 35, FARO 37 and FARO 46, also between FARO 36 and FARO 44. At 14 WAS, BOUAKE 189 had significantly higher disease severity index compared to the other cultivars. The lowest severity index was recorded on MOROBEREKAN and FARO 46. Disease severity ranged from 48.1 – 77.7 %. However, statistically similar disease severity index were recorded between FARO 36 and FARO 44, FARO 37 and FARO 57 and among FARO 11, FARO 35 and FARO 52. There was observable increase in the severity index of RYMV in all the rice cultivars, The mean disease severity index showed that MOROBEREKAN had the lowest mean severity index of (25.37 %) followed by FARO 37 (25.9 %). BOUAKE 189 had the highest mean severity index of 53.91 %. Generally, the mean severity index was higher at Bomo than at Sayen Gobirawa. However, the rate of infection was higher at Sayen Gobirawa than at Bomo (Table 4.27).

At Sayen Gobirawa in the 2008 rainy season, the highest paddy yield was obtained in MOROBEREKAN while the lowest was in FARO 36, respectively. The mean paddy yield recorded in FARO 46 and MOROBEREKAN were statistically similar, but differed significantly from the other test cultivars. However, there were no significant differences in paddy yield obtained among the rice cultivars of FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 52, FARO 57 and BOUAKE 189 (Table 4.27).

4.2.11. Effect of RYMV incidence and severity index on paddy yield during the 2009 rainy seasons at Sayen Gobirawa.

In the 2009 rainy season at Sayen Gobirawa, the highest incidence were observed on FARO 44 (25 %), followed by FARO 35 (23.33 %) and BOUAKE 189 (23.33 %) at 6 WAS.

Table 4.27: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2008 rainy season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
Cultivar	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**Kg/ha**
FARO 11	0.00[a]	0.00[c]	10.00[d]	25.00[f]	60.00[f]	0.00[b]	0.00[c]	33.30[c]	55.30[d]	62.90[c]	1732.4[b]
FARO 35	0.00[a]	5.00[b]	11.67[c]	35.00[d]	66.67[d]	0.00[b]	11.20[b]	33.30[c]	40.70[c]	62.90[c]	1446.0[b]
FARO 36	1.67[a]	8.33[a]	20.00[b]	51.67[b]	96.33[b]	11.10[a]	22.20[a]	40.70[b]	55.50[b]	70.30[b]	1428.0[b]
FARO 37	0.00[a]	0.00[c]	8.33[e]	35.00[d]	56.67[g]	0.00[b]	0.00[c]	22.20[d]	40.70[c]	55.50[d]	1644.3[b]
FARO 44	1.67[a]	10.00[a]	35.00[a]	75.00[a]	92.67[c]	11.10[a]	22.20[a]	40.70[b]	55.50[b]	70.30[b]	1484.7[b]
FARO 46	0.00[a]	0.00[c]	8.33[e]	25.00[f]	56.67[g]	0.00[b]	0.00[c]	22.20[d]	40.70[c]	48.10[e]	2371.8[a]
FARO 52	1.67[a]	8.33[a]	11.67[c]	78.33[a]	95.33[b]	11.10[a]	22.20[a]	33.30[c]	48.10[b]	62.90[c]	1482.3[b]
FARO 57	0.00[a]	0.00[c]	11.67[c]	47.00[c]	63.33[e]	0.00[b]	0.00[c]	33.30[c]	48.10[b]	55.50[d]	1479.8[b]
MOROBEREKAN	0.00[a]	0.00[c]	5.00[f]	26.67[e]	50.00[h]	0.00[b]	0.00[c]	22.20[d]	33.30[d]	48.80[e]	2813.4[a]
BOJAKE 189	3.33[a]	10.00[a]	35.00[a]	76.67[a]	99.00[a]	11.10[a]	22.20[a]	48.10[a]	62.90[a]	77.70[a]	1679.0[b]
Mean	0.83	5.00	15.67	47.53	73.67	4.44	10.00	32.93	45.88	61.49	1756.2
SE ±	0.37	1.22	3.44	6.94	6.21	1.81	3.49	2.78	3.13	3.05	147.00

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keul (SNK) test.
WAS = Weeks after sowing
SE=Standard error of the mean

However, there were no visible RYMV symptoms on FARO 46 and MOROBEREKAN. At 8 WAS there were significant ($P \leq 0.05$) incidences of RYMV among the treatments. BOUAKE 189 had the highest disease incidence of 31.67 % while the lowest incidence of 1.70 % was recorded on MOROBEREKAN. However disease incidence among cultivars FARO 35, FARO 36, FARO 44, FARO 52 and FARO 57 did not differ significantly. At 10 WAS , BOUAKE 189 (43.33 %) had significantly higher incidence than the other cultivars, though it did not differ statistically from those of FARO 35, FARO 36, FARO 44, FARO 52 and FARO 57 (Table 4.28). The lowest incidence of RYMV was recorded on MOROBEREKAN, though it was statistically similar to that of FARO 46. At 12 WAS, there was significant ($P \leq 0.05$) difference in the incidence of RYMV among the test plants. BOUAKE 189 and FARO 44 had significantly higher disease incidence than the other cultivars. The lowest incidence was recorded on MOROBEREKAN, though it was statistically similar to FARO 46. At 14 WAS, disease incidence was highly significant ($P \leq 0.01$) among the cultivars. The highest incidence was recorded on BOUAKE 189 and FARO 44, while the lowest was on MOROBEREKAN. However, the disease incidence was insignificant among the rice cultivars FARO 11, FARO 36, FARO 37 and FARO 57 (Table 4.28).

Results of the 2009 rainy season at Sayen Gobirawa showed that cultivars differed significantly in their responses to RYMV severity (Table 4.28). At 6 WAS, disease severity index ranged from 7.40 % to 20.98 % among the test cultivars, but no visible symptom of RYMV was observed on FARO 46 and MOROBEREKAN. At 8 WAS again there were significant differences ($P \leq 0.05$) among the cultivars. Higher severity index value was recorded on FARO 35 but no visible symptom of RYMV was observed on MOROBEREKAN. At 10 WAS, significantly lower severity was recorded on

MOROBEREKAN while the higher severity was observed on FARO 44 though it was statistically similar to the other cultivars. At 12 WAS, severity index significantly varied among the rice cultivars. Lowest and highest RYMV severity index was observed on MOROBEREKAN and FARO 44, respectively. At 14 WAS disease severity index varied from 35.86 % to 70.55 %. Significantly lowest severity index was recorded on MOROBEREKAN while the highest was on BOUAKE 189. However, disease severity index was statistically similar among the other cultivars and BOUAKE 189, with exception of MOROBEREKAN and FARO 46 (Table 4.28).

Results of the 2009 rainy season at Sayen Gobirawa showed that there was significant ($P \leq 0.05$) variation among the test cultivars in the paddy yield harvest. The lowest and highest paddy yield was obtained in FARO 35 and MOROBEREKAN, respectively. However, there were no significant differences in the paddy yield obtained among the rice cultivar of FARO 11, FARO 36, FARO 37, FAR0 44, FARO 52 and BOUAKE 189. Also, the difference in paddy yield obtained between FARO 35 and FARO 57 are not significant (Table 4.28).

4.2.12. Effect of RYMV incidence and severity index on paddy yield during the 2010 rainy seasons at Sayen Gobirawa.

In the 2010 rainy season at Sayen Gobirawa the effect of RYMV incidence among the treatment was significantly different ($P \leq 0.05$) (Table 4.29). At 6 and 8 WAS, a higher disease incidence was observed on FARO 44 and BOUAKE 189, while the lowest was observed on MOROBEREKAN.. However, at 10 WAS the effects of the incidence among the test cultivars was highly significant ($P \leq 0.01$). The highest number of RYMV infected plant was recorded on BOUAKE 189 while the lowest incidence was recorded on MOROBEREKAN. Similarly, at 12 and 14 WAS higher disease incidences were observed on BOUAKE 189, while the lowest was on MOROBEREKAN. There were significant

differences ($P \leq 0.01$) in the disease incidence observed among the other cultivars, except between FARO 11 and FARO 46, FARO 35 and FARO 52, and FARO 36 and FARO 44 at 12 WAS (Table 4. 29).

Results of the 2010 rainy season at Sayen Gobirawa showed that the cultivars differed significantly in their responses to RYMV severity index at 6 WAS (Table 4.29). Significantly higher and lower disease severity index was recorded on BOUAKE 189 and FARO 46, respectively. But there was no sign of RYMV symptoms noticed on the test cultivar of MOROBEREKAN. At 8 WAS significantly lower RYMV severity index was recorded on MOROBEREKAN (3.70 %) while the highest was on BOUAKE 189 (40.74 %). At 10 WAS, severity index significantly varied among the rice cultivars. Lowest and highest RYMV severity index was observed on MOROBEREKAN and BOUAKE 189, significantly ($P \leq 0.01$) higher diseases severity indices ranging from 40.74 % to 85.18 % among the test cultivars in the season was observed at 12 WAS,. However, the RYMV severity index values among the test cultivars reduced to ranges of 33.33 % to 85.18 % at 14 WAS (Table 4.29).

Results of the 2010 rainy season at Sayen Gobirawa also showed that significantly highest paddy yield was obtained in cultivar MOROBEREKAN, while the least was recorded in FARO 44. However, the mean paddy yield recorded in FARO 44 was statistically similarly to those of FARO 11, FARO 35, FARO 36, FARO 37, FARO 52, FARO 57 and BOUAKE 189 (Table 4.29).

Table 4.28: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2009 rainy season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
Cultivar	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14WAS**	**Kg/ha**
FARO 11	3.33^{bc}	11.67^{c}	21.67^{c}	31.67^{cd}	48.33^{b}	7.40^{f}	28.52^{a}	40.13^{ab}	58.00^{a}	64.48^{a}	1904.0^{c}
FARO 35	23.33^{a}	26.70^{ab}	33.33^{ab}	45.00^{ab}	60.00^{a}	13.70^{c}	38.27^{a}	50.67^{a}	60.46^{a}	67.88^{a}	1573.3^{d}
FARO 36	16.70^{a}	23.33^{ab}	33.33^{ab}	43.33^{ab}	56.70^{ab}	11.10^{d}	26.05^{a}	52.42^{a}	60.46^{a}	68.24^{a}	2063.3^{c}
FARO 37	3.33^{bc}	10.00^{c}	25.00^{bc}	36.67^{d}	46.70^{b}	8.64^{e}	28.52^{a}	40.13^{ab}	54.87^{a}	61.20^{a}	1964.0^{c}
FARO 44	25.00^{a}	30.00^{ab}	36.67^{a}	55.00^{a}	63.33^{a}	16..0^{ba}	37.64^{a}	58.01^{a}	62.92^{a}	67.89^{a}	2004.3^{c}
FARO 46	0.00^{c}	5.00^{c}	13.3^{3d}	25.00^{de}	36.70^{c}	0.00^{g}	13.71^{b}	30.86^{b}	40.13^{b}	52.42^{b}	2703.7^{b}
FARO 52	16.67^{a}	28.33^{ab}	38.33^{a}	48.33^{ab}	61.67^{a}	16.04^{b}	35.33^{a}	52.42^{a}	61.99^{a}	68.06^{a}	1953.0^{c}
FARO 57	13.33^{ab}	20.00^{b}	31.70^{ab}	41.67^{bc}	51.70^{ab}	13.70^{c}	33.33^{a}	50.67^{a}	59.54^{a}	67.88^{a}	1996.7^{d}
MOROBEREKAN	0.00^{c}	1.70^{c}	8.33^{d}	16.67^{e}	26.70^{d}	0.00^{g}	0.00^{c}	18.64^{c}	30.86^{c}	35.86^{c}	3500.7^{a}
BOJAKE 189	23.33^{a}	31.6^{a}	43.33^{a}	55.00^{a}	63.33^{a}	20.98^{a}	35.80^{a}	54.87^{a}	61.99^{a}	70.55^{a}	1820.7^{c}
Mean	12.50	18.84	28.50	39.83	51.52	10.78	27.71	44.88	55.12	62.45	2148.7
SE $\pm$	3.17	3.46	3.53	3.96	3.87	2.17	3.85	3.92	3.42	3.38	174.94

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test.
WAS = Weeks after sowing
SE=Standard error of the mean

Table 4.29: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Sayen Gobirawa during 2010 rainy season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
Cultivar	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**Kg/ha**
FARO 11	3.33^{cd}	8.33^{b}	21.67^{f}	35.00^{f}	46.67^{g}	11.11^{e}	25.92^{c}	48.14^{c}	70.36^{c}	55.55^{d}	1668.0^{bc}
FARO 35	5.00^{bc}	6.67^{c}	28.33^{e}	55.00^{d}	63.33^{e}	14.81^{d}	22.22^{d}	55.55^{b}	70.36^{c}	55.55^{d}	1623.3^{bc}
FARO 36	6.67^{ab}	8.33^{b}	33.33^{d}	61.67^{b}	71.67^{b}	22.22^{c}	25.92^{c}	48.14^{c}	77.77^{b}	70.36^{c}	2123.7^{bc}
FARO 37	3.33^{cd}	5.00^{d}	16.67^{g}	40.00^{e}	51.67^{f}	14.81^{d}	18.52^{e}	33.33^{d}	55.55^{d}	55.55^{d}	1960.0^{bc}
FARO 44	6.67^{ab}	10.00^{ab}	41.67^{b}	60.00^{bc}	78.33^{a}	14.81^{d}	33.33^{b}	62.96^{a}	77.77^{b}	77.77^{b}	1383.3^{c}
FARO 46	2.67^{d}	3.33^{e}	15.00^{h}	33.33^{f}	45.00^{h}	3.70^{f}	14.81^{f}	33.33^{d}	55.55^{d}	48.14^{e}	2640.0^{bc}
FARO 52	8.33^{a}	8.33^{b}	28.33^{e}	53.33^{d}	68.33^{d}	18.52^{b}	33.33^{b}	55.55^{b}	77.77^{b}	70.36^{c}	1740.0^{bc}
FARO 57	5.00^{bc}	10.00^{ab}	36.67^{c}	58.33^{c}	70.00^{c}	14.81^{d}	33.33^{b}	48.14^{c}	77.77^{b}	77.77^{b}	1896.2^{bc}
MOROBEREKAN	0.00^{e}	1.67^{f}	6.67^{i}	13.33^{g}	28.33^{i}	0.00^{g}	3.70^{g}	25.92^{e}	40.74^{e}	33.33^{f}	3500.0^{a}
BOJAKE 189	8.33^{a}	11.67^{a}	50.00^{a}	65.00^{a}	78.33^{a}	33.33^{a}	40.74^{a}	62.96^{a}	85.18^{a}	85.18^{a}	1789.7^{bc}
Mean	4.93	7.33	27.83	47.50	60.17	14.81	25.18	47.40	68.88	62.96	2032.7
SE $\pm$	0.84	1.00	4.17	5.22	5.23	2.92	3.44	4.05	4.39	5.06	194.98

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test.
WAS = Weeks after sowing
SE=Standard error of the mean

4.2.13. Effect of RYMV incidence and severity index on paddy yield during the 2008/ 2009 dry season at Nasarawan Buhari.

In the 2008/ 2009 dry season at Nasarawan Buhari, the effect of RYMV incidence among the treatments was significantly different ($P \leq 0.05$). At 6 and 8 WAS, a higher disease incidence was observed on FARO 44 and BOUAKE 189, while the lowest was observed on MOROBEREKAN. But there were no significant differences in the RYMV incidence observed among the other cultivars. At 10 WAS, the highest incidence was observed on FARO 44 while the lowest was recorded on MOROBEREKAN. There was no significant difference in disease incidence recorded among cultivars FARO 11, FARO 35, FARO 36, FARO 37, FARO 52 and FARO 57. At 12 WAS higher disease incidences were observed on FARO 44 and BOUAKE 189, while the lowest was observed on MOROBEREKAN. There were no significant differences ($P \leq 0.05$) in the disease incidence observed among the other cultivars, At 14 WAS disease incidence were highly significant ($P \leq 0.05$) among the rice cultivars. Highest incidence of RYMV was recorded on BOUAKE 189 and FARO 44 while the lowest was recorded on MOROBEREKAN. However, the disease incidence did not differ significantly among the other test cultivars (Table 4.30).

During the 2008/ 2009 dry season at Nasarawan Buhari, the results showed that rice cultivars differed significantly ($P \leq 0.01$) in their responses to RYMV infection. From 6 to 10 WAS, the lowest disease severity index was recorded on MOROBEREKAN and the highest was observed on BOUAKE 189. Thereafter disease severity index did not differ significantly among cultivars. At 12 WAS significantly higher diseases severity index was recorded on FARO 44 while lowest severity index was observed on MOROBEREKAN. Disease severity index was statistically similar among the test cultivars FARO 35, FARO 36, FARO 52, and BOUAKE 189. The mean disease severity index at 14 WAS showed that

BOUAKE 189 had higher mean severity index of 70.55 % followed by FARO 36 with 68.24 % and the lowest 35.86 % was obtained on MOROBEREKAN (Table 4.30).

During the 2008/2009 dry season at Nasarawan Buhari, among the rice cultivars significantly higher paddy yield was recorded on MOROBEREKAN. Similarly, the lowest paddy yield was obtained in FARO 11, though it was not significantly different from those of FARO 35, FARO 36, FARO 37, FARO 44, FARO 52, FARO 57 and BOUAKE 189 (Table 4.30).

4.2.14. Effect of RYMV incidence and severity index on paddy yield during the 2009/ 2010 dry season at Nasarawan Buhari.

In 2009/2010 dry season at Nasarawan Buhari, incidence among the test cultivar was significantly different ($P \leq 0.05$) (Table 4.31). At 6 WAS, thirty percent of the test cultivars had recorded more than 50 % disease incidence. The highest incidence (53.33 %) was observed on BOUAKE 189 and FARO 44, while the lowest was on MOROBEREKAN (31.67 %). Similarly, from 8 to 14 WAS there were highly significant ($P \leq 0.01$) variation among the test cultivars, the number of infected plant ranges from 40 % to 91.67 %, 41.67 % to 98.33 %, 45 % to 98.33 % and 48.33 % to 98.67 % at 8, 10, 12 and 14 WAS, respectively (Table 4.31).

During the 2009/ 2010 dry season at Nasarawan Buhari the effect of RYMV severity index was significant ($P \leq 0.05$). At 6 WAS, significantly higher and lower severity index was recorded on FAR0 52 and MOROBEREKAN, respectively (Table 4.31). Similarly, at 8 WAS the effect of RYMV severity index at $P \leq 0.05$ among the rice cultivars FARO 44, FARO 52 FARO 57 and BOUAKE 189 was statistically insignificant. In the same week, lowest and the highest disease severity index was computed on rice cultivars

MOROBEREKAN (26.40 %) and BOUAKE 189 (58.83 %), respectively. At 10 WAS, significantly lower and higher disease severity indices were recorded on rice cultivar MOROBEREKAN and BOUAKE 189, respectively. While differences in severity indices among the rice cultivars FARO 44, FARO 52 and BOUAKE 189 were not statistically significant ($P \leq 0.05$). At 12 WAS, significantly higher intensity of the virus infections was observed on all the test cultivars compared to the other weeks. Similarly, the effect of RYMV severity index was significant ($P \leq 0.05$) among the test cultivars at 12 WAS (Table 4.31). However, there were no significant differences in disease severity indices at $P \leq 0.05$ among the rice cultivars FAR0 35, FARO 36, FARO 52 and FARO 57. At 14 WAS, the intensity of disease severity indices reduced among the test cultivars in the season, significantly higher and lower RYMV severity index was observed on cultivars FARO 44 (75.30 %) and MOROBEREKAN (32.27 %). However, there were no significant differences in disease severity index at $P \leq 0.05$ among the rice cultivars FARO 11, FARO 36 and FARO 52, and similarly, between FARO 35 and FARO 57 (Table 4.31).

At Nasarawan Buhari during the 2009/ 2010 dry season, rice cultivar of MOROBEREKAN had significantly higher paddy yield than the other test cultivars, while FARO 11 recorded the lowest paddy yield. However, no significant differences recorded on paddy yield among the rice cultivars of FARO 11, FARO 35, FARO 36, FARO 37, FARO 44, FARO 52 and FARO 57 (Table 4.31).

Table 4.30: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Nasarawan Buhari during 2008/ 2009 dry season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yield
Cultivar	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**Kg/ha**
FARO 11	10.00^{d}	23.33^{bc}	38.33^{b}	46.67^{b}	51.67^{bc}	11.00^{b}	11.11^{c}	40.13^{ab}	58.00^{a}	64.48^{a}	1218.0^{c}
FARO 35	15.00^{c}	25.00^{bc}	38.33^{b}	48.33^{b}	53.33^{bc}	11.11^{b}	18.52^{bc}	50.67^{a}	60.46^{a}	67.88^{a}	1246.7^{c}
FARO 36	23.33^{ab}	28.33^{bc}	36.67^{b}	46.67^{b}	51.67^{bc}	11.11^{b}	16.04^{bc}	52.42^{a}	60.46^{a}	68.24^{a}	1470.3^{bc}
FARO 37	20.00^{b}	33.33^{b}	45.00^{b}	51.67^{b}	58.33^{b}	22.22^{a}	25.92^{a}	40.13^{ab}	54.87^{a}	61.20^{a}	1253.3^{c}
FARO 44	25.67^{a}	51.67^{a}	63.33^{a}	66.67^{a}	71.67^{a}	11.11^{b}	40.74^{a}	58.01^{a}	62.92^{a}	67.89^{a}	1616.7^{bc}
FARO 46	8.33^{d}	16.67^{c}	23.33^{c}	26.67^{c}	33.33^{d}	11.00^{b}	11.11^{c}	30.86^{b}	40.13^{b}	52.42^{b}	1933.3^{b}
FARO 52	20.00^{b}	31.67^{b}	45.00^{b}	53.33^{b}	51.67^{bc}	11.11^{b}	18.52^{b}	52.42^{a}	61.99^{a}	67.06^{a}	1403.3^{bc}
FARO 57	15.00^{c}	33.33^{b}	43.33^{b}	55.00^{b}	51.67^{bc}	11.11^{b}	13.71^{c}	50.67^{a}	59.54^{a}	67.88^{a}	1550.0^{bc}
MOROBEREKAN	0.00^{e}	3.33^{d}	5.00^{d}	8.33^{d}	11.67^{e}	0.00^{c}	11.11^{c}	18.64^{c}	30.86^{c}	35.86^{c}	2303.3^{a}
BOUAKE 189	25.67^{a}	53.33^{a}	60.0^{0a}	68.33^{e}	75.00^{a}	22.20^{a}	35.80^{ab}	54.87^{a}	61.99^{a}	70.55^{a}	1616.1^{bc}
Mean	16.30	29.50	39.83	47.17	51.01	12.19	20.26	44.88	55.12	62.45	1561.2
SE $\pm$	2.64	4.76	5.30	5.65	5.70	1.99	3.35	3.92	3.42	3.38	107.50

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test.
WAS = Weeks after Sowing
SE=Standard error of the mean

Table 4.31: Effect of Rice yellow mottle virus incidence and severity index on paddy yield at Nasarawan Buhari during 2009/20010 dry season

	RYMV incidence (%)					RYMV severity index (%)					Paddy yiel
Cultivar	**6WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14WAS**	**6 WAS**	**8 WAS**	**10 WAS**	**12 WAS**	**14 WAS**	**Kg/ha**
FARO 11	48.33^{a-d}	75.00^{ab}	85.00^{bc}	90.00^{a}	96.67a	35.13^{c}	45.28^{c}	58.62^{c}	72.84^{c}	63.6^{3d}	1216.0^{d}
FARO 35	51.67^{ab}	83.33^{ab}	90.33^{ab}	95.00^{a}	98.33a	47.54^{a}	55.28^{b}	63.56^{d}	75.28^{b}	65.43^{c}	1259.7^{cd}
FARO 36	50.00^{abc}	86.67^{a}	88.33^{b}	93.33^{a}	98.33^{a}	41.88^{b}	53.98^{b}	62.02^{d}	75.28^{b}	63.83c	1446.3^{cd}
FARO 37	43.33^{d}	68.33^{bc}	78.67^{c}	86.67^{a}	95.00^{a}	35.13f	47.08^{c}	51.95^{f}	67.87^{d}	58.69^{e}	1266.7^{cd}
FARO 44	53.33^{a}	88.33^{a}	96.67^{a}	98.33$_{a}$	98.33^{a}	42.54^{b}	58.82^{a}	69.43^{b}	80.18^{a}	75.30^{a}	1410.0^{cd}
FARO 46	45.00^{cd}	58.33^{c}	61.67^{d}	65.00^{b}	70.00^{b}	23.58^{d}	37.02^{d}	43.48^{g}	46.34^{e}	45.67^{f}	1870.0^{b}
FARO 52	50.00^{abc}	83.33^{ab}	91.67^{ab}	95.00^{a}	96.67^{a}	44.28^{a}	58.82^{a}	69.43^{b}	75.30^{b}	63.63^{d}	1353.3^{cd}
FARO 57	46.67^{bcd}	80.00^{ab}	92.00^{ab}	96.00^{a}	96.67^{a}	32.66^{c}	57.08^{a}	66.96^{c}	75.30^{b}	65.43^{c}	1433.3^{cd}
MOROBEREKAN	31.67^{e}	40.00^{d}	41.67^{e}	45.00^{c}	48.33^{c}	16.04^{e}	26.40^{e}	30.40^{h}	40.18^{f}	32.27^{g}	2300.0^{a}
BOUAKE 189	53.33^{a}	91.67^{a}	98.33^{a}	98.33^{a}	98.33^{a}	48.00^{a}	58.82^{a}	72.84^{a}	80.18^{a}	70.36^{b}	1593.3^{c}
Mean	47.33	75.49	82.43	86.27	89.66	36.88	49.86	58.88	68.59	60.40	1514.9
SE $\pm$	2.04	5.06	5.62	5.54	5.35	3.38	3.47	4.23	4.39	3.96	106.10

Column mean under the same week after sowing followed by the same letter(s) are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test.
WAS = Weeks after sowing
SE=Standard error of the mean

4.2.15. Transmission Test of some Insect Found in and around the Experimental Fields

Results of the transmission tests with some insects found in the experimental field are presented in Table 4.32. Among the 14 insect species tested, ten species viz: *Zonocerus variegatus* (Plate IV), *Oxya* sp. (Plate V), *Dactylispa* sp. (Plate VI), *Chaetocnema* sp. (Plate VII), *Chnootriba similis* (Plate VIII), *Conocephalus* sp. (Plate IX), *Cheilomenes* sp.(Plate XI), *Nezara viridula* (Plate XII), *Locris rubra* (Plate XIII) and *Paratettix* sp. transmitted RYMV from diseased BOUAKE 189 to healthy BOUAKE 189 seedlings. While the remaining four insect's species of *Diopsis* sp., *Mylabris* sp., *Clavigralla* sp. and *Altica* sp. did not transmit the virus. A low level of transmission was obtained with the Bomo isolate (virus) compared to the Sayen Gobirawa isolate by the same species of insects used (Table 4.32).

The insect transmission rate was significantly different (P = 0.05) among the different insect species tested with the Bomo and Sayen Gobirawa isolates, respectively. The highest percentage RYMV disease incidence (100 %) was caused by *C. similis*, *Chaetocnema* sp. and *Conocephalus* sp. with Sayen Gobirawa isolate. While in the case of Bomo isolate, the highest percentage of RYMV infected plants (77.78 %) was caused by *Conocephalus* sp. Similarly, there were no significant differences in the transmission rate of Sayen Gobirawa isolate by Oxya sp., *Cheilomenes* sp*., Zonocerus variegatus, Paratettix* sp. and *N. viridula*. Moreso, there were no significant differences among *L. rubra, C. similis*, and *Chaetocnema* sp. and also among *Cheilomenes sp., Paratettix* sp., *Oxya* sp. and *Dactylispa* sp. in the transmission rate of Bomo isolate (Table 4.32).

Table 4.32: **Transmission test of RYMV by some rice insects found in the experimental fields at Bomo (B) and Sayen Gobirawa (S.G)**

Scientific Name	Common Name	Number of Insect per plant	Source of RYMV Isolate	Number of infected plants/ number of plants tested	Rate of transmission (%)
Locris rubra	Spittle bugs	1	B	6/9	66.67[d]
		1	S.G.	8/9	88.90[b]
Chnootriba similis	Ladybird	1	B	6/9	66.67[d]
	beetle	1	S,G.	9/9	100.00[a]
*Cheilomenes sp.***	----------	1	B	3/9	33.33[f]
		1	S.G	6/9	66.67[d]
*Zonocerus variegatus***	Variegated	1	B.	5/9	55.56[e]
		1	S.G.	6/9	66.67[d]
*Parattetix sp***	Pygmy	1	B	3/9	33.33[f]
	grasshopper	1	S.G.	6/9	66.67[d]
Conocephalus sp	Long-horned	1	B	7/9	77.78[c]
	grasshopper	1	S.G	9/9	100.00[a]
Chaetocnema **sp.**	Flea beetle	1	B	6/9	66.67[d]
		1	S.G.	9/9	100.00[a]
*Oxya s*p.	Short-horned	1	B	3/9	33.33[f]
	grasshopper	1 .	S.G	6/9	66.67[d]
Mylabris sp.	Blister beetle	1	B	0/9	0.00[g]
		1	S.G	0/9	0.00[g]
Nezara viridula *	Shield bug	1	B	5/9	55.56[e]
		1	S.G	6/9	66.67[d]
Dactylispa sp.	--------	1	B	3/9	33.33[f]
*Diopsis s*p.	Stalked –eyed	1	B	0/9	0.00[g]
.	Flies	1	S.G.	0/9	0.00[g]
Altica sp.		1	B	0/9	0.00[g]
		1	S.G	0/9	0.00[g]
*Clavigralla s*p.	Spiny brown	1	B	0/9	0.00[g]
	bug	1	S.G	0/9	0.00[g]
Mean					46.09
SE ±					6.83

Colunm mean followed by the same letter are not significantly different at P = 0.05 according to Student Newsman Keuls (SNK) test. * = reported for the first time in Africa

B = Bomo. SG = Sayen Gobirawa ** = reported for the first time in Nigeria

Insect vectors of Rice yellow mottle virus (RYMV)



Plate IV: Zonocerus variegatus L.



Plate V: Oxya sp.



Plate VI: *Dactylispa* sp.



Plate VII: *Chaetocnema sp.*



Plate VIII: ***Chnootriba similis Thunberg***



Plate IX: ***Conocephalus*** **sp.**



Plate X: ***Trichispa sericea Guerin***



Plate XI: ***Cheilomenes sp.***

Insect vectors of Rice yellow mottle virus (RYMV)



Plate XII: *Nezara viridula.* L



Plate XIII: Locris rubra Fabricus

4.2.16. Correlation Coefficient for the field Experiments in the 2008, 2009 and 2010 wet and 2008/2009 and 2009/2010 dry seasons.

At Bomo in 2008 rainy season under field conditions, there was significant positive correlation between the following factors: disease incidence and severity index (0.7405), and *Chaetocnema* sp. (0.6529); disease severity index and *Chaetocnema* sp. (0.8742), and *C. similis* (0.8111*; T. sericea and C. similis* (0.7130), and mean temperature (0.6521); *L. rubra* and mean temperature (0.6739), Paddy yield and mean rainfall (0.6573) (Table 4.33). However, there were significant negative correlations between the following factors: paddy yield and mean temperature (- 0.7587), disease incidence (- 0.6680), severity index (-0.6508), *Chaetocnema* sp. (-0.7168), and L. *rubra* (-0.7587); mean rainfall and paddy yield (- 0.6631), Oxya sp. (-0.6593), and *L. rubra* (-0.6631); mean temperature and mean rainfall (-0.6840), and age of plant (- 0.8210). All other associations were not significant (Table 4.33).

At Bomo in the 2009 rainy season there were significant positive correlations between the following factors: disease incidence and disease severity index (0.8034), *L. rubra* (0.6619), and paddy yield (0.7823); disease severity index and *L. rubra* (0.8504), and mean temperature (0.7355); *L. rubra* and paddy yield (0.7680); age of plant and mean temperature (0.6412), mean rainfall (0.8079); paddy yield and rainfall (0.6658); mean temperature and rainfall (0.6528); sunshine hours and relative humidity (0.7505), and mean temperature (0.6528) (Table 4.34). Similarly, there were significantly negative correlations between the following factors: disease incidence and mean temperature (-0.6541); paddy yield and disease severity index (-0.9455), and mean temperature (-0.8474); *Cheilomenes* sp. and *Conocephalus* sp. (-0.6608), and mean temperature (-0.6418). All other associations were not significant (Table 4.34).

Table 4.33: Correlation coefficient for the field experiment at Bomo in 2008 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
V1	1.00												
V2	-0.1426	1.00											
V3	0.2736	0.4612	1.00										
V4	0.1655	-0.0022	0.3619	1.00									
V5	-0.4793	0.7130*	0.4543	0.0424	1.00								
V6	0.3673	0.1098	0.6529*	0.4110	0.0908	1.00							
V7	0.1625	0.8111**	0.8742**	0.3909	0.2836	0.7405*	1.00						
V8	-0.7587**	-0.1260	-0.7168*	-0.0870	0.1649	-0.6680*	-0.6508*	1.00					
V9	0.6739*	0.1600	0.1638	-0.3640	-0.4420	-0.0560	0.1987	-0.7587**	1.00				
V10	-0.2952	0.1355	-.0.1840	0.1037	0.2995	0.0384	0.0595	0.2348	-0.0970	1.00			
V11	-0.6631*	0.2854	-0.1954	-0.6593*	0.6521*	-0.3750	-0.3086	0.5573	-0.6840*	0.1067	1.00		
V12	-0.3465	-0.0700	0.0206	-0.0630	-0.1710	0.2416	0.1971	-0.0020	-0.0991	-0.0164	-0.3556	1.00	
V13	-0.4570	0.0015	-0.0019	0.2912	0.4267	0.2957	0.0626	-0.4831	-0.8210**	-0.0420	0.3100	0.2830	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Chaetocnema sp*.
V4 = *Oxya* sp.
V5 = *Trichispa secerea*
V6 = Disease incidence
V7 = Disease severity index
V8 = Paddy yield
V9 = Mean temperature
V10 = Mean relative humidity
V 11 = Mean rainfall
V12 = Sunshine hours
V13 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Table 4.34: Correlation coefficient for the field experiment at Bomo in 2009 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15
V1	1.00														
V2	0.1070	1.00													
V3	0.1820	-0.2209	1.00												
V4	0.3671	0.4163	-0.6608*	1.00											
V5	0.3723	0.1790	0.2110	0.3273	1.00										
V6	0.3111	0.5153	-0.1278	0.4903	0.5560	1.00									
V7	0.6619*	0.1652	-0.0641	0.1414	0.1464	0.0861	1.00								
V8	0.8504**	-0.0345	0.3735	0.0682	0.4686	0.0988	0.8034**	1.00							
V9	0.7680**	0.2161	0.4970	-0.1751	0.2952	0.0034	0.7823**	0.9455**	1.00						
V10	-0.5641	0.0181	-0.6418*	0.4384	-0.1224	0.1709	-0.6541*	-0.7355*	-0.8474**	1.00					
V11	0.1592	-0.0817	0.0472	0.1599	0.2391	0.4546	-0.1468	-0.0356	-0.0712	0.0701	1.00				
V12	-0.3743	-0.3017	-0.1017	0.0654	-0.0424	-0.1683	-0.4259	-0.2649	-0.3112	0.6528*	0.1295	1.00			
V13	0.0993	-0.2102	-0.1009	0.0103	0.2050	-0.0835	-0.1064	-0.0428	-0.0794	0.6658*	0.7505*	-0.0449	1.00		
V14	-0.5198	-0.3488	-0.1503	-0.1405	-0.2294	-0.0070	-0.5503	-0.5091	-0.4529	0.6412*	0.3410	0.8079**	0.0848	1.00	

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Cheilomenes sp.*
V4 = *Conocephalus sp*
V5 = *Oxya* sp.
V6 = *Zonocerus variegatus*
V7 = Disease incidence
V8 = Disease severity
V9 = Paddy yield
V10 = Mean temperature
V 11 = Mean relative humidity
V 12 = Mean rainfall
V 13 = Sunshine hours
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

At Bomo in the 2010 rainy season there were significant positive correlations between the following factors: disease incidence and severity index (0.9157), sunshine hours (0.6605), and *Conocephalus* sp.(0.6554); *L. rubra* and *Cheilomenes sp.(*0.7741*); ,Oxya sp.and Conocephalus* sp. (0.7570); mean rainfall and paddy yield (0.6818) and, severity index (0.6859); sunshine hours and mean temperature (0.7837) (Table 4.35). Similarly, there were significantly negative correlations between the following factors: disease incidence and paddy yield (-0.7011), and mean rainfall (- 0.7437); *Oxya sp* and age of plant (-0.6388); paddy yield and sunshine hours (- 0.6889); mean rainfall and disease severity index (- 0.6959), mean temperature (-0.7534), and sunshine hours (-0.7485). All other associations were not significant (Table 4.35).

Combined analysis of the three rainy seasons at Bomo under field conditions showed significantly positive correlations between the following factors: RYMV incidence and severity index (0.9912), and number of grain per panicle (0.9361); disease severity index and 1,000 grain weight (0.6957); plant height and paddy yield (0.9235); number of tillers per plant and number of days to 50% flowering (0.9034), threshing percentage (0.9772), and 1,000 grain weight (0.7875); number of days to 50% flowering and threshing percentage (0.7917), and 1,000 grain weight (0.9757); number of grains per panicle and paddy yield (0.7475); 1,000 grain weight and threshing percentage (0.6388) (Appendix CLXXII). Similarly, there were significant negative correlations between the following factors: plant height and number of tillers per plant (-0.9129), number of days to 50% flowering (-0.9478), threshing percentage (-0.9452), and 1,000 grain weight (-0.8550),; number of tillers per plant and paddy yield (-0.8716); number of days to 50% flowering and number of grains per panicle (-0.6999), and paddy yield (-0.9076); number of grains per panicle and 1,000 grain weight (-0.8393), and RYMV severity index (-0.9744); paddy yield and RYMV severity

index(-0.6792), threshing percentage (-0.7477), and 1,000 grain weight (-0.9085). All other relationships were not significant (Appendix CLXXII).

At Sayen Gobirawa in 2008, there were significant positive correlations between the following factors: disease incidence and disease severity index (0.8400), *Chaetocnema* sp. (0.7100), and *L. rubra* (0.6450); disease severity index and *Chaetocnema* sp. (0.6700), C. *similis* (0.6551), and *L. rubra* (0.6490); mean temperature and *L. rubra* (0.8040), and age of plant (0.6649) (Table 4.36). Similarly, there were significant negative correlations between the following factors: mean relative humidity and *C. similis* (-0.6570), and mean temperature (-0.7005); mean rainfall and *Conocephalus* sp (- 0.6510), All other associations were not significant (Table 4.36).

At Sayen Gobirawa in 2009 wet season, there were significant correlations between the following factors: disease incidence and severity index (0.6839), *L. rubra* (0.6726), and *T. sericea* (0.7894); severity index and *T. sericea* (0.6776); *L. rubra* and paddy yield (0.7931),

Table 4.35: Correlation coefficient for the field experiment at Bomo in 2010 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
V1	1.00													
V2	0.2917	1.00												
V3	0.7741**	0.1716	1.00											
V4	0.5233	0.4705	0.3563	1.00										
V5	0.3544	0.2926	0.1425	0.7570**	1.00									
V6	0.3387	0.4966	-02544	0.3116	0.1928	1.00								
V7	0.3912	0.0592	0.1266	0.6554*	0.3907	0.1104	1.00							
V8	0.3177	-0.2054	0.1457	0.4251	0.2792	-0.0956	0.9157**	1.00						
V9	0.3659	0.3587	0.2258	-0.0717	0.1608	0.4708	-0.7011*	-0.7984**	1.00					
V10	0.4410	0.1587	0.1124	0.0941	-0.2968	-0.0207	0.5246	0.3771	-0.5662	1.00				
V11	- 0.0917	-0.0937	-0.1637	-0.0468	0.3003	0.3884	0.3127	0.3368	0.0019	0.0459	`1.00			
V12	-0.2354	-0.0714	-0.1808	-0.1908	0.2018	-0.1184	-0.7437**	0.6859*	0.6818*	-0.7534*	-0.2834	1.00		
V13	0.3646	-0.2745	0.2073	0.1934	-0.1339	-0.1054	0.6605*	0.5667	-0.6889*	0.7837**	0.0243	-0.7485*	1.00	
V14	-0.0121	0.1918	-0.2217	-0.4928	-0.6388*	-0.2696	-0.3556	-0.3474	0.0202	0.4291	0.2588	-0.0555	0.0812	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Cheilomenes sp*.
V4 = *Conocephalus sp*
V5 = *Oxya* sp.
V6 = *Zonocerus variegatus*
V7 = Disease incidence
V8 = Disease severity
V9 = Paddy yield
V10 = Mean temperature
V 11 = Mean relative humidity
V 12 = Mean rainfall
V 13 = Sunshine hours
V14= Age of plant (weeks)
* * = *Significant* at $P \leq 0.01$
* = Significant at $P \leq 0.05$

Table 4.36: Correlation coefficient for the field experiment at Sayen Gobirawa in 2008 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
V1	1.00												
V2	0.4033	1.00											
V3	0.3930	0.1280	1.00										
V4	0.1420	-0.2240	-0.1900	1.00									
V5	-0.1900	-0.2110	-0.4300	-0.3260	1.00								
V6	0.6450*	0.2352	0.7100*	-0.2650	0.1179	1.00							
V7	0.6490*	0.6551*	0.6700*	-0.0991	-0.4340	0.8400**	1.00						
V8	-0.0700	-0.4090	0.3900	-0.1700	0.0631	0.1400	-0.4103	1.00					
V9	0.8040**	0.1675	0.2800	0.1342	-0.1221	0.5800	0.4816	-0.0320	1.00				
V10	-0.2600	-0.6570*	0.3200	-0.2110	-0.1330	0.0601	-0.2660	0.4934	-0.7005*	1.00			
V11	-0.1110	-0.2360	-0.0800	-0.6510*	0.5100	0.1801	-0.4559	0.4877	-0.1051	0.1067	1.00		
V12	0.2780	-0.2460	-0.0801	0.2620	0.1,000	0.2301	0.0501	0.0293	0.5968	0.0164	-0.3560	1.00	
V13	0.5770	-0.1130	0.3901	0.0920	0.1201	0.2101	-0.0281	0.5112	0.6649*	-0.0420	0.3100	0.2830	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Chaetocnema* sp.
V4 = Conocephalus sp
V5 = *Oxya* sp.
V6 = Disease incidence
V7 = Disease severity index
V8 = Paddy yield
V9 = Mean temperature
V 10 = Mean relative humidity
V 11 = Mean rainfall
V 12 = Sunshine hours
V13 = Age of plant (weeks)
* * = Significant at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Chaetocnema sp. and age of plant (in weeks) (0.8010); mean relative humidity and sunshine hours (0.8079) (Table 4.37). Also there were significantly negative correlations between the following factors at Sayen Gobirawa in 2009 wet season: paddy yield and RYMV incidence (-0.8530), and RYMV severity index (-0.8660); RYMV incidence and mean temperature (-0.6617); RYMV severity index *and L. rubra* (-0.7414). All other associations were not significant (Table 4.37).

At Sayen Gobirawa in 2010 wet season, there were significant correlations between the following factors: disease incidence and severity (0.9664), sunshine hours (0.6643), paddy yield (0.7541), and *L. rubra* (0.9430); disease severity index and sunshine hours (0.6618); paddy yield and mean rainfall (0.7290); *L. rubra* and *C. similis* (0.7066), and *Oxya* sp. (0.8510); *C. similis* and *Chaetocnema* sp. (0.6767), *Conocephalus* sp. (0.8885), *Oxya* sp. (0.9004), and *Z. variegatus* (0.6507); *Oxya* sp. and *Z. variegatus* (0.6407), and *Conocephalus* sp. (0.8115); temperature and sunshine hours (0.7874) (Table 4.38). Similarly, there were significant negative correlations between the following factors: disease severity index and paddy yield (-0.7683), and sunshine hours (-0.6940); *Chaetocnema* sp. and Z. *variegatus* (-0.6538); sunshine hours and rainfall (- 0.6723). All other associations were not significant (Table 4.38).

Similarly, at Sayen Gobirawa when data of the three rainy seasons under field conditions were combined, significant positive correlations were obtained between the following factors: RYMV severity index and disease incidence (0.8521), threshing percentage (0.6551), and number of tillers per plant (0.7001); threshing percentage and 1,000 grain weight (0.9138); number of tillers per plant and paddy yield (0.6519). (Appendix CLXXIII). Furthermore, there were significant negative correlations between the following factors RYMV disease incidence and plant height (-0.6416)), number of grain per panicle (-0.6518), and number of days to 50% flowering (-0.8356); RYMV severity index and number of grains per panicle (-0.7396), and

number of days to 50% flowering (-0.6973); 1,000 grain weight and paddy yield (-0.7122), and number of grains per panicle (-0.8505); threshing percentage and number of grains per panicle (-0.9865). All other associations were not significant (Appendix CLXXIII).

At Nasarawan Buhari during the 2008/ 2009 dry season, the following factors were found to be significantly positive correlated to each other: RYMV incidence and severity index (0.6680), RYMV severity index and *Z. variegatus* (0.7650), *C. similis* and relative humidity (0.6724) *Conocephalus* sp. and Oxya sp. (0.6430), mean temperature and sunshine hours (0.8490), age of plant (in weeks) and paddy yield (0.6910), and relative humidity (0.7120) (Table 4.39).

The following factors were found to be correlated negatively to each other at Nasarawan Buhari in 2008/ 2009 dry season: paddy yield and RYMV incidence (-0.6504), RYMV severity index (-0.8200), *Z. variegatus* (-0.6500), and mean temperature (-0.7301); age of plant (in week) and *Conocephalus* sp (- 0.6480), mean temperature (-0.9401), and sunshine hours (- 0.7500). All other associations were not significant (Table 4.39).

At Nasarawan Buhari, in 2009/ 2010 dry season, there were significant positive correlations between the following factors: disease incidence and severity index (0.6622), *Z. variegatus* (0.6608), C. *similis (*0.6616), and *Oxya* sp (0.6540); L. *rubra and Conocephalus* sp. (0.7301); *Oxya* sp and *C. similis (*0.7233), and Z. *variegatus* (0.7006); mean rainfall and relative humidity (0.6523) (Table 4.40). Similarly, there were significant negative correlations between the following factors: Age of plant (in weeks) and *C. similis* (-0.8756), and Oxya sp (-0. 6644); paddy yield and disease incidence (-0.7250), and disease severity index (- 0.9494). All other associations were not significant (Table 4.40).

Table 4.37: Correlation coefficient for the field experiment at Sayen Gobirawa in 2009 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
V1	1.00													
V2	0.1483	1.00												
V3	0.0622	0.1170	1.00											
V4	-0.3074	-0.4959	-0.1037	1.00										
V5	0.3289	-0.0832	0.4550	-0.3483	1.00									
V6	0.5089	-0.2553	0.4534	0.1524	0.4844	1.00								
V7	0.7931*	0.3809	-0.0825	0.0007	0.3309	0.5958	1.00							
V8	0.6726*	-0.0060	0.1074	0.0123	0.5320	0.7894*	0.8530**	1.00						
V9	-0.7414*	-0.1850	0.4723	-0.0621	-0.0578	0.6776	-.0.8660**	0.6839*	1.00					
V10	0.3027	-0.0240	0.4627	-0.0238	0.3175	0.2370	-0.0367	-0.6617*	0.0718	1.00				
V11	-0.2423	-0.3541	0.5061	-0.2952	0.4248	0.2664	-0.3570	-0.1292	0.4846	0.1295	1.00			
V12	0.1003	-0.0618	0.0869	0.3475	0.2090	-0.0221	-0.2026	0.1277	0.0887	0.2615	-0.0449	1.00		
V13	-0.1476	-0.0751	0.3581	-0.5363	0.2425	-0.1176	-0.5476	-0.4726	0.5453	0.3410	0.8079**	0.0840	1.00	
V14	0.0329	-0.3215	0.8010**	0.1324	0.3561	0.5431	-0.1570	0.1869	0.4352	0.3921	0.3891	0.2318	0.2299	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Chaetocnema* sp.
V4 = *Conocephalus* sp
V5 = *Oxya* sp.
V6 = *Trichispa sericea*
V7 = Paddy yield
V8 = Disease incidence
V9 = Disease severity index
V10 = Mean temperature
V 11 = Mean relative humidity
V 12 = Mean rainfall
V 13 = Sunshine hours
V14 Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Table 4.38: Correlation coefficient for the field experiment at Sayen Gobirawa in 2010 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14
V1	1.00													
V2	0.7066*	1.00												
V3	0.3755	0.6767*	1.00											
V4	0.5691	0.8885**	0.4523	1.00										
V5	0.8510**	0.9004**	0.6107	0.8115**	1.00									
V6	0.4542	0.6507*	-0.6538*	0.4750	0.6517*	1.00								
V7	0.2560	0.2024	-0.0507	0.3693	0.3221	-0.0205	1.00							
V8	0.9430**	0.2163	0.5886	-0.0159	0.1491	0.3386	0.7541**	1.00						
V9	0.1151	0.3487	0.6048	0.1466	0.2423	0.4090	-0.7683**	0.9664**	1.00					
V10	-0.1371	-0.2003	0.2544	-0.5427	-0.1589	0.1050	-0.4434	0.4701	0.4582	1.00				
V11	0.0559	0.2246	0.5644	0.1635	0.1016	0.6183	0.2742	0.3378	0.3357	0.0459	`1.00			
V12	0.3010	0.4921	0.2845	0.5227	0.5139	0.2825	0.7290*	-0.2747	-0.3694	0.5082	0.0131	1.00		
V13	-0.1719	-0.2895	0.1349	-0.5378	-0.3306	0.0328	-0.6940*	0.6643*	0.6618*	0.7874**	0.0243	-0.6723*	1.00	
V14	-0.3657	-0.3208	-0.0740	-0.4835	-0.2982	-0.4418	-0.1049	-0.0954	0.1081	0.6069	-0.1793	-0.3640	0.1516	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = *Chaetocnema* sp.
V4 = *Conocephalus* sp
V5 = *Oxya* sp.
V6 = *Zonocerus variegatus*
V7 = Paddy yield
V8 = Disease incidence
V9 = Disease severity
V10 = Mean temperature
V 11 = Mean relative humidity
V 12 = Mean rainfall
V 13 = Sunshine hours
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Table 4.39: Correlation coefficient for the field experiment at Nasarawan Buhari in 2008/2009 dry season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
V1	1.00												
V2	-0.1567	1.00											
V3	-0.1175	-0.0900	1.00										
V4	-0.5620	-0.0200	-0.0800	1.00									
V5	-0.4812	-0.2600	0.1360	0.6430*	1.00								
V6	-0.5459	0.5730	-0.0200	0.3830	0.0660	1.00							
V7	-0.2562	0.3070	0.3690	0.1810	0.5230	0.2850	1.00						
V8	-0.5187	0.4570	0.2820	-0.2540	0.2510	0.7650*	0.6680*	1.00					
V9	0.5325	-0.0900	-0.0010	-0.2301	-0.1600	-0.6500*	-0.6504*	-0.8200**	1.00				
V10	-0.1449	-0.2701	0.1580	0.2510	-0.2300	0.1730	-0.1,000	0.4320	-0.7301*	1.00			
V11	0.1251	0.6724*	0.3010	0.4100	0.4190	-0.0400	0.2850	-0.1201	0.4610	-0.6901*	1.00		
V12	-0.2258	-0.1600	0.3451	-0.2701	-0.0201	0.0740	0.3210	0.5201	-0.5701	0.8490**	-0.5100	1.00	
V13	-0.0526	0.1960	-0.0901	0.6480*	0.4550	-0.1200	0.2020	-0.2901	0.6910*	-0.9401**	0.7120*	-0.7500*	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = Cheilomenes sp.
V4 = Conocephalus *sp*
V5 = *Oxya* sp.
V6 = Zonocerus *variegatus*
V7 = Disease incidence
V8 = Disease severity
V9 = Paddy yield
V10 = Mean temperature
V 11 = Mean relative humidity
V 12 = Sunshine hours
V13 = Age of plant (weeks)
* * = Significant at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Table 4.40: Correlation coefficient for the field experiment at Nasarawan Buhari in 2009/2010 rainy seasons

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13
V1	1.00												
V2	0.3724	1.00											
V3	0.6105	-0.0800	1.00										
V4	0.7301*	0.4575	0.4649	1.00									
V5	0.4028	0.7233*	0.3501	0.4649	1.00								
V6	.0.4028	0.4056	0.5126	0.5425	0.7006*	1.00							
V7	0.1793	0.6616*	0.2375	0.5377	0.6540*	0.6608*	1.00						
V8	0.3736	0.0948	0.4232	0.2375	0.2503	0.2706	0.6622*	1.00					
V9	0.4165	0.3215	0.3825	0.4232	0.3991	0.2997	-0.7260*	-0.9494**	1.00				
V10	-0.1487	-0.1477	-0.1417	0.3825	-0.0952	-0.1168	0.0305	-0.2670	-0.2987	1.00			
V11	0.1567	0.2871	0.1423	-0.1417	0.1863	-0.2119	0.1289	0.4130	0.4805	0.2631	1.00		
V12	0.4326	-0.0835	0.2009	0.2003	-0.0543	-0.5224	-0.0968	0.3695	0.4123	-0.3456	0.6523*	1.00	
V13	-0..1696	-0.8756**	0.2163	0.2153	-0.6644*	-0.3081	-0.4257	0.1852	0.0225	0..0858	-0.1604	0.1599	1.00

V1 = *Locris rubra*
V2 = *Chnootriba similis*
V3 = Conocephalus sp.
V4 = *Oxya* sp.
V5 = Zonocerus *variegatus*
V6 = Disease incidence
V7 = Disease severity
V8 = Paddy yield
V 9 = Mean temperature
V 10 = Mean relative humidity
V 11 = Mean rainfall
V 12 = Sunshine hours
V13= Age of plant (weeks)
* * = *Significant* at $P \leq 0.01$
* = Significant at $P \leq 0.05$

At Nasarawan Buhari when data of the two dry seasons under field conditions were combined. There were significant positive correlations between the following factors: disease severity index and number of grains per panicle (0.6533); number of days to 50 % flowering and RYMV incidence (0.7556), threshing percentage (0.6893), and 1,000 grain weight (0.6884); number of grains per panicle and number of tillers per plant (0.7064); threshing percentage and 1,000 grain weight (0.7024) (Appendix CLXXIV). Similarly, there were significant negative correlations between the following factors: RYMV incidence and plant height (-0.8263), threshing percentage (-0.7524), and 1,000 grain weight (-0.7798); plant height and number of days to 50 % flowering (-0.8393), threshing percentage (-0.8137), and 1,000 grain weight (-0.9133). All other correlations were not significant (Appendix CLXXIV).

4.3 THE WEED HOSTS OF RYMV ACROSS THE SURVEYED STATES

Some of the weed species collected across the hotspot and epidemic areas in northern Nigeria tested positive to RYMV infection in ELISA tests (Table 4.41). The virus was detected in *Imperata cylindrica* L., *Digitaria horizontalis* Wild. *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers. on farmer's fields in Kaduna, Kano, Niger and Zamfara states, *Dactyloctenium aegyptium* (L.) P. Beauv. in Kaduna, Kano and Niger states, *Eragrostis tenella* (L.) Roener & Schultes in Kaduna and Kano states, *Eragrostis cillaris* L. in Kaduna, Kano and Zamfara states, *Eleusine indica* Gaertner *in* Gombe, Kaduna, Kano and Niger states, *Eleusine corocana* L. in Kaduna state, *Panicum* sp. in Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states, *Brachiaria lata* (Shumach) C.E. Hubbard ex Robyns in Gombe, Kano and Niger states, *Axonopus compressus* (Sw) P. Beauv. in Kano state, *Cyperus difformis* L. in Gombe, Kano and Zamfara states, *Oryza longistaminata* A. Chev.& Roehr. in Borno, Gombe, Kano and Zamfara states, *Oryza barthii* A. Chev. in Gombe state and *Pennisetum pedicellatum* Trim. in Gombe and Kano states.(Table 4.41)

Table 4.41: Results of Double Antibody Sandwich Enzyme- Linked Immuno-Sorbent Assay (DAS-ELISA) test showing reaction profiles of the weed hosts of Rice yellow mottle virus in northern Nigeria

	State of collection	Ecology	ELISA rating
Dactylactenium aegyptium L.[a]	KN, KD and NG	Upland and Lowland	*
Imperata cylindrica L.	KD, KN, NG and ZF	Upland and lowland	**
Eragrostis tenella L.[a]	KD and KN	Upland	*
Eragrostis cillaris L.[a]	KD KN and ZF	Upland	*
Digitaria horizontalis- Wild. [a]	KD, KN, NG and ZF	Upland and lowland	*
Eleusine indica (L.) - Gaertner	GB, KD, KN, and NG	lowland	*
Eleusine corocana L.[c]	KD	Upland	**
Panicum sp	GB, KD, KN, NG, SK and ZF	Upland and lowland	**
Brachiaria lata - (Schum.) C.E. Hubb.[b]	GB, KN, and NG	Upland	*
Axonopus compressus- (Sw) P. Beauv [b]	KN	Lowland	*
Cyperus rotundus L.	KD, KN, NG and ZF	Upland and lowland	**
Cyperus difformis L.[a]	GM, KN and ZF	Upland and lowland	*
Cynodon dactylon (L) Pers.	KD, KN NG and ZF	Upland	*
Oryza. longistaminata, A. Chev.&Roehr.	BO , GM, KN and ZF	Upland and lowland	**
Oryza. Barthii A. Chev	GM,	lowland	**
Pennisetum pedicellatum Trim.[c]	GM and KN	Upland and lowland	**

BO=Borno, GM= Gombe, KD= Kaduna, KN= Kano, NG= Niger, SO = Sokoto & ZF = Zamfara

* = positive detection of RYMV infection, **= Strong positive detection of RYMV infection

[a] = First report in Nigeria [b] = First report in West Africa [c] = First report in Africa

Table 4.42: Number of isolates of Rice yellow mottle virus collected from rice (*Oryza sativa* L.) in seven Northern states of Nigeria

Locality	Number of isolates	Ecosystem	Global system Position		State	Ecological zone
			Latitude	Longitude		
Konnduga	8	Lowland	11° 38′N	7° 24′E	Borno	Sudan savanna
Mandurari	4	Lowland	11° 38′N	13° 23′E		
Malari	4	Upland	11° 43′N	13° 19′E		
Dadinkowa	10	Lowland	10° 16′N	11° 29′E	Gombe	Sudan savanna
Hinna	13	Lowland	10° 19′N	11° 31′E		
Bomo	5	Upland	11° 07′N	7° 41′E	Kaduna	Northern guinea
Kurmi Bomo	3	Upland	11° 07′N	7° 41′E		savanna
Sayen Gobirawa	5	Upland	11° 06′N	7° 44′E		
Nasarawan Buhari	4	Lowland	11° 07′N	7° 39′E		
Shika	2	Upland	11° 07′E	7° 42′E		
Giwa	3	Upland	11° 12′E	7° 37′E		
Anguwan Sogiji	4	Upland	11° 08′N	7° 34′E		
Zabi	2	Upland	11° 07′N	7° 43′E		
Hayen Sambo	3	Upland	11° 34′N	7° 20′E		
Wusasa	2	Upland	11° 65′N	7° 18′E		
Zango shanu	2	Upland	11° 07′N	7° 42′E		
Kura	5	Upland	11° 46′N	8° 25′E	Kano	Sudan savanna
Chiromawa	5	Upland	11° 38′N	8° 24′E		
Kadawa	4	Upland	11° 38′N	8° 25′E		
Dakastalle	4	Upland	11° 28′N	8° 22′E		
Kwanan Yari	3	Upland	11° 31′N	8° 45′E		
Rano	4	Upland	11° 33′N	8° 33′E		
Wushishi	5	Upland	9° 44′N	6° 08′E	Niger	Sourthern guinea
Badeggi	9	Lowland	9° 03′N	6° 08′E		savanna
Goronyo	9	Upland	13° 26′N	5° 39′E	Sokoto	Sudan savanna
Sokoto	9	Lowland	13° 03′N	5° 14′E		
Talata Mafara	9	Lowland	12° 34′N	6° 07′E	Zamfara	Sudan savanna
Rini	5	Lowland	12° 35′N	6° 05′E		
Birnin Tudu	4	Lowland	12° 36′N	6° 02′E		

4.4. SEROLOGICAL PROFILE OF RICE YELLOW MOTTLE VIRUS ISOLATES

Six serological profiles (Sep) were apparent using four discriminate monoclonal antibodies (MAbs) panel (AS 0478/11, AS O478/12, AS0478/21 and AS 0478/22) raised against Nigerian isolates of RYMV obtained from plant virus collection centre, DSMZ (German collections of Microorganism and cell cultures) Braunschweig, Germany. Table (4.43) shows the reactivity of 135 different RYMV isolates after tests with MAbs in TAS-ELISA. The first profile included some isolates collected from Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states. They showed positive reaction with all the MAbs and were designated as serotype Sep A .The second serological profile included isolates collected from Borno, Gombe, and Kaduna and Kano states. They showed positive reactions with all MAbs except MAb1 and were designated as serotype Sep B. The third serological profile was isolate collected from Gombe state, which showed positive reaction with all the MAbs except MAbs 4 and was designated as serotype Sep C. The fourth serological profiles included some isolates collected from Borno, Sokoto and Zamfara states. They showed positive reaction with MAbs 3 and MAbs 4 and had negative reaction with MAbs 1 and MAbs 2, and were designated as serotype Sep D. The fifth serological profiles were some isolates collected from Borno, and Zamfara states, which had a positive reaction with only MAbs3 and were designated as serotype Sep E. The sixth serological profiles included some isolates collected from Kano, Niger and Sokoto states which had positive reaction with only MAbs 4 and were designated as serotype Sep F (Figure 6, Table 4.43).

Several variants of the serological profiles were distinguished by their unusual reactions with the four MAbs. In serotype Sep A twenty isolates from Kano, Kaduna and Gombe states showed a strong positive reaction with all the MAbs. Sixty five isolates from Gombe, Kano, Kaduna, Niger, Sokoto and Zamfara states showed mild to weak positive reactions

Table 4.43: Serological profile of RYMV isolates detected with monoclonal antibodies in Triple antibody sandwich enzyme linked immunosorbent assay (TAS ELISA)

S/no	State	Site of collection	Number of isolates	Monoclonal antibodies			
				M1	M2	M3	M4
1	Borno	Konduga 1	4	-	+	+	++
2		Konduga 2	4	-	-	+	-
3		Madurari	3	-	-	+	+
4		Malari	2	-	-	+	++
5	Gombe	Dadinkowa1	5	+++	+++	+++	+++
6		Dadinkowa 2	5	++	++	++	-
7		Hinna 1	5	++	+++	+++	+
8		Hinna 2	4	-	++	++	+
9		Hinna 3	4	+++	+++	+++	+
10	Kaduna	Bomo	5	-	+	+	++
11		Kurmi Bomo	3	+++	+++	+++	+++
12		Sayen Gobirawa	5	+	++	++	++
13		Nasarawan Buhari	4	+	+	++	+
14		Shika	2	++	++	++	++
15		Giwa	2	-	+	+	+
16		Anguwan Sogiji	4	+++	+++	+++	+++
17		Zabi	2	+	+	+	+
18		Hayen Sambo	3	+	+	++	+
19		Wusasa	2	+	+	++	+
20		Zango Shanu	2	-	+	+	+
21	Kano	Kura	5	+++	+++	+++	+++
22		Chiromawa	4	++	++	+++	+++
23		Kadawa	5	+	+	++	+++
24		Dakastalle	4	-	-	-	+
25		Kwanan Yari	4	-	+	+	+
26		Rano	3	+++	+++	+++	+++
27	Niger	Wushishi	4	-	-	-	+
28		Badeggi	5	+	+	++	+++
29	Sokoto	Goronyo 1	5	++	++	+++	+++
30		Goronyo 2	4	-	-	+	+
31		Sokoto	4	-	-	-	+
32	Zamfara	Talata Mafara 1	5	-	-	+	+
33		Talata Mafara 2	4	-	-	++	-
34		Rini	5	+	++	++	+++
35		Birnin Tudu	4	-	-	+	+

Strong positive reaction = +++
Positive reaction = ++
Weak positive reaction = +
Negative reaction = - -

M1= Monoclonal antibody AS-0478/11
M2 = Monoclonal antibody AS-0478/12
M3= Monoclonal antibody AS-0478/21
M4= Monoclonal antibody AS-0478/22

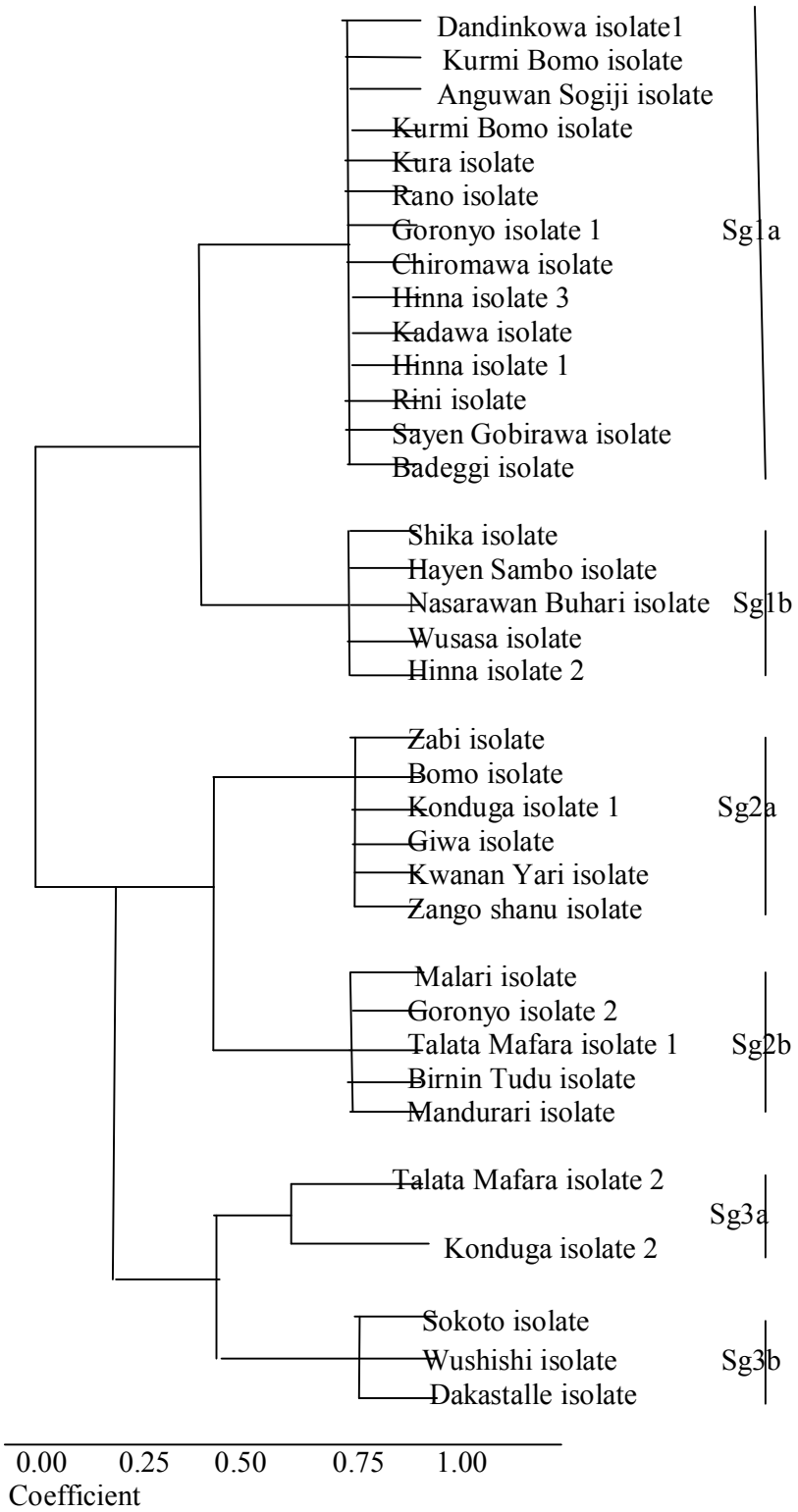


Figure 5: Hierrachical relationship dedrogram of RYMV isolates of seven state in northern Nigeria derived fromm 35 serological profiles data using 4 monoclonal antibodies in TAS-ELISA.

with all the MAbs. In serotype Sep B nine isolates from Borno and Gombe states showed mild reaction with MAbs 4 and weak reaction with MAbs 2 and MAbs 3. Similarly eight isolates from Kaduna and Kano states showed weak reaction with MAbs 2, MAbs 3 and MAbs 4 (Table 4.43).

4.4.1. Hierarchical Cluster Dendrogram analysis of RYMV serological profile

There were considerable diverse serological relationships obtained among 35 representatives RYMV isolates serological profiles from seven states in northern Nigeria (Figure 5). The rescaled distance cluster combine, using average linkage between groups by hierarchical cluster dendrogram analysis, giving rise to 0.25 to 1.00 coefficient similarity ranges. At 0.25 coefficient similarity levels, all the isolates were separated into three major serogroups (SG1, SG2 and SG3). While at 0.75 coefficient similarity levels SG1, SG2 and SG3 were further separated into two subgroups (Sg1a and Sg1b), (Sg2a and Sg2b) and (Sg3a and Sg3b), respectively.Similarly, based on the rescaled distances among the isolates linkage analysed at 1.00 coefficient similarity levels, Some isolates were serolologically identical at subgroups Sg1a (14), Sg1b(5), Sg2a (5), Sg2b(6), Sg3a (5) and Sg3b(5) respectively (Figure 5).

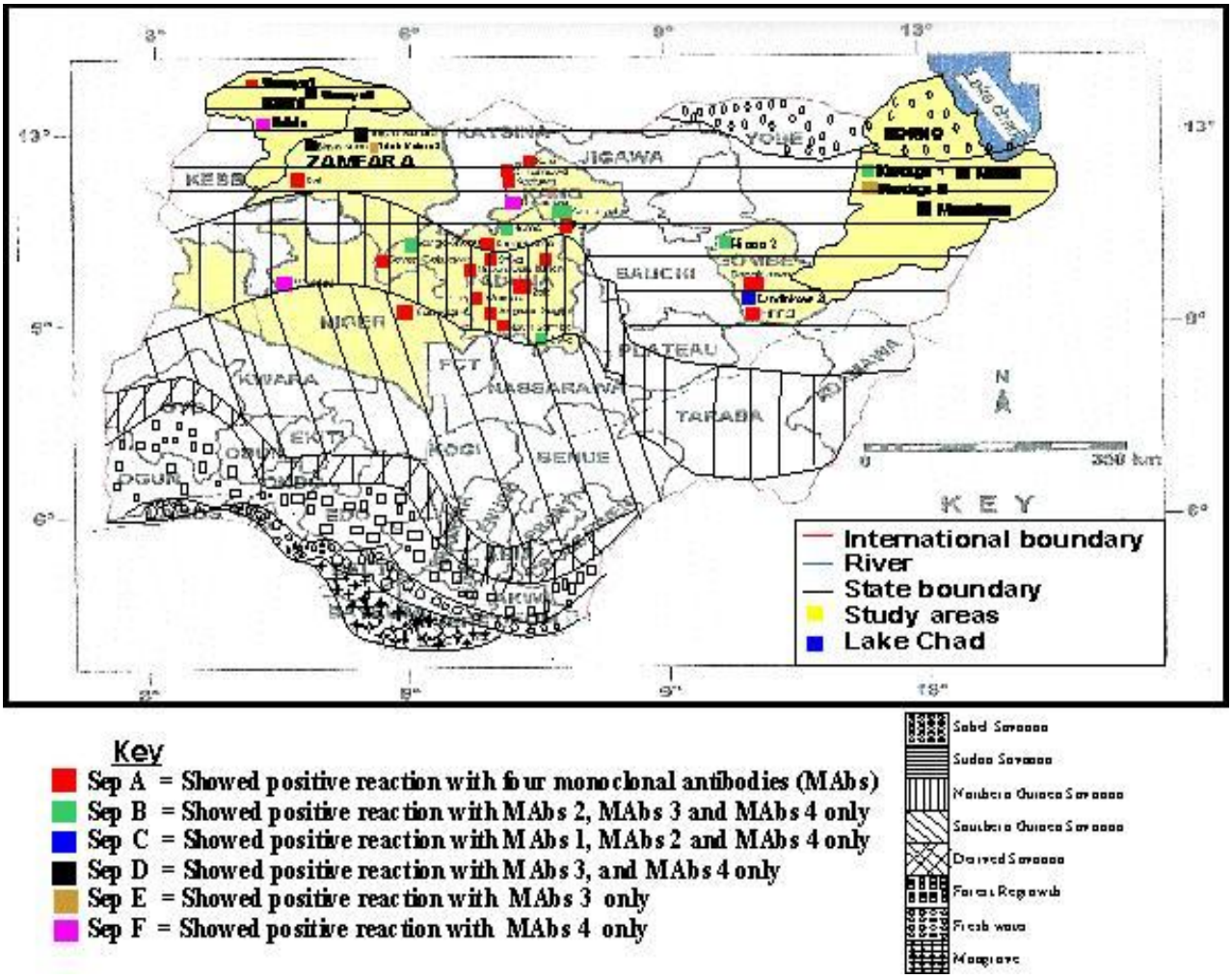


Figure 6: Map showing location and distribution of serological profiles of Rice yellow mottle virus (RYMV) isolates collected

4.5. MOLECULAR CHARACTERIZATION AND DISTRIBUTION OF RYMV ISOLATES

More than two RYMVstrains were apparent after using two pairs of strain-specific and non-specific (random) hexamer primers. The first strain included all isolates that were successfully amplified by the first pair of primers (A1 B1) targeting preferentially strain S1 isolate, there were collected from Konduga (Borno state), Dadinkowa and Hinna (Gombe state), Bomo, Sayen Gobirawa, Nasarawan Buhari, Shika, Anguwan Sogiji, Hayen Sanbo and Wusasa (Kaduna state), Kadawa, Kura, Chiromawa and Rano (Kano state), Wushishi (Niger state), Goronyo (Sokoto state) and Talata Marafa and Rini (Zamfara state). They were designated as S1 (Figure 7, Table 4.44, Plates XIV, XVI and XVIII). The second strain included all isolates that were successfully amplified by the second pair of the primers (A2 B2) targeting preferentially strain S2, there were collected from Dadinkowa and Hinna (Gombe state), Zabi (Kaduna state) and Badeggi (Niger state). They were designated as S2 (Figure 7, Table 4.44 and Plate XV). The third strain included all isolates that showed negative reaction with the above mentioned RYMV strain-specific primers, but were successfully amplified by the non-specific hexamer (random) primers, there were collected from Mandurari and Malari (Borno state), Hinna (Gombe state), Kurmi Bomo, Giwa and Zango Shanu (Kaduna state), Dakastale and Kwanan Yari (Kano state), Sokoto (Sokoto state) and Birnin Tudu (Zamfara state) and were designated as SX (other strain) (Figure 7, Table 4.44 and Plate XVII).

Table 4.44: Polymerase chain reaction of some Rice yellow mottle virus isolates to two specific pair of primers designed to amplify Strain S1 and S2 and non specific hexamer (random) primer

RYMV isolate	Ecosystem	S1 Strain	S2 Strain	SX Strain	Ecological zone
Konnduga 1	Lowland	+	-	NA	Sudan savanna
Konnduga 2	Lowland	+	-	NA	-do-
Mandurari	Lowland	-	-	+	-do-
Malari	Upland	-	-	+	-do-
Dadinkowa 1	Lowland	+	-	NA	-do-
Dadinkowa 2	Lowland	-	+	NA	-do-
Hinna 1	Lowland	+	-	NA	-do-
Hinna 2	Lowland	-	+	NA	-do-
Hinna 3	Lowland	-	-	+	-do-
Bomo	Upland	+	-	NA	Northern guinea
Kurmi Bomo	Upland	-	-	+	savanna
Sayen Gobirawa	Upland	+	-	NA	-do-
Nasarawan Buhari	Lowland	+	-	NA	-do-
Shika	Upland	+	-	NA	-do-
Giwa	Upland	-	-	+	-do-
Anguwan Sogiji	Upland	+	-	NA	-do-
Zabi	Upland	-	+	NA	-do-
Hayen Sambo	Lowland	+	-	NA	-do-
Wusasa	Upland	+	-	NA	-do-
Zango shanu	Upland	-	-	+	-do-
Kura	Upland	+	-	NA	Sudan savanna
Chiromawa	Upland	+	-	NA	-do-
Kadawa	Upland	+	-	NA	-do-
Dakastalle	Upland	-	-	+	-do-
Kwanan Yari	Upland	-	-	+	-do-
Rano	Upland	+	-	NA	-do-
Wushishi	Upland	+	-	NA	Sourthern guinea
Badeggi	Lowland	-	+	NA	savanna
Goronyo 1	Upland	+	-	NA	Sudan savanna
Goronyo 2	Upland	+	-	NA	-do-
Sokoto	Lowland	-	-	+	-do-
Talata Mafara 1	Lowland	+	-	NA	-do-
Talata Mafara 2	Lowland	+	-	NA	-do-
Rini	Lowland	+	-	NA	-do-
Birnin Tudu	Lowland	-	-	+	-do -

+ = Positive reactions
- = Negative reactions
NA = Not applicable

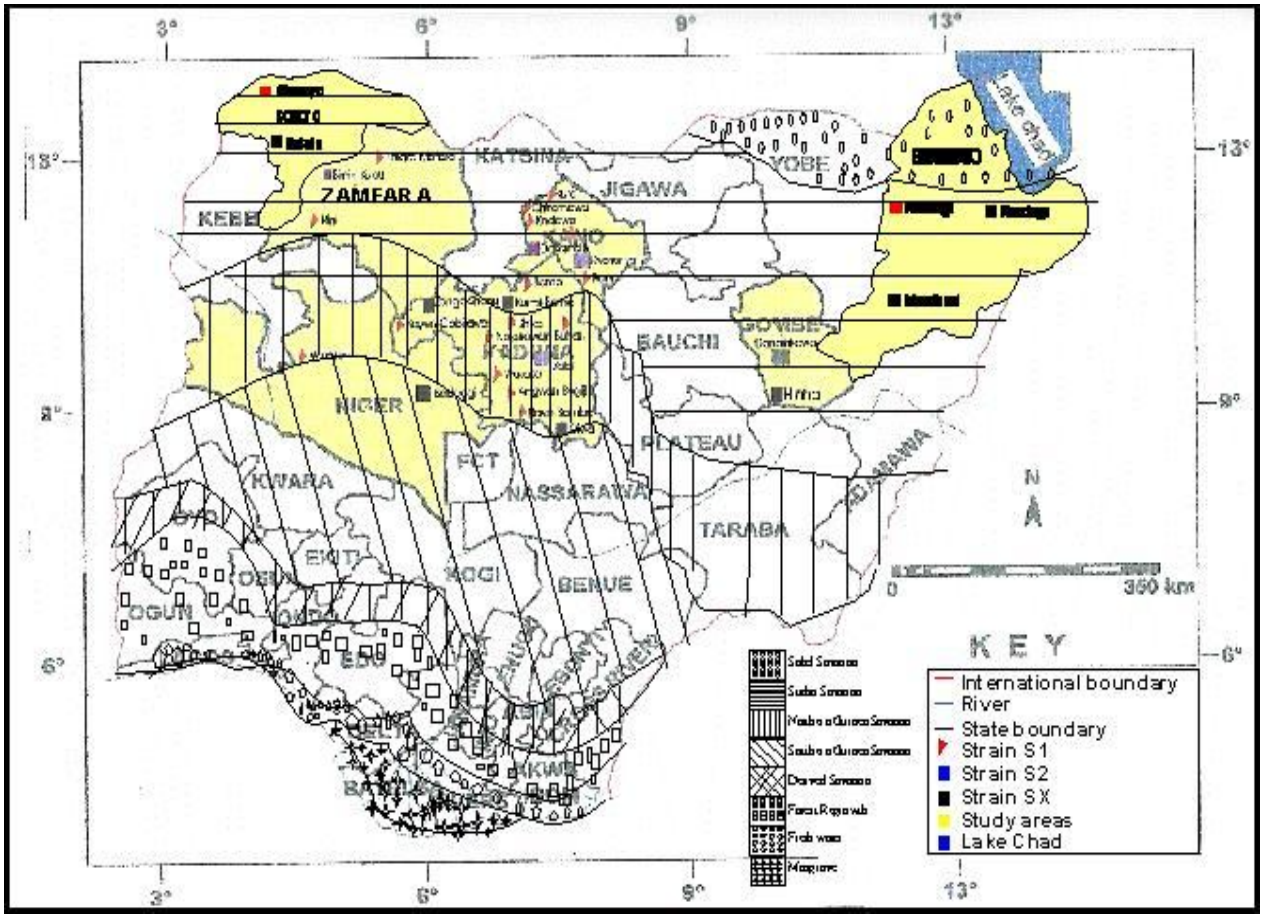


Figure 7: Map showing locations and distributions of RYMVstrains collected

4.5.1. Percentage Distribution of RYMV strains across the surveyed State

The distribution of strains S1, S2 and SX was 60 %, 11.43 % and 28.57 %, respectively in Northern Nigeria. The frequency of occurrence of strain S1 was 40 %, 17 %, 14 % and 2.86 % in Sudan, Northern Guinea and Southern Guinea Savannas, respectively. While strain S2 was 2.86 % in Northern and Southern Guinea Savanna. Similarly, 8.57 % and 20 % isolate of strain SX was recorded in Northern Guinea and Sudan Savannas, respectively (Table 4.45).

Assessment of the distribution of RYMV strains revealed that strain S1 occurs predominantly in lowland in Borno, Gombe and Zamfara states, and also in Kaduna, Kano, Niger and Sokoto states in upland ecosystem. By constrast, strain S2 was recorded more in lowland in Gombe and Niger states, with the exception of an isolate which was recorded in upland in Kaduna state. Strain SX was recorded in lowland in Borno, Gombe, Sokoto and Zamfara states, and also found in upland ecosystems in Borno, Kaduna and Kano (Table 4.45).

The distributon of RYMV strains across the seven states in Northern Nigeria showed that strain S1 was 2.86 %, 8.57 %, 11.43 % and 19.99 % in Niger, Zamfara, Kano and Kaduna states, respectively, while 5.72 % each in Borno, Gombe and Sokoto states. Strain S2 was 2.86 % and 5.72 % in Kaduna, Niger and Gombe states, respectively. Strain SX has 5.72 % and 8.57 % in Borno, Kano and Kaduna states, respectively, and 2.86 % each in Gombe, Sokoto and Zamfara states. Among the seven states only Gombe and Kaduna states had strains S1, S2 and SX, while the remaining five states had two strains each (Table 4.45).

Table 4.45: Percentage distribution of RYNV strain across the surveyed states

State	Ecosystem	Ecological zone	Percentage frequencies (%)		
			S1 Strain	S2 Strain	SX Strain
Borno	Lowland	Sudan savanna	5.72	-	2.86
	Upland		-	-	2.86
Gombe	Lowland	Sudan savanna	5.72	5.71	2.86
Kaduna	Lowland	Northern guinea savanna	5.72	-	-
	Upland		14.28	2.86	8.57
Kano	Upland	Sudan savanna	11.40	-	5.70
Niger	Lowland	Sourthern guinea savanna	-	2.86	-
	Upland		2.86	-	-
Sokoto	Lowland	Sudan savanna	-	-	2.86
	Upland		5.72	-	-
Zamfara	Lowland	Sudan savanna	8.58	-	2.86
Total			60.00	11.43	28.57

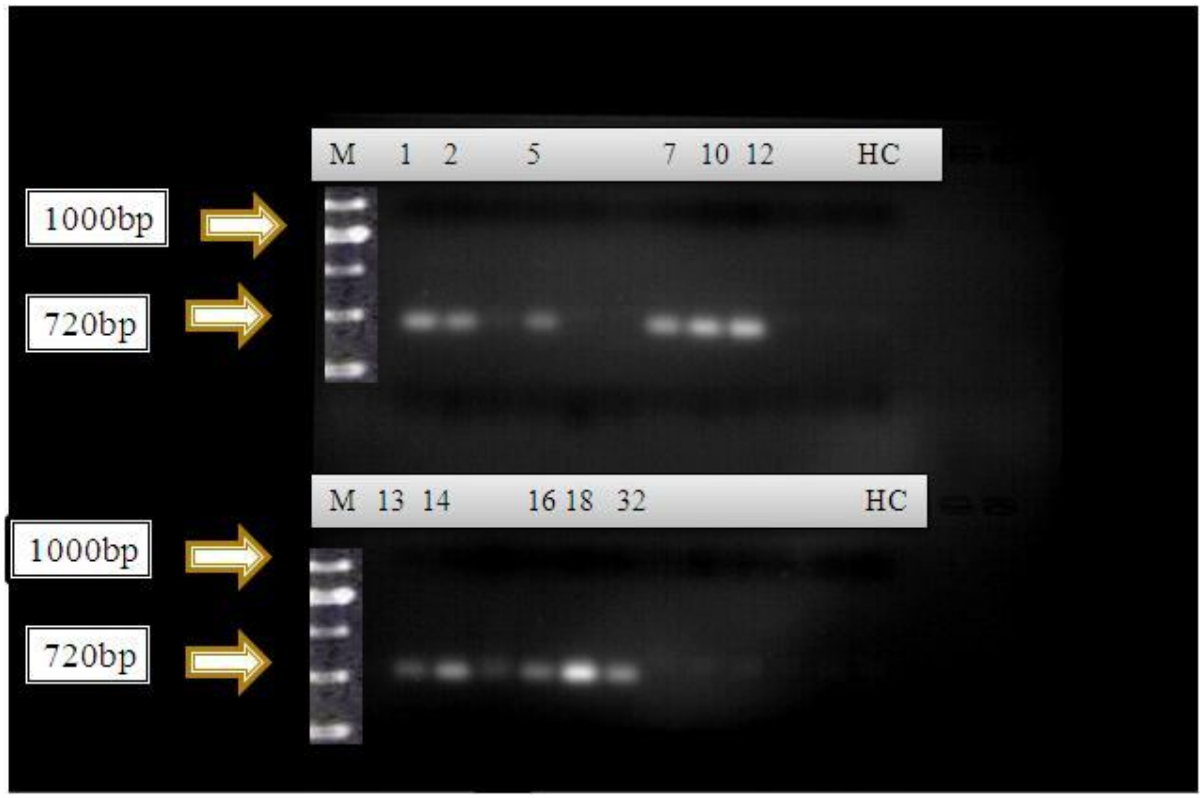


Plate XIV: RYMV detection by PCR using S1 strain specific primer pairs

1. = Konduga isolate 1 2 = Konduga isolate 2 5 = Dandinkowa isolate 1
7 = Hinna isolate 1 10 = Bomo isolate 12 = Sayen Gobirawa isolate
13= Nasarawan Buhari isolate 14= Shika isolate 16 = Anguwan Sogiji isolate
18 = Hayen Sambo isolate 32 = Talata Mafara isolate 1 HC = Healthly control



Plate XV: RYMV detection by PCR using S2 strain specific primer pairs

M = DNA ladder (1Kb) 6 = Dadinkowa isolate 2 8 = Hinna isolate 2
17 =Zabi isolate 28 = Badeggi isolate HC = Healthy Control

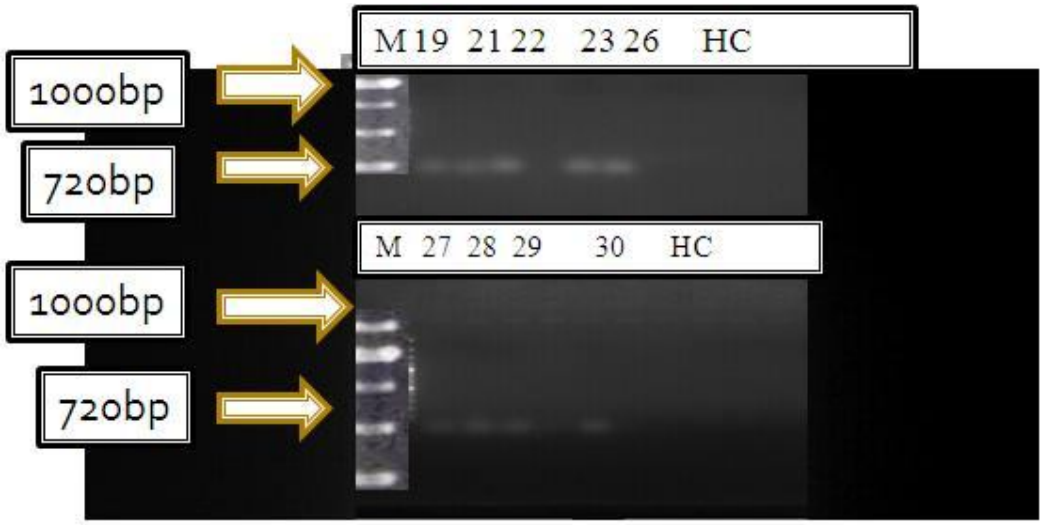


Plate XVI: RYMV detection by PCR using S1 strain specific primer pairs

M = DNA ladder (1Kb) 19 = Wusasa isolate 21 = Kura isolate
22 = Chiromowa isolate 23 = Kadawa isolate 26 = Rano isolate
27 = Wushishi isolate 29 = Goronyo isolate 1 30 = Goronyo isolate2
HC = Healthy control

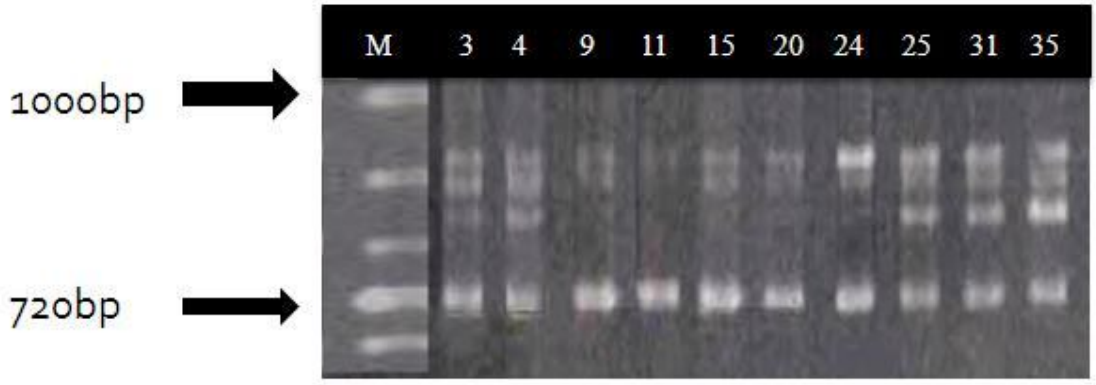


Plate XVII: RYMV detection by PCR using random hexamer primer

3= Madurari isolate
4= Malari isolate
9 = Hinna isolate 3
11= Kurmi Bomo isolate
15= Giwa isolate
20= Zango Shanu isolate
24= Dakastalle isolate
25= Kwanan Yari isolate
31 = Sokoto isolate
35 =Birnin Tudu isolate
M = DNA ladder (1Kb)

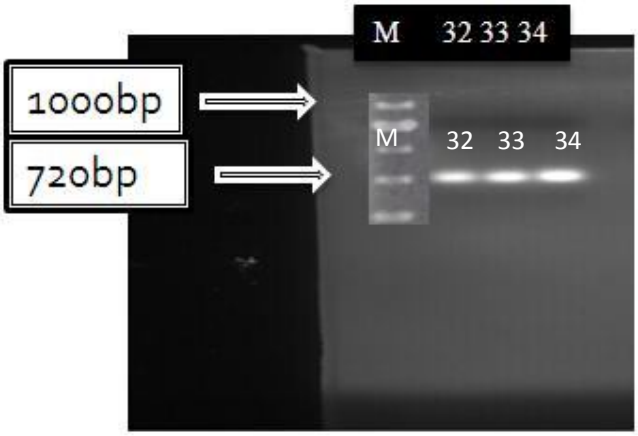


Plate XVIII RYMV detection by using S1 strain specific primer pairs
M DNA ladder 1Kb)
32 = Talata Mafara isolate 1
33 = Talata Mafara isolate 2
34 = Rini isolate

CHAPTER 5

5.0 DISCUSSION

The economic impact of RYMV is difficult to evaluate due to the influence of many factors such as local environment in which rice is grown, the rice cultivars grown, the date of infection, the parameter selected and virus isolate used (Awoderu, 1991a; Ali, 1999; Luzi-Khupi *et al*., 2000; Konate and Fargette, 2001; Kouassi *et al*., 2005; Zouzou *et al*., 2008). The results of the screenhouse studies show that the impact of RYMV on growth parameters varied with cultivars and time of pathogen inoculations. There were significant differences in the mean plant height among the various inoculation regimes of the rice cultivars. Lowest plant height was obtained at the 4 WAS inoculation regimes though not significantly different from that at 6 WAS inoculation regimes. The present result is consistent with those of Kouassi e*t al*. (2005) who reported that if infection occurs from 20-50 days after planting the plant will continue to grow but will be stunted. The interaction effect of inoculation regimes on different cultivars shows that test plants inoculatrd at 10 WAS were significantly taller than the other test cutivars at 4, 6 and 8 WAS inoculation regimes. This could be due to the variation in the inoculation period at different stage of the plant growth. However, this report is not in agreement with the observation of Luzi Kihupi *et al*. (2000) that the plant height was not affected by this pathogen. This might be due to differences in day length, growth stage of the plant, humidity, light intensity and temperature (Bakker, 1974; Albar *et al*., 1995) as well as difference in the pathogenicity of the isolate used (N' Guessan *et al*., 2001). This study shows that there is highly significant reduction in plant height in susceptible cultivars such as BOUAKE 189, FARO 35, FARO 36, FARO 37, FARO 44 and FARO 52 compared to resistant cultivars of MOROBEREKAN and FARO 46, when infected with RYMV, both in the field and screenhouse, irrespective of the locations and

seasons (rainy and or dry seasons). The results are in agreement with those of other authors (Salaudeen *et al*., 2008b; Zouzou *et al*., 2008; Onwughalu *et al.,* 2010).

The consistence status of the test cultivar Bouake 189 production of higher number of tillers compared to cultivar MOROBEREKAN, which were to act as susceptible and resistant check, respectively, indicates that a cultivar with genetic potential for resistance to infection may lack traits for one or more agronomic qualities (Salaudeen *et al*., 2008b). The variability whch existed among the test cultivars in number of tillers produced per plant during the trial periods in both dry and rainy seasons under screenhouse and field conditions, shows that the effect of pathogen infection on a cultivar can be enhanced or reduced by factors other than the invading pathogen. Combined analysis of the results at Bomo, Sayen Gobirawa and Nasarawan Buhari, showed that the numbers of tillers produced per plant among some of the cultivars were statistically insignificant, with the exception of cultivar MOROBEREKAN can partly be explained by their genetic make-up. However, the variations in number of tillers per plant of the same cultivar in different trail periods could probably be attributed to disease infection. Similarly, the higher number of tillers produced per plant at Bomo than at Sayen Gobirawa and Nasarawan Buhari, could be ascribed to the existence of different RYMV strains in the field (Konate *et al*., 1997; N'Guassan *et al*., 2000), that are different in their virulence among genotype with heavy implication on agronomic performace and reaction to RYMV under local condition. There were significant ($P \leq 0.01$) variations in the number of tillers per plant among the inoculated plants in the screenhouse. Generally, the lowest number was recorded on plants at 4 WAS inoculation regimes, irrespective of seasons. This is probably due to the growth stage of the crop at which infection occurred (Onwughalu *et al*., 2010).

There were significant differences in the reduction of the number of tillers per plant among the various cultivars. The lowest reduction in tillers production per plant was obtained in MOROBEREKAN. The reason for this is not known but one explanation could be due to the lower disease severity recorded on this cultivar. The significant reduction in number of tillers per plant recorded on BOUAKE 189 is in line with an earlier report by Ghesquire *et al*. (1997) that susceptible lines were characterized by reduced tillering. The interaction effect of RYMV inoculation regimes and cultivar show that plant inoculated at 10 WAS had significantly, lower number of tillers reduction per plant than the other inoculation regimes. This might be as a result of the more favourable environmental conditions for the crop with virtually low pressure of RYMV on the plant during tillering period.

The effect of the pathogen on days to 50 % flowering was highly significant ($P \leq 0.01$) irrespective of the location and season at both field and screennhouse conditions. The average number of days to 50 % flowering recorded in FARO 46 (70 days) corroborates the finding of Salaudeen (2007) while the mean number of days to 50 % flowering recorded on FARO 52 (97 days) by Abo *et al.* (2005) is contrary to the result obtained 105 days (FARO 52) in this study. Probably due to the differences in climatic factors such as temperature and relative humidity (Awoderu, 1991a) and pathogenicity of the virus (N'Guessan *et al*., 2001).

There was a significant difference in the mean number of days increase to 50 % flowering among the rice cultivars. The lowest increase in number of days to 50 % flowering was recorded on FARO 46 (2.51). This might be as a result of early maturity nature of the cultivars. However, the interaction effects of inoculation regimes of RYMV and cultivars show that inoculated plants had an increase of 11.35, 8.47, and 6.02 and 2.93 days to 50 % flowering at 4, 6, 8 and 10 WAS, respectively. This shows that RYMV infection has an

inevitable consequence on the time of panicle emergence, particularly if infection occurs early and on susceptible host. A similar observation was also made by Ghesquiere *et al*. (1997) that susceptible cultivars were characterized by delayed panicle emergence. It is evident that RYMV infection delayed days to 50 % flowering in rice cultivars as compared to uninoculated control entries. It is Possible that prolonged vegetative lag phase as well as other physiological changes resulting from virus infection, caused the delay in days to 50 % flowering observed in this study (Gnanamananickan, 2009).

Bakker (1974) and Taylor (1990) stated that infected plants especially those which are infected early in the growing season, often fail to produce grains. Similar results were obtained in this study. Generally, the interaction effects of inoculation regimes and cultivar on the number of grain per panicle were highly significant ($P \leq 0.01$) statistically. This might be linked to effect of the virus, which might have hampered the normal growth, development and functioning of the plant parts, which consequently led to the reduction in average number of grain per panicle.

The consistence status of test cultivar MOROBEREKAN of higher paddy yield, irrespective of the location and season under the field and screenhouse conditions, and recording lowest paddy yield on different test cultivars of FARO 35, FARO 36, FARO 44 and FARO 11 during the trial periods, implies that the behaviour of the test cultivars in relation to the disease is not homogenous. It varies according to the cultivar, time of virus infection and climatic conditions (Awoderu, 1991b; Zouzou *et al*., 2008; Onwughala *et al*., 2010). Generally the mean paddy yield was higher during the wet season than the dry season under both field and screenhouse conditions, probably due to the differences in climatic factors such as rainfall, temperature and relative humidity (Bakker, 1974; Awoderu, 1991a).

Similarly, the average paddy yield was higher at Bomo than at Sayen Gobirawa, probably due to the difference in the isolates (N'Guessan *et al*., 2001) the stage of the crop growth at which infection occurred (Onwaghalu *et al*., 2010), and the edaphic environmental conditions of the two sites.

Plants inoculated at 4, 6, 8 and 10 WAS had average paddy yield losses of between 25.99 -79.11 %, 23.56 - 66.18 %, 16.23 - 49.79 % and 6.59 - 17.78 %, respectively during the rainy season, and similarly 14.24 - 81.67 %, 12.44 - 78.68 %, 10.15 - 45.13 % and 3.65 - 22.99 % average paddy yield losses to plant inoculated at 4, 6, 8 and 10 WAS, respectively during dry season in relation to their respective control entries in the screenhouse, this establishes the fact that yield losses to RYMV are strongly influenced by growth stages of the rice cultivar as well as time of virus infection (Rossel *et al.*, 1982a; Onwughala *et al.*, 2010). More so, this shows that period from 4 to 8 WAS represents the most vulnerable stage to RYMV infection in paddy yield losses phase in rice cultivars. The study show that interaction of inoculation regimes of RYMV on cultivar had significant effects on paddy yield, because the highest yield loss of 81.67 %, 78.62 %, 45.13 % and 22.99 % obtained in BOUAKE 189 at 4, 6, 8 and 10 WAS inoculation regime, respectively. This might be due to effect of the virus, which might have hampered the normal growth, development and functioning of the plant parts, which consequently led to the reduction in seed formation, among the inoculated plants resulting in lower paddy yield. Similarly, Bakker (1974) and Taylor (1990) stated that infected plants especially those which are infected early in the growing season, often fail to produce grains.

There were significant difference in threshing percentage of the cultivar, during the rainy and dry seasons under both field and screenhouse conditions. This change in yield

component may be due to the plants response to its environment which may or may not permit the full genetic expression of each component. However, the mean threshing percentage was higher during the dry season than rainy season. This is probably due to lower level of disease severity index during this period, because of lower temperature (Bakker, 1974; Awoderu, 1991a) of the cool harmattan during the period. Similarly, the lower threshing percentage recorded during the rainy seasons in both field and screenhouse trials, might be linked with the higher severity index, on the test cultivars. This might have hampered the normal growth, development and functioning of the leaves, thereby affecting the photosynthetic proceesss which consequently led to the reduction in seed formation and thus lower threshing percentage. This agrees with the report of Thomas *et al*. (1996) that severe foliar infection during grain formation can contribute to reduction in grain weight. The interaction effect of inoculation regime on rice cultivars had a significant effect on the threshing percentage irrespective of the seasons in the screenhouse. Inoculated plant had lower threshing percentage than to they respective uninoculated control treatment. This agrees with the report by Pixley *et al.* (1990) that healthier leaf canopy are more photosynthetically effective than a canopy of leaf area index with higher chlorotic infection.

There were generally insignificant differences in 1,000 grain weight among the cultivars in both dry and wet seasons under field codition compared to the screennhouse experiment. This could probably be due to low level of the disease severity index recorded under the field conditions, with virtually low pressure of pathogen on the plant during seed formation. It may also be due to the differences in the isolates (N'Guessan *et al*., 2001) and climatic factors (Awoderu, 1991a). However, 1,000-grain weight varied significantly among the inoculated plant in both the rainy and dry seasons in the screenhouse. The lowest 1,000-grain weight was recorded on test plants inoculated at 4 WAS, compared to plants

inoculated at 6, 8 and 10 WAS, and uninoculated treatment in increasing order. This might be due to the differences in the time of infection of the pathogen. This showed that severity of infection and the resulting grain weight depends on the growth stage of plant at which infection occurred among other factor (Bakker, 1974; Albar *et al*., 1995). Similarly, the mean 1,000- grain weight was higher during the rainy than the dry season. This could be as a result of early maturity nature of the crop during the rainy than in the dry season. This suggests that either infection is relatively low or other variables relating to plant physiology or environmental conditions played a role in grain development. As suggested by Abo *et al*. (2002a) grain weight differences might be attributed to the virus causing reduction of starch deposited in the endosperm.

The observed differences in prevalence of the RYMV insect vectors caught from one season to another can probably be ascribed to the variation in climatic factors. The results of this study showed that seasonal fluctuations in RYMV incidence corresponded closely to the changes in the population density of its insect vectors. Periods of high incidence of insect vectors at early stage of the plant growth, coincided with periods of high RYMV incidence and vice versa. This is in line with the observations of Alegbejo and Banwo (2005a) who reported that maize streak virus (MSV) incidence is closely associated with it vector population dynamics. Although fewer number of RYMV insect vectors were recorded in 2008 compared to 2009 and 2010 wet seasons, but significantly higher incidence of RYMV was recorded in 2008 than in 2009 and 2010 wet seasons. The most likely explanations for this situation would appear to be early but intermittent rainfall recorded in 2008 wet season which probably resulted in early disease spread, because of the early dispersal and build-up of insect vectors, and rapid growth of weed hosts of RYMV vectors, giving rise to high incidence of RYMV in that season. This confirms the earlier findings of Abo *et al.* (2002b)

that RYMV and its insect vectors were found in abundance in the fields during drought period. Also Alegbejo (2001) observed that in the epidemiology of groundnut rosette virus (GRV) early rains in a season encouraged the rapid growth of weed hosts of GRV and its aphid vectors. This is probably true to RYMV. Similarly, Bosque-Perez *et al*. (1998) and Walz *et al*. (1998) reported that MSV occurrence is severe after periods of irregular rains. Fairly low incidence of RYMV was recorded in 2009 and 2010 wet seasons at both Bomo and Sayen Gobirawa, apparently due to the heavy and evenly distributed rainfall which probably washed off insect vectors from the plant and kept down their populations The findings also in agreement with the reports by Alegbejo and Banwo (2005b) that heavy and consistent rains during the growing seasons washed off some of the leafhopper vectors of MSV from maize plant and hence the incidence of MSV in those periods were fairly low. However, during the 2008/2009 and 2009/2010 dry seasons trials at Nasarawan Buhari, the highest disease incidence was not consistent with the number of insect vectors. There was no relationship between RYMV symptom expression and peak number of colonizing insect vectors. This suggests that other variables relating to plant physiology or climatic conditions might play a role in RYMV symptoms development. Generally, climatic factors affect the life of insects and thus their population, not only by their direct impact but also indirectly by their influence on the growth and nutrient status of the plants on which they feed. The present work has shown that highest number of insect vectors was caught in 2008/2009 compared to 2009/2010 dry seasons at Nasarawan Buhari, but the incidence and severity index values of RYMV were significantly lower in 2008/2009 than in 2009/2010 dry seasons. A similar trend was observed in weather factors; average temperature and light intensity (sunshine hours) was lower in 2008/2009 compared to 2009/2010 but mean relative humidity was higher in 2008/2009 compared to 2009/2010 dry season. This indicated that expression of RYMV symptom was strongly influenced by variation in

temperature, sunshine hours and relative humidity. Similarly, Bakker (1974), Awoderu, (1991a) and Albar *et al*. (2005) stated that temperature affects symptom expressions differently in host plants. At low temperature, RYMV shows only mild symptoms while at high temperature severe symptoms developed, these was also greater expression of RYMV symptoms when the relative humidity was low. Hull (1989) and Cardove *et al*. (1991) stated that the anatomy and physiology of the host, as well as environmental factors such as temperature and water stress affect virus mobility. This study has showed that level of incidence and severity index caused by RYMV depend on the season, host species or cultivars and plant age at which infection occurred either by insect vectors or otherwise. The results of the study generally showed that RYMV incidence and severity rates declined significantly with decreasing temperature and insect vector population However, the understanding of the exact role of rainfall frequency and level of relative humidity in the epidemiology of RYMV incidence and severity required further investigation. Further studies on the effect of environmental factors and plant host on the dynamics of insect vectors and RYMV incidence are necessary to provide more information on the epidemiology of the virus in Nigeria.

Atiri *et al*. (2000) postulated that if vector efficiency varies with species and /or population, then virus transmission rates will depend on the predominant vectors species/populations. In this regard, the incidence of RYMV recorded in the present study could be due to *L. rubra* population, irrespective of the seasons and locations. Because it was most abundant across all the locations and investigation period.There is a need to determine the interrelationship between the insect vector population and predominant RYMV strains which they transmit as part of understanding the spread or vectorial capacity of insect vector found in and around RYMV infected fields.

Generally, epidemic prevalence of a disease is a probability phenomenon, it occurs in a wave, the probability being that of transfer of an effective dose of the infections agent from the infected individual to susceptible one. The present results from three locations under similar environmental conditions have confirmed this hypothesis. Ten rice cultivars namely, FARO 11, FARO 35 FARO 36, FARO 37, FARO 44, FARO 46, FARO 52, FARO 57, MOROBEREKAN (resistant cheek) and BOUAKE 189 (susceptible check) were used to assess the progress of RYMV in each cultivar under natural field conditions during the rainy and dry seasons (upland and lowland). There were significant differences; in RYMV incidence amongst the cultivars. These show that the rate at which the plant becomes infected differ from cultivar to cultivar. At Bomo, Sayen Gobirawa and Nasarawan Buhari a significant increase of infected plants was noticed on BOUAKE 189 FARO 36 FARO 44 and FARO 52 cultivars while less on FARO 46 and MOROBEREKAN in the period between 10-13 WAS and 11-13 WAS during 2008, 2009 and 2010 wet and 2008/2009 2009/2010 dry seasons, respectively. These observations are in line with the earlier report by Abo *et al.* (2002b) that some farms in Kano and Gombe states were destroyed by RYMV, because the commonly cultivated rice cultivars in those states included FARO 44 and FARO 35 which are known to be susceptible to RYMV. Also Onasanya *et al.* (2004) reported BOUAKE 189 and MOROBEREKAN cultivars were highly susceptible and resistant to RYMV, respectively. Similarly, Zouzou *et al.* (2008) reported that the behaviour of rice cultivars in relation to RYMV is not homogenous, it varies according to the cultivar and the parameter selected. Generally the mean disease incidence was higher at Sayen Gobirawa than at Bomo; in 2008 while the reverse was the case in 2009 wet season. This might be due to the difference in the pathogencity of the isolates at the two locations (Salaudeen *et al.*, 2008a) as well as time of infection of the plant (Konate and Fargette, 2001). Also this shows that in nature a subtle balance is often maintained between hosts plant and their

associated pathogens. Any change in this complex system may upset the delicate balance. Thus, the degree of resistance and or the level of susceptibility of a rice cultivar to the virus, and possibly to the infestation by some insect vectors of RYMV play critical roles in the incidence of RYMV in the field. Therefore, these two types of responses of the host can be harnessed in the development of virus- resistant cultivars after adaptive study in the localities to curtail epidemic of RYMV. Similar observation had been observed by Konat*e* and Fargette (2001) that two types of resistance to RYMV were identified in rice *Oryza* species. A mild polygenic resistance in *Oryza sativa,* Japonica type which can slow down the spread of the virus and a high monogeni*c* resistance in *O. glaberrima* which prevent it. Kouassi *et al.* (2005) reported a highly susceptible response in varieties such as BG-90-2 and BOUAKE 189, which are generally from the *indica* sub-species of *O*. s*ativa*. .

The mean severity undex of RYMV was higher during the rainy seasons than the dry seasons irrespective of either in the field or screenhouse conditions. This shows that pathogenicity and virulence of the virus was higher during the rainy seasons. This is consistent with the results of Reckhaus and Andriamasintseheno (1997) that some rice cultivar planted in the rainy season suffer most from RYMV than those grown mainly under irrigation. Similarly, Moore (1993) reported that many diseases are favoured by humid and rainy weather and may be more common and severe in a year favouring crop production. However, during the rainy season some results obtained on the same test cultivar in a year, irrespective of their locations are comparatively similar. The pathogenicity and virulence of the virus was consistent at all locations on the test cultivars. Comparatively, the level of RYMV severity index recorded in the screenhouse differed considerably from the field experiments. This show that rice plant grown under experimental condition are likely to allow a higher rate of virus replication known to be critical (Hanada *et al*., 2004) than that in

field- grown rice plant, where virus particles survive part of the year in senescent plants or in stubble fields, with low or no replication, respectively (Fargette *et al.,* 2008). There were significant ($P \leq 0.01$) differences in the disease severity indices among the inoculation regimes on the test cultivars in the screenhouse during both rainy and dry seasons. This indicates that severity index of RYMV was strongly influenced by susceptibility of the cultivar and the stage of the plant growth at which infection occurred among other factors (Bakker, 1974; Albar *et a*l., 1995). Generally, the severity index recorded on test cultivars, inoculated at 4 and 6 WAS, were significantly higher compared to those at 8 and 10 WAS. This shows that plants infected early are more severely affected than those infected later and the symptoms were more pronounced and necrotic in the screenhouse than in the field (Bakker, 1974). Similarly, the mean severity index was higher at Bomo than at Sayen Gobirawa in field during the rainy seasons, although, the rate of infection was higher at Sayen Gobirawa than at Bomo. This probably, implies the existence of different RYMV strains in the fields (Konate *et al.,* 1997; N.Guessan *et al.*, 2000) that are different in their pathogenicity.

A significant positive correlation was found between plant height and threshing percentage, while negative significant correlation was found between plant height and disease incidence. However, non-significant correlation was found between plant height and paddy yield. This is in agreement with the reports of Luzi-Kihupi *et al.* (2000) who reported that there was no significant correlation between plant height and grain yield. There was a positive correlation between disease incidence and mean temperature in both locations during 2008 wet season, possibly because of erratic rainfall and abnormal high temperature recorded in the season. Similar observations were made by Bakker (1974), that high temperatures (30 ^{o}C and above) could reduce the period of expression of symptoms in susceptible cultivars. At Sayen

Gobirawa there were significant positive correlations between the following factors: RYMV incidence and C*heatocnema* sp., RYMV incidence and *Z. variegatus,* RYMV incidence and *L. rubra*; RYMV severity index and *Chaetocnema sp.,* RYMV severity index and C. *similis,* RYMV severity index and *L. rubra*. At Bomo there were significant positive correlations between RYMV incidence and *Z. variegates*, RYMV incidence and *Cheilomenes* sp., RYMV incidence and *L. rubra*; RYMV severity index and *Chaetocnema sp*., RYMV severity index and *Cheilomenes* sp., RYMV severity index and *L. rubra,* RYMV severity index and *C. similis*. However, the correlation phenomenon reported here, contradicts the report of Heinrich*s et al.* (1997) who found no correlation between vector abundance and RYMV incidence. Sarra and Peters (2003) reported that virus spread cannot often be correlated with the number of beetles present. The most likely explanation for this relationship would appear to be due to the diverse nature of relationship between Sobemoviruses and their vectors (Walters, 1969; Fulton *et al*., 1987; Seghal, 1981; Hull, 1988). Similarly, under screenhouse conditions in the dry or rainy season conditions, significant positive correlations were found between: RYMV incidence and severity index, reduction in number of tillers per plant and paddy yield loss. This corroborates the findings of N'Guessan *et al*. (2000) who reported significant positive correlations between disease severity index and paddy yield loss. However, this report is contrary to the earlier results of the screennhouse experiments by Salaudeen (2007). This could be due to the difference in the pathogenicity of the isolate involved (N'Guessan *et al*., 2000), climatic factors (Awoderu 1991a) and emergence of resistance breaking effect of the isolates used (Traore *et al*., 2006). The significant negative correlation which was observed between plant height and days to 50% flowering is in agreement with the earlier work of Luzi-Kihupi *et al.* (2000) and Salaudeen (2007) who indicated a significant correlation between plant height and days to 50 % flowering.

Virus transmission by insect is a common way for viruses to travel between different host plants and this is possibly as a result of a protein that the plant viruses attach to as they hitch an insect ride between plants (Uzest *et al*., 2007). Studies carried out by Abo *et al*. (1998; 2002a, 2002b) to test transmission of RYMV disease show that, *L. rubra* was unable to transmit RYMV to susceptible rice cultivar. This disagrees with the results of this investigation. This could be due to differences in the serotypes used (N'Guessan *et al.*, 2001). This study reports transmission of RYMV by *Z. variegatus, Paratettix* sp. and *Cheilomenes* sp. for the first time in Nigeria and *N. Viridula* as a vector of RYMV for the first time in Africa. The results of the transmission test showed that isolates collected from Sayen Gobirawa developed RYMV symptoms on higher number of BOUAKE 189 cultivar (test plant) than the Bomo isolate by the same species of insect vector. This contradictory result could be explained by differences in aggressiveness between the isolates used. Several authors (Konate *et al*., 1997; N'Guessan *et al*., 2000; Salaudeen *et al*., 2008b; Zouzou *et al*., 2008) have reported that RYMV is highly variable and biological, serological and virulence differences among isolates have been established.

The detection of RYMV under natural field conditions in *Eleusine indica* and *Imperata cylindrica* in this study is in line with the earlier reports by Awoderu (1991b) and Saluadeen *et* al. (2008c). However, this report is contrary to the findings of Abo *et al*. (2002b) who reported them as non-host of RYMV. This could be attributed to the differences in the virulence of the RYMV isolates involved (N'Guessan *et al*., 2000). The detection of RYMV in *O. longistaminata* and *I. cylindrica* in lowland by Sy (1994) is in agreement with this study. Furthermore, Awoderu (1991b) also reported *O. longistaminata* as a natural host of RYMV. The detection of the virus in *Digitaria horizontalis, Cynodon dactylon*, *Cyperus difformis* in this study is contrary to the finding of Abo *et al*. (2002b). This might be due to

the differences in the pathogenecity of the isolates involved (Fargette *et al*., 2004). Specific isolate –host interactions may also be responsible for contrasting results observed with some plant species about their status of being or not being host plant for RYMV (Allarangaye *et al*., 2007). For instance *Digitaria sanguinalis, Echinochloa crus-galli., Eragrostis atrovirens, E. tenufolia*, *Panicum maxima* and *P. repens* identified as experimental or natural host species in West Africa (Awoderu, 1991a; Konate *et al.,* 1997; Traore *et al*., 2006) were not susceptible to the virus in East Africa (Bakker, 1974). Similarly, the present study demonstrate that some plant species found to be positive to RYMV in ELISA test in one location, often give a negative reaction in another location. Bakker (1974) reported a localised nature of RYMV symptom with *E. coracana* in East Africa, while Fauquet and Thouvenel (1977) did not obtain any mechanical infection with *E. corocana* in Cote d'I voire. The differences observed in RYMV host range studies could be bypassed by using a diversity of isolates in the same inoculum (Allanrangaye *et al.,* 2007). This study shows that natural infection by the pathogen simultaneously across some RYMV hotspot or epidemic areas in Northern Nigeria on *I. cylindrica, E. tenella, E. Ciliaris, D. horizontalis, Eleusine indica, E. coronata, Panicum sp., Brachiaria lata, Axonopus compressus, Dactyloctenium aegyptium, Cyperus rotundus, C. difformis, Oryza barthii, O. longistaminata* and *Pennisetum pedicellatum.* This is probably due to similarity in the level of pathogenicity and serotypes of the isolates across the surveyed areas. This is the fisrt report of *P. pedicellatum* and *E. coronata* as natural host of RYMV in Africa, *B. lata,* and *A. compressus* in West Africa, *E. tenella, E. Ciliaris, D. horizontalis,, D. aegyptium* and *C. difformis* in Nigeria . In addition to being narrow, RYMV host ranges species is complex and belong to highly heterogenous Poaceae group (Allarangaye *et al*., 2007). A more detailed survey of rice irrigation farms and river banks in northern Nigeria may reveal additional weed hosts of RYMV.

The occurrence of immunological diversity of the RYMV isolates assessed with panel of monoclonal antibodies in the surveyed areas, suggested that several serotypes co-exist in the surveyed ecological zones of northern guinea savanna (Kaduna state), southern guinea savanna (Niger state) and sudan savanna (Borno, Gombe, Kano, Sokoto and Zamfara states) in northern Nigeria. This result is consistent and complementary to the findings of N'Guessan *et al*. (2000) and Saluadeen *et al.* (2008b) who reported that several serotypes of RYMV can co-exist in the same country. In addition to the serological relationship found in the surveyed areas, differential reactivity was observed among isolates collected from a few metres apart in the same area, but similar to an isolate from a different area. This explains the fact that within a set of isolates of related strains in the same host plant, many possibilities of interaction exist (Mathews, 1991). It also indicates the existence and levels of serodiversity among RYMV isolates in the surveyed areas. This is consistent with the earlier reports by Fargette *et al*. (1995) and N'Guessan *et al*. (1995) that isolates from the same areas could be quite different among each other and close to an isolate from a remote country. Sere *et al.* (2007) also reported that many isolates of RYMV emanating from same locality, field and host were observed to be serologically different.The serological similarities observed between isolates within the same and different localities in the surveyed areas, confirm the great cross-infection potential of RYMV transmitted under natural conditions by different insect vectors (Bakker, 1971; Hammond *et al*., 1999). This possibly accounted for the different serological profiles obtained among different RYMV isolates collected in the surveyed areas. RYMV has been described as a variable virus with many pathological and serological variants (Konate *et al*., 1997; Sasaya *et al*., 1997; NGuessan *et al*., 2000 and Sere *et al*., 2007). This result are in agreement with the observed prevalence of several variants of the serological profiles recorded in this study, distinguished

by their unusual reactions with the same MAbs tested in some isolates collected across the surveyed areas. This information implies that weak and strong reaction recorded in this study by some of the isolates tested with the panel of MAbs, can probably be ascribed to weak reaction with the virus isolates rather than low concentration of the virus in the infected tissue, because a conspicuous symptom was observed after propagating the virus in susceptible rice cultivar BOUAKE 189 (to most of the isolates used.). Most of the sobemoviruses are known to occur in relatively large concentrations in infected plants (Edwardson *et al.,* 1966; Hartman *et al.,* 1973; Bakker, 1974; Mohammed and Mossop, 1981; Hull, 1988). The result of this study agrees with the findings of Konate *et al*. (1997) that the weakness of reaction in RYMV could be attributed to a poor interaction between antisera and RYMV isolate(s) contained in samples. Similar results were reported by Mansour and Baillis (1994) who used RYMV isolates collected from rice in Cote d'lvoire, Kenya, Niger, Nigeria and Sierra Leone. However, it is contrary to the view of Dijkstra and De-Jagar (1998) that different reaction might be caused by virus concentration in the infected tissues, the higher the concentration of the virus the stronger the reaction that will be produced (Hidayat *et al.*, 2009).

Based on the reaction pattern to the panel of MAbs in TAS- ELISA six serological profiles or groups have been identified (Sep A to F) in this study. The Sep A isolates were present in Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states. Sep B isolates were common in Borno, Gombe, Kaduna and Kano states. Sep C isolate was identified only in Gombe state. Sep D isolate were detected in Borno, Sokoto and Zamfara states. Sep E isolates were identified in Borno and Zamfara states. Sep F isolates were identified in Kano, Niger and Sokoto states. However, serological typing sometimes gives ambiguous result and could be less discriminating than molecular typing (Kanyeka *et al.*, 2007). This may probably explain

the fact that some of the isolates grouped under the same serological profiles had no reaction with the same specific primer, but had similar reaction with other isolates grouped under different serological profiles in molecular typing in this study. It could also explain the fact that within a set of isolates of related strains in the same host plant, many possibilities of interaction exist (Mathews, 1991). Hierarchical classification of all the RYMV isolates into three main serogroups (SG1, SG2 and SG3) and six subgroups (Sg1a, Sg1b, Sg2a, Sg2b, Sg3a and Sg3b) in this study, indicates the existence and levels of serodiversity among RYMV isolates in northern Nigeria. Such possibilities of interaction within a set of isolates of related strains might lead to frequent occurrence of mutants which might be responsible for the high level of serological variation among the isolates (Boccard and Baulcombe, 1993). Similarly Sere *et al.* (2005) suggested that as a result of possible interaction between different strains of the same isolate in the same host plant, which varies from one ecological zone to another, diverse serological variability tends to exist between isolates of RYMV in West Africa. High serological profile or serotype diversity of RYMV found in this study may be associated with occurrence of resistance breaking isolates (Traore *et al.,* 2006), which urgently calls for deliberate efforts to study the potential problem for future development of resistant cultivar to RYMV in the surveyed areas. Similarly hierarchical classification of RYMV isolates into main serogroup and subgroup obtained from cross reactivity of four monoclonal antibodies derived from serological profiles data in TAS-ELISA, could be useful for epidemiological studies to assess isolate identity and interaction in the fields.

Six strains of RYMV (S1, S2, S3, S4, S5 and S6) have been reported to be present in Africa (Pinel *et al*., 2000; Fargette and Konate, 2004; Kanyeka *et al.,* 2007) and at least three strains (S1, S2 and S3) were known to exist in West Africa. Results of the molecular

characterization of RYMV isolates using PCR revealed that more than two strains of RYMV were present in the surveyed areas. Assessment of the distribution of RYMV strains revealed that strain S1 and SX occurs predominantly in both lowland and upland ecosystems in Sudan Savanna, which was consistent with the detection of strain S1 isolates from Sudan Savanna parts of Ivory coast, Mali and Burkina - Faso (N Guessan *et al.*, 2001). By constrast, strain S2 was recorded not only in lowland and upland ecosystems in Northern and Sourthern Guinea Savannas, but also in Gombe state wthin the Sudan Savanna. This is inline with the report of Koaussi *et al*. (2005) that West Africa was consistent with RYMV strains having large and overlapping distribution with virus adaptation to savanna, forest and other ecological conditions Strains S1 (60%) is widespread and occurs predominantly in the seven states surveyed. By contrast, strain S2 (11.42%) is restricted to a few sites only (Gombe, Kaduna and Niger states). Isolates of strains SX (28.58%) because of their distinguished negative reactions with S1 and S2 strain- specifics primers, showed positive reaction with random hexamer primers and occured predominantly in swampy sites in Borno, Gombe, Kaduna, Kano and Zamfara states. This is consistent with the findings of Pinel *et al.* (2000) who reported wide and overlapping spatial distributions of RYMV strains along both North-South and East –West transects within West and East Africa. The high diversity among isolates of strains S1 was consistent with their wide range distribution of serological profiles or group (Sep A and Sep B) within the surveyed areas. This indicates that molecular typing is consistent with serological typing but more discriminating (Kouassi *et al.*, 2005). Strain S2 was reported for the first time in Nigeria in the present study. Further studies on a greater number of isolates, from northern Nigeria especially where diversity is highest, and on a larger portion of the isolates are needed to confirm their significance, because identification of RYMV strains often lacks consistency and precision (Bakker, 1974; Mathews, 1991).

However, the data provided in this study, on the molecular characterization and strain differentiation could provide useful information on the identification of isolates/strains in pathogeneicity and breeding studies of RYMV in the country. Distinction between strains is critical in epidemiological surveys, as strains differ in their geographical distribution; interactions between each other sometimes have constrasted pathogenic properties.

CHAPTER 6

6.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY AND CONCLUSION

Five sets of investigations were understaken to study: yield losses due to RYMV in selected rice cultivars and to identify the critical stage of the plant growth when the disease has serious effect on the yield components; the epidemiology of RYMV (relating the influence of weather factors on the insect vector population and RYMV incidence); search for alternative host or wild reseviour of RYMV in hotspots or epidemics areas in northern Nigeria; identify the serotypes of RYMV and their distribution in hotspots or epidemic areas in northern Nigeria; molecular characteristics of RYMV to provide information relating the isolate or strain within the study area to a wide range of biological hypotheses of the virus in other parts of West Africa.

From the results of first experiments: significant relationship was found between disease incidence and severity index and yield losses components. The critical periods of RYMV infection that affect yield for most of the rice cultivars used in the current study were between 4 - 8 WAS. The assessment of yield loss component allowed better determination among cultivars responses to RYMV infection at different stage of the plant growth. Keeping the rice RYMV free for up to 10 WAS resulted in grain yield almost similar to those kept RYMV free throughout crop growth. When different stages of the plant growth were monitored large differences in susceptibility were observed among the different cultivars exposed to a particular isolates pathogencity. The virus significantly reduced plant height and number of tillers per plant, prolonged days to 50 % flowering, decreased number of grains per panicle, threshing percentage and 1,000 grain weight and led to paddy yield losses. However, no significant RYMV effects were found with some, moderately

resistant cultivars (MOROBEREKAN, FARO 57, FARO 37, and FARO 46) compared to some susceptible (FARO 44, BOUAKE 189, FARO 36 and FARO 52) cultivars at later stages of the plant growth under screenhouse conditions. The study revealed that the periods from 4 to 8 WAS represent the most vulnerable phase in RYMV infection in all the test cultivars growth stages. This information will surely assist breeder's programmes in the development of management strategies for rice cultivars to RYMV disease.

The results of the second study on the relationships among some weather factors (rainfall, temperature, relative humidity, sunshine hours) at Bomo, Sayen Gobirawa and Nasarawan Buhari (Northern Guinea Savanna of Nigeria) shows that there is a relationship between RYMV incidence, severity index and number of insects vector caught per season. The results of the experiments showed that seasonal fluatuations in RYMV incidence corresponds closely to the changes in the population density of its insect vectors. Periods of high incidence of insect vectors at early stage of plant growth, coincided with periods of high RYMV incidence and vice versa. Expression of RYMV symptom was strongly influenced by variation in temperature, sunshine hours and relative humidity. The study indicates that the epidemiology of RYMV is very complex and can be initiated in susceptible rice cultivars by a few infeced plants, under field conditions and involving several insect vectors directly or indirectly influenced by climatic factors. The mean population density of vectors recorded across the three years study, shows statistically significant differences ($P \leq 0.05$) in the number of insect vectors caught per season. Insect vectors caught included the following*: L rubra, Oxya sp., C. similis, Conocephalus sp., Chaetocnema sp., Cheilomenes sp., Z. variegatus* and *T. sericea* in order of abundance at Bomo. *L rubra, Oxya sp., C. similis, Chaetocnema sp., Cheilomenes sp., Conocephalus sp., T. sericea and Z. variegatus* in order of abundance at Sayen Gobirawa and *L. rubra,*

Cheilomenes sp., Z. variegatus, C. similis, Oxya sp., Conocephalus sp. and *Chaetocnema sp,* in order of abundance at Nasarawan Buhari.

Ten out of fourteen insects found in and around the experimental field: including L. *rubra, C. similis*, *Chaetocnema* sp., *Cheilomenes sp., Z. variegatus, Paratettix* sp., Oxya sp., *Conocephalus* sp., *N. viridula* and *Dactylispa* sp. potentially transmitted RYMV from diseased Bouake 189 to healthy Bouake 189 seedlings.There is a need to determine the insect vector population and composition, and the predominant RYMV strains which they transmit as part of understanding the spread or vectorial capacity of RYMV disease in different localities and under different environmental conditions.

Results of the third study indicate that serological studies of some weed species collected across RYMV endemic locations in northern Nigeria tested positive to RYMV under natural infection. The weeds included the following (*Imperata cylindrica, Eragrostis tenella, Digitaria horizontalis, Eleusine indica, E. Corocana, Dactylotenium aegyptium, Panicum* sp., *Cynodon dactylon, Brachiaria lata, Axonopus compressus, Cyperus rotundus, C. difformis, Pennisetum pedicellatum, Oryza longistaminata* and *O. barthii*) This is the first report that adds *Pennisetum pedicellatum* to the list of natural RYMV host.

From the results of the fourth objective, based on the reaction pattern of the panels of MAbs in TAS- ELISA six serological profiles or serotypes have been identified (Sep A to F) in this study. The Sep A isolates were identified in Gombe, Kaduna, Kano, Niger, Sokoto and Zamfara states. Sep B isolates were common in Borno, Gombe, Kaduna and Kano states.

Sep C isolates was identified only in Gombe state. Sep D isolate were detected in Borno, Sokoto and Zamfara states. Sep E isolate were identified in Borno and Zamfara states. Sep F isolates were found in Kano, Niger and Sokoto states. The occurrences of immunological diversity of the RYMV isolates assessed with a panel of monoclonal antibodies with consistent grouping into several serological profiles in the surveyed areas, suggested that several serotypes co-exist in the northern Nigeria ecological zones. The high viral load in some of the surveyed sites in Gombe, Kano, Kaduna, Niger and Zamfara states, implies that these are suitable locations for strategic studies aimed at designing management interventions against RYMV disease.

The results of the molecular characterization of RYMV isolates using PCR revealed that more than 2 strains of RYMV were present in the surveyed areas. Strains S1 is widespread (forming 60 % of samples) and occurs predominantly in the seven states surveyed. By contrast, strain S2 is restricted to few sites only in Gombe, Kaduna and Niger states and accounted for 11.42% of the samples collected, occurred predominantly in swampy sites in Borno, Gombe, Kaduna, Kano and Zamfara states and was 28.58 % of the samples. This is the first report that adds Borno to the list of RYMV endemic states in the country.

6.2 RECOMMENDATIONS

In view of the increasing incidence and importance of RYMV on rice production in the country, more information on the periods representing the most vulnerable phase in RYMV infection on different rice cultivars growth stages on yield losses is needed under different localities and ecologies, so as to determine rice plants the stage at which rice plant develop tolerance to the pathogen. Protection of the plant against RYMV vectors in the fields before the vulnerable stage could reduce the effect of the disease on yields.

In addition more information on the epidemiology and dynamics of the virus spread and the role of insects found in and around rice fields under the prevailing weather conditions are needed in each of the RYMV endemic or hotspots in the country. Since the disease is not epidemiologically static, information gathering should be continous. Provided that sufficient and high quality epidemiological data continue to be collected with technological advances, availability and sophistication of computer models, it will be possible to incorporate and simulate weather factors to predict RYMV epidemics effectively.

More research is recommended on differential reaction of some weed host of RYMV in terms of locations and season of the year. Knowledge of such relationship between RYMV isolates and their weed hosts are valuable in diagnostic work and may prove to be important in epidemiological studies and disease management.

Evidences from the field surveys of high serological profiles or serotypes diversity of RYMV isolates in the surveyed areas, suggest the possible existence of different strains of RYMV in northern Nigeria. This may be associated with emergence of resistance breaking isolates that cause different serotypes of disease. For this reason reliable criteria are needed for distinguishing and identifying these serotypes. This urgently calls for more research work to investigate the potential problem for future development of resistant cultivars to RYMV in the northern part of the country

More information on molecular characterization and strain differentiation of RYMV in Northern Nigeria will be useful in the identification of strains, pathogenicity and breeding studies of RYMV in the country. For these to have a practical meaning for the rice grower, specific distinct pattern for each isolate must be related to the degree of virulence to rice

cultivar in that particular ecology. Hence, coat protein (CP) genes of representative isolates of the different serotypes in the country should be sequenced to verify the serology-based conclusions for routine test in comprehensive epidemiological studies.

6.3 RESEARCH FINDINGS

The study shows that vulnerable stage to RYMV is from 4 to 8 weeks after sowing.

This is the first report on molecular characterization of RYMV in northern Nigeria; the study also revealed the existence of several serotypes of RYMV in northern Nigeria and first report of two main strains of RYMV S1 and S2 in northern Nigeria.

The study identified *Eluesine corocana* and *Pennisetum pedicellatum* for the first time as natural hosts of RYMV in Africa, *Axonopus compressus and Brachiaria lata* in West Africa; *Digitaria horizontalis, Cyperus difformis, Eragrostis tenella, E. cilliaris* and *Dactyloctemum eagyptium i*n Nigeria,

This is the first report of *Cheilomenes* sp., *Zonocerus variegates* and *Parattetix* sp as potential vectors of RYMV in Nigeria and *Nezera viridula* in the whole of Africa. It is also first report of RYMV in Borno state, Nigeria.

REFERENCES

Abo, M.E. (1998). Studies on the mode of transmission of rice yellow mottle virus Sobemovirus. Unpublished Ph.D Thesis, Ahmadu Bello University, Zaria, Nigeria, pp. 148.

Abo, M.E. and Alegbejo, M. D. (1997). Strategies for sustainable control of viral disease of some crops in Nigeria. *Journal of sustainable Agriculture,* 10 (2/3): 57-80.

Abo, M. E. and Sy, A. A. (1998). Rice Virus Diseases: Epidemiology and Management Strategies. *Journal of Sustainable Agriculture,* 10 (2/3): 113-134.

Abo, M.E., Okusanya, B. A. and Imolehin, E. D. (1995). The status of rice yellow mottle virus (RYMV) in Nigeria.paper presented at the 1st International symposium on RYMV from 18-22 September, 1995, Mbe, WARDA/ADRAQ, Bouake, Cote d'Ivoire.

Abo, M.E., Sy, A. A. and Alegbejo, M. D. (1998). Rice yellow mottle virus (RYMV*)* in Africa. Evolution, distribution and economic significance on sustainable rice production and management strategies. *Journal of Sustainable Agriculture.* 11 (2/3): 85-111.

Abo, M. E., Ukwangwu, M. N., Hughes, J.d' A. and Misari, S.M. (2001). Possible sources of resistance to Rice yellow mottle virus (RYMV), genus Sobemovirus in some rice genotypes in Nigeria. *Journal of Agriculture and Environmen,,* 2 (2): 263 - 270.

Abo, M. E., Alegbejo, M. D., Sy, A. A. and Sere, Y. (2002a). Field incidence of rice yellow mottle virus genus Sobemovirus on rice and a weed species in the field in Cote d'ivoire. *Acta Agronomica Hungarica,* 50 (1): 85-89.

Abo, M. E., Ukwungwu M.N. and Onasanya, A. (2002b). The distribution, incidence, natural reservoir hosts and insect vectors of Rice yellow mottle virus (RYMV), genus Sobemovirus in Northern Nigeria. *Tropiculture,* 20: 198-202.

Abo, M. E., Gana, A. S., Maji, A. T., Ukwangwu, M. N. and Imolehin, E. D. (2005). The resistance of farmers rice varieties to rice yellow mottle virus (RYMV*)* at Badeggi, Nigeria. *Tropiculture,* 23 (2): 100-104.

Absa, J. (2010). Screening and molecular characterisation of near-isogenic lines for resistance to Rice yellow mottle virus. unpublished M.Sc. Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. PP. 61.

Abubakar, Z., Ali, F., Pinel, A.,Traore, O., N'Guessan, P., Notteghem, J.-L., Kimmins, F., Konate, G. and Fargette, D. (2003). Phylogeography of Rice yellow mottle virus in Africa. *Journal of General Virology,* 84: 733-743.

Adagba, M. A ., Lagoke, S.T.O. and Ndalu, W. B. (2005). Control of *Striga hermocthica* (Del) Benth through host plant resistance in upland rice (*Oryza sativa L.)*. *Nigerian Journal of Plant Protection,* 22: 57 – 71.

Aheer, G. M., Ahmed, K.J. and Ali, A. (1994). Role of weather in fluctuating aphid density in wheat crop. *Journal of Agricultural Research,* 32: 295-301.

Alam, M. S., John, V. T. and Zan, K. (1984). Insect pests and diseases of rice in Africa. In Rice in Africa IITA Rice Production Manual, IITA, Ibadan, Nigeria.

Alam, M. S. (1988). Evaluation of Rice cultivars for resistance to *Diapsis pongicarnis* (Diptera: Diopsidae). *Journal of Economic Entomology,* 81(3): 934-936.

Albar, L., Pinel, M. L., Fargette, D. and Ghesquire, A. (1995). Evaluation of the concentration of rice yellow mottle virus. Paper presented at the 1st International Symposium on rice yellow mottle virus (RYMV*)*, 18-22 September, 1995, Mbe, WARDA/ADRAW, Bouake Cote d'Ivoire.

Alegbejo, M. D. and Kashina, B.D. (2000). Survey of weed hosts of blackeye cowpea mosaic and cowpea aphid-borne mosaic potyviruses at Samaru, Nigeria. *Journal of Pure and Applied Science,* 3(2): 119- 125.

Alegbejo , M. D. (2001). Epidemiology of groundnut rosette virus of Samaru, Northern Guinea Savanna of Nigeria. *Nigeria Journal of Entomology*, 18: 95-102.

Alegbejo, M. D. and Banwo, O. O. (2005a). Host plants of *Bemisia tabaci* Genn in Northern Nigeria. *Journal of Plant Protection Research,* 45**:** 93-98.

Alegbejo, M. D. and Banwo, O. O. (2005b). Relationship between some weather factors, Maize streak virus genus Mastrevirus incidence and vector population in Northern Nigeria. *Journal of Plant Protection Research,* 45 (2):99-105.

Alegbejo, M. D., Raji, B. A., and Abubakar, I. U. and Banwo, O.O. (2006). Rice yellow mottle virus disease A new disease of rice in Zamfara, Nigeria. *Internatiomal Rice Research News, 33.1.*

Ali, F. (1999). Epidemiology of Rice Yellow Mottle Virus in Tanzania Unpublished Ph.D Thesis University of Greenwich.

Allarangaye, M. D., Traore, E. V. S.,Millogo, R.J. and Konate, G. (2006). Evidence of non-transmission of Rice yellow mottle virus through seeds of wild host species. *Journal of Plant Pathology,* 88(30): 309- 315.

Allarangaye, M. D., Traore, D., Traore, E. V. S., Millogro, R. J., Guinico, S. and Konate, G. (2007). Host range of Rice yellow mottle virus in Sudano-Sahellean Savannah. *Pakistan Journal of Biological Science,* 10: 1414-1421.

Anno-Nyako, F. O. and Twumasi, K. K. (1995). The threat of RYMV and the future of rice production in Ghana. In 1st int. symp. RYMV. 18-22 Sept.1995, Mbe, WARDA, ADRAQ, Bouke, Cote d'Ivoire.

Anonymous (2005). *Oryza* Africa Nigeria report http/www/oryza.com. Africa Nigeria index shml.

Anonymous (2010). United State Department of Agriculture, Foreign Agricultural Service, Agriculture information Network.

Atiri, G., Njukeng, A.P.,Ekpo, E.J.A.(2000). Climate in relation to plant virus epidemiology and sustainable disease management. *Journal of Sustainable Agriculture,* 16(1):17-30.

Awoderu, V. A. (1991a). Rice Yellow Mottle Virus in West Africa. *Tropical Pest Management,* 37**:** 356-363.

Awoderu, V. A. (1991b). The rice yellow mottle virus situation in West Africa. *Journal of Basic Microbiology,* 31 (2): 91-99.

Awoderu, V. A., Alam, M. S., Thottappilly, G., and Alluri, K. (1987). Occurrence of rice yellow mottle virus in upland rice in Cote d'Ivoire *FAO-plant protection bulletin,* 35(1): 32-33.

Bakker, W. (1970). Rice Yellow Mottle, a mechanically transmissible virus disease of rice in Kenya. *Netherlands Journal of Plant Pathology,* 76: 53-63.

Bakker, W. (1971). Three new beetles vectors of rice yellow mottle virus in Kenya. *Netherlands Journal of plant pathology,* 77: 201-206.

Bakker, W. (1974). Characterization and ecological aspect of rice yellow mottle virus in Kenya. Agricultural Research Doctoral thesis, University of WASeningen, the Netherlands, 152p.

Bakker, W. (1975). Rice yellow mottle virus CMI/AAB Descriptions of Plants Viruses No. 149.

Banwo, O.O., Makundi, R.H., Abdallah, R. S., Mbapila, J. C. and Kimmins, F.M. (2002a). Bionomics and importance of two species of *Chaetocnema* in Rice yellow mottle virus transmission in lowland rice in Tanzania. *Phytoparasitica* ,30: 96-104.

Banwo, O. O., Winter, S., Koerbler, M., Abdullahi, L. Abdullah, R. S. and Marundi, R. H. (2002b). Molecular characterization of rice yellow mottle virus isolates from Tanzania 1n: 8th Int. plant virus Epidemiology symp. May 12-17, 2002-|Aschersleben, Germany.

Banwo, O. O., Alegbejo, M. D. and Abo, M. E. (2004a). Rice yellow mottle virus genus Sobemovirus: A continental problem in Africa. *Plant Protection Science,* 40: 26-36.

Banwo, O. O., Winter, S., Koerbler, M., Abdallah, N. and Makundi, R. H. (2004b). Molecular variability and distribution of Rice yellow mottle virus in Tanzania. *Acta Virologica,* 48: 67-71.

Boccard, F. and Baulcombe, D. (1993). Mutational analysis of Cis-acting sequence and gene function in RNA 3 of cucumber mosaic mosaic virus. *Virology*,198: 563-578 .

Bosque-Perez, N.A., Olojede, S.O. and Buddenhagen, I.W. (1998). Effect of maize streak virus disease on the growth and yield of maize as influenced by varietal resistance levels and plant stage at time of challenge. *Euphytica* 101: 307-317.

Breniere, J. (1983). Principal insect pests of rice in West Africa and their control. WARDA publication. Monrovia Liberia, second edition 87pp.

Brugidou, C., Bonneau, C., Ngon., A., Ayassi, M. Holt, C., Beach, R. N. and Fauquent, C.M. (1995). An infectious full length cDNA clone of RYMV. A molecular tool for Engineering Virus Resistance and Developing a viral expression vector. Paper presented at the 1st Int. Symp. On RYMV 18-22 September, 1995, Mbe WARDA/ADRAQ, Bouake, Cote d'Ivoire.

Buddenghagen, I.W. (1983). Disease Resistance in Rice. In: Durable resistance in crops (Lamberti, F., Walter, J. M. and Graaf, M.A. eds). Plenum publishing corporation 1983 pp. 401 – 428.

Chen, C. C. (1991). Epidemiology and control of insect transmitted disease of rice. Taiwan proceedings of the international workshop on the implementation of integrated control of virus disease of important crops, held in TARI, Taiwan, April, 9-14, 1990.

Chiu, M. T., Chiu, Y.C. and Wu, Y.L. (1986). Studies on the epidemiology of and varietal resistance in rice stripe disease. *Journal Agricultural Association China,* 135**:** 56-621.

Clark, M. K. and Adams, A.N. (1977). Characteristics of the micro plate method of enzyme linked immunosorbent assay for the detection of plants viruses. *Journal of General Virology,* 34**:** 475-483.

Cardove, A.R., Talelsnik, E., Brunoto, N. and Racca, R. (1995). Mitigation of tomato spotted wilt virus infection and symptom expression by water stress. *Journal of phytopathology,* 133: 255- 263.

Coulibaly, Y. M. (1995). Le *RYMV* ou mosaique du riz. Une menance pour I'intensification de la riziculture a I office du Niger, paper presented at the 1st International Symp. On RYMV Mbe, 18-22 September 1995, WARDA/ADRAQ, Bouake, Cote d'Ivore.

Danson, I. N. (1994). Screening rice varieties for resistance to Rice yellow mottle virus in Kenya. *International Rice Research Notes,* 19 (3): 11-12.

Dijkstra, J. and De-jagar, C. P. (1998). Practical plant virology. Protocol and excercises. Newyork : Springer Varley Berlin Heidolberg.

Edwardson, I. R., Puricifull, D. E. and Chritie, R.G. (1966). Electron microscropy of two small spherical plants viruses in thin sections. *Canadian Journal of Botany,* 44**:** 821.

Fagade, S.O., Pillai, P.G. and Kehinde, J. K. (1988). Improved rice varieties released in Nigeria. *International Rice Research Newsletter,* 3:1.

FFTC (1991) (Food and Fertilizer Technology Centre for the ASPAC. Integrated control of plant virus disease. In proceeding of the international workshop on the implementation of integrated control of virus disease of important crops held 10-12 June, 1991 in Tar, Taiwan.

FAO (1994). Annual Report Research Highlights, Rome, Italy.

FAO (2001a). Annual Report Research Highlights. Rome, Italy 2:22-23.

FAO (2001b). Bulletin of statistics Food and Agriculture Organization Rome 2(2):22.

FAO (2003). Bulletin of statistics Food and Agriculture Organization Rome 4 (10):22.

Fargette, D., Pinel, A., Albar, L., Sadiky, R., Nguessan, P., Frutos, R.., Nottengham, J. L. and Ghesquine, A. (1995). Assessment of biological, serological and molecular variability of a range of RYMV isolates from different geographical areas. Paper presented at the 1st International Symposium on RYMV, 18-22 september, 1995 Mbe,WARDA/ADRAO, Bouake, Cote d"Ivoire.

Fargette, D., Pinel, A., Halimi, H., Brugidau, C., Fauquent, C., and Van-Regenmortel, M. (2002). Comparing of molecular and immunological typing of isolates of Rice yellow mottle virus. *Archieves of Virology,* 147**:** 583-596.

Fargette, D. and Konaté, G. (2004). An overview of Rice yellow mottle virus. In: proceeding of a Conference organized by IITA; Plant Virology for Sub-Saharan Africa 4-8 June 2001, Ibadan, Nigeria. 1-17.

Fargette, D., Pinel, A., Abubakar, Z., Traore, O., Brugidou, C., Fatogoma, S., Hebrard, E., Choisy, M., Sere, Y., Fauquet, C. and Kanote, G. (2004). Inferring the evolutionary history of Rice yellow mottle virus from genomic, phylogenetic and phylogeographic studies. *Journal of Virology,* 78(7)**:** 3252-3261.

Fargette, D., Pinel, A., Rakotomalala, M., Sangu, E., Traoré, O.,Sérémé, D., Sorho, F., Issaka, S., Hébrard, E., Séré, Y., Kanyeka, Z. and Konaté, G. (2008). Rice yellow mottle virus, an RNA plant virus, evolves as rapidly as most RNA animal viruses. *Journal of Virology,* 82: 3584–3589.

Fauquet, C. M. and Thouvenel, J. C. (1977). Isolation of Rice yellow mottle virus in Cote d'Ivoire. *Plant Disease Reporter,* 61: 443-446.

Fauquet, C.M. and Thouvenel, J.C. (1987). Plant viral disease in Ivory Coast, initiations documentation techniques no 46 ORSTOM, Paris 243pp.

Fauquet, C. M., Brugidiou, C., Koussi, N., Bonneous, C., Ngon, A., Ayassi, M., Opalka, N., Yeager, M. and Beachy, R. N. (1995). Rice yellow mottle virus: A threat to African farmers and a model for plant virologists. Paper presented at the 1st International Symposium on RYMV, 18-22 september, 1995 Mbe,WARDA/ADRAO, Bouake, Cote d"Ivoire.

Fischer, A. L., Ramire, H.V., Gibson, K. D. and Pinheiro, B.D.S. (2001). Competitiveness of semi dwarf upland rice cultivar against palisade grass (*Bruchiara brizantha*) and signal grass (*Brachiara decumbens*). *Agronomy Journal, 95* (5): 967-973.

Fomba, S. N. (1988). Screening for seedling resistance of rice yellow mottle virus in some rice cultivar in Sierra Leone. *Plant Disease* , 72**:**641-642.

Fomba, S. N. (1990). Rice yellow mottle virus on Swamp rice in Guinea. *IRRI Newsletter,* 15**:**6.

Francki, R.I.B., Miline, R. and Italita, T. (1985). Atlas of plant viruses, Vol. 1. pp 153-169. CRC press, BocaRaton, FLO.

Fulton, J.P., Gergerich, R.C. and Scott, H.A. (1987) Beetle transmission of plant viruses. *Annual Review of Phytopathology,* 25:111-123.

Ghesquere, A., Albar, L., Loreux, M., Ahmadi, N., Fargette, D. , Huong, N., McCouch, S.R. and Notteghem, J .L. (1997). A major quantitative trait locus for rice yellow mottle virus resistance maps to a cluster of blast resistance genes on chromosomes *Phytopathology,* 87: 1243-1349

Gnanamanickam, S.S. (2009). Biological Control of Rice Diseases. Vol.8, Springer.The Netherlands, pp:13-42.

Goa, S. Tanji K. K. and Scardaci S. C. (2004). Impact of rice straw incorporation on soil redox status and sulfide toxicity. *Agronomy Journal,* 96 (1): 70-76.

Gomez, K. A. and Gomez, A. A. (1984). Statistical procedure for Agricultural Research 2nd edition, John Willey and sons. 653 pp.

Hamadoun, A., Coulibaly, M. Coulibaly, M. Y. and Ahmadu, M. (1995). Status de la marbure du riz au Mali: Cas de I' office du Niger. Paper presented at the 1st International symp. On RYMV, Mbe, 18-22, September; 1995, WARDA/ADRAQ, Bouake, Cote d'Ivoire.

Hammond, J., Lecoq, H. and Reccah, B. (1999). Epidemiologcal risk from mixed virus infections and transgenic plant expressing viral genes. *Advances in virus Research,* 54: 189- 314.

Hanada, K., Suzuki, Y. and Gojobori, T. (2004). A large variation in the ates of synomymous substitution for RNA viruses' transmission modes. M*olecular Biology Evaluation,* 21: 1074-1070.

Harder, D. E. and Bakker, W. (1973). African cereal streak, a new disease of cereal in East Africa. *Phytopathology,* 63: 1407-1411.

Hartman, J. X., Bath, J. E. and Hopper, G.R. (1973). Electron microscopy of virus-like particles from shoestring diseased high bush blueberry (*Vaccinium carmbocum* L). *Phytopathology,* 63**:**423**.**

Heinrichs, E.A., Sy, A. A., Akator, S.K. and Oyediran, I. (1997). Seasonal occurrence of rice yellow mottle virus in lowland rice in Côte d'Ivoire. *International Journal of Pest Management,* 44:291–297.

Hidayat, S.H., Heryadi, D. and Nurhayti, E. (2009). Use of serological based assay for the dection of pepper yellow leaf curl Indonesia virus. The Korean society of plant pathology. *Plant Pathology Journal,* 25(4): 328-332.

Houston, D. F. (1972). Rice chemistry and technology. American Association of cereal chemists Inc. St. Paul Minnesota.

Hull, R. (1986). The potential for using dot-blot hybridization in the detection of plant viruses in: R.A.C. Torrance, L. (eds) development and applications in virus testing. *Development Application Biology,* **1:**3-12.

Hull, R. (1988). The Sobemovirus group. In Koening I.K. (eds). The plant viruses. Vol 3. polyhedral virus with monopartite RNA genomes. Plenum press, New York.

Hull, R. (1989). The movement of viruses in plants. *Annual Review of phytopathology,* 27: 213- 240.

Hynes, E. (2007). "Rice" Microsoft Student (DVD) Redmond WA Microsoft Corporation 2006.

IITA (1977). International Institute of Tropical Agriculture (IITA), Ibadan Nigeria. Rice Research Program, Annual Report, pp.20-21.

IITA (1981). Annual Report, Research highlights IITA, Ibadan Nigeria. pp. 66.

IITA (1982). Rice Research Program, Annual Report, Ibadan, Nigeria. pp. 116.

IITA (1984). Annual Report, Rice improvement programme, IITA, Ibadan, Nigeria. pp 19-22.

IITA (1986). Annual Report, Research highlights, IITA, Ibadan, Nigeria. pp. 130-132.

IRRI (1988) (International Rice Research Institute). Standard Evaluation System for rice Los Banus, Laguna, the Phillipines 3rd edition pp 23.

IRRI (1996). INGER. Genetic Resources Centre Standard Evaluation system for Rice, IRRI, Los Banus the Philippines 4th edition pp. 25.

John, V. T. and Thottappilly, G. (1987). A Scoring System for Rice yellow mottle virus *International Rice Research Newslette,r* 12:26.

John, V. T. and Thottapilly, G. and Awoderu, V.A. (1984). Occurrence of rice yellow virus in some Sahelian countries in West Africa. *FAO Plant Protection Bulletin,* 32**:**86-87.

John, V. T., Masayo, T. M. and Thottapilly, G. (1986). Breeding rice for resistance to rice yellow mottle virus. *IITA Research Briefs,* **7**:4-5.

Kanyeka, Z..L., Kibanda, J. and Mbapila, J. (1996). Rice yellow mottle virus in Tanzania. In: Seminar, potential and constraints for improvement of rice cultivation in Tanzania, 11-13 March, 1996, KATC, Moshi, Tanzania.

Kanyeka, Z. L., Sanya, E., Fargette, D., Pinel-Galzi, A. and Herbrard, E. (2007). Distribution and diversity of local strains of rice yellow mttle virus in Tanzania. *African Crop Science Journal,* 15(4) :201-209.

Kissimoto, R. (1969). Ecology of Insect vectors, forecasting and chemical control, in: Virus disease of the rice plant pp 243-255. Baltimore Maryland, John Hopkins press.

Koening, R. (1981). Indirect ELISA methods for the broad specificity detection of plant viruses. *Journal of General Virology* , 55:53-62.

Koklu, G. and Yilmazi, O. (2004). Research on Rice ragged stunt and Rice yellow mottle viruses and rice in Edime, Turkey. *Cereal Research Commission* ,32(3): 389-395.

Konate, O. (1995). Les Hotes relais du RYMV au Burkina Faso. Paper presented at the 1st International Symposium of RYVM from 18-22 September, 1995, Mbe, MARDA/ADRAQ, Bouke, Coted'Ivoire.

Konate, G. O., Sarra, S. and Traore, O. (2002). Rice yellow mottle virus is seed-borne but not seed transmitted in rice seeds. *European Journal of Plant Pathology,* 107**:**361-364.

Konaté, G. and Fargette, D. (2001). Overview of rice yellow mottle virus. In proceeding of a Conference organized by IITA; Plant Virology for Sub-Saharan Africa held 4-8 June 2001, Ibadan, Nigeria.

Konate, G.O., Traore, O. and Coulibaly, M. (1997). Characterization of rice yellow mottle virus isolates in Sudano-Sahelian area. *Archives of Virology,* 142**:**1117-1124.

Kouassi, N. K., N'Guessan, P., Albar, L., Fauquet, C., Brugidou, C. (2005). Distribution and characterization of Rice yellow mottle virus: a threat to African farmers. *Plant Disease,* 89:124-132.

Kwaga, J. K. P. (2006). Introduction to Molecular Genetics. Ahmadu Bello Uniersity, Press Limited Samaru, Zaria, Nigeria pp. 120.

Lingle, Z. and Micheal, C.S. (2000). Effects of salinity on grain yield component of rice at different seedlings densities. *Agronomy Journal,* 92**:**418-425.

Luth, B.S. (1980). Rice production and utilization. AVI publishing co Westport CT.

Luo, Y. and Zeng, S. M. (1995). Simulation studies on epidemics of wheat stripe rust (*puccina striformis)* on slow rusting cultivars and analysis of effects of resistance component. *Plant Pathology,* 44(2): 340-349.

Luzi-Kihupi, A. Mcozi, M.R.S., Mahagala, R.B., Mushobozy, D.M.K. and Nchimbi-msolla, S. (2000). Occurrence of rice yellow mottle virus in Tanzania. *Tanzania Journal of Agricultural Science,* **3** (2): 87-96.

Luzi-Kihupi, A. (2001). Rice yellow mottle virus in Tanzania. In Rice Research Workshop for rice researcher in Kenya, Malawi, Tanzania and Zambia, March 12-16, 2001. kilimanjaro Agricultural and Trainy Centre, Moshi, Tanzania.

Mansour, A. N. and Baillis, K. W. (1994). Serological relationship among rice yellow mottle virus isolates. *Annals of Applied Biology,* 125: 133-140.

Matthews, R.E.F. (1991). Plant Virology. Academic Press, London, UK. 835 PP.

Maudit, C. C. and Browning, J. A. (1995). Genetic diversity and cereal rust management.In: the cereal rust vol 11 New York USA Academic Press. pp 527-560

Mbodj. Y., Sidibe, B. D. and Sere, Y. (1984). Rice phytosanitary problem in the Sahel and attempts for solution. Paper presented at an international seminar organized by CILSSM on the integrated management of pests and disease in the Sahel, Niamey, Niger, 6-13 Dec. 1984.

Mohammed, N.A. and Mossop, D. W. (1981). Cynosurus and Cocks foot mottle viruses: a comparison. *Journal of General Virology,* 55**:** 63.

Moore, S. S. (1993). Examining the origins of emerging viruses. In Moore S. S. (ed) Emerging Viruses. New York Oxford University Press 10-28.

Ndjiondjop, M.N., Albar, L., Fargette, D., Fauquet, C. M. And Ghesquiere, A. (1999).The genetic basis of high resistance to rice yellow mottle virus species. *Plant Disease,* 83: 931 – 935.

Ng, N. Q. (1988). Use of African rice germplasm. In: proceedings of the international workshop on rice testing program for Africa, October 1987, Saint Louis, Senegal.

N'Guessan, N. P. Sy. A. A. and Fargette, D. (1995).Charaterization Biologique at Seroqiqus d' isolats du virus de la morbrare du riz en. Cote d"Ivoire. Paper presented at the 1st International Symposium on RYMV, 18-22 september, 1995 Mbe,WARDA/ADRAO, Bouake, Cote d"Ivoire.

N'Guessan, P., Pinel, A., Caruana, M., Frutos, R., Sy, A., Ghesquiere, A., and Fargette, D. (2000). Evidence of the presence of two serotypes of Rice yellow mottle sobemovirus in Côte d'Ivoire. *European Journal of Plant Pathology*. 106:167- 178.

N'Guessan, P. N., Pinel, A., Sy., A. A., Ghesquire, A. and Fargette, D. (2001). Distribution, pathogenicity and interactions of two strains of Rice yellow mottle virus in forested and savanna zones of West Africa. *Plant Disease,* 85(1): 59-64.

Nwilene, F. E., Sere, Y., Ndjonodjop, M. N., Abo, M. E., Traore, A. K., Asidi, A. N., Onasanya, A., Togola, A. and Agunbade, T. A. (2009a). Rice yellow mottle virus (RYMV) and its insects vectors: ecology and control- field guide and technical manual. WARDA, Cotonou, 36 pp.

Nwilene, F. E., Traore, A. K., Asidi, A. N., Sere, Y., Onasanya, A. and Abo, M.E. (2009b). New records of insect vectors of Rce yellow mottle virus (RYMV) in Cote d'Ivoire, West Africa. *Journal of Entomology,* 6: 189-197.

Ochola, D. and Tuslime, G. (2011a). Survey on incidences and severity of Rice yellow mottle virus disease in Eastern Uganda. *International Journal of Plant Pathology,* 2: 15-25.

Ochola, D. and Tuslime, G. (2011b). Pathogenicity of Rice yellow mottle virus and the potential sources of resistance against the disease in Eastern Uganda. *Asian Journal of Plant pathology,* 5 (1): 1-15.

Okioma, S.N.M., Mackoki, R.N. and Gathuru, E.M. (1983). Alternate hosts of rice yellow mottle virus in the Lake Victoria Basin in Kenya. *Tropical Pest Management,* 29 (3): 295-296.

Onasanya, A., Sere Y., Nwilene, F., Abo, M. E. and Akator, K. (2004). Reactions and resistance status of differential rice genotypes to rice yellow mottle virus Genus Sobemovirus in Cote d'Ivoire. *Asian Journal of plant science,* 3 (6):718-723.

Onasanya, A., Nwilene, F. E., Sere, Y. and Abo, M. E. (2006). Screening for Rice yellow mottle virus resistance using insect vectors .Africa Rice Congress 31, July -4 August 2006 Dar es Salaam, Tanzania.

Onasanya, R. O., Olafolaji, D. B., Onasanya, A., Sere, Y., Nwilene, F. E., Wopereis, M. and Kiepe, P. (2011). Occurrence, distribution and characterazation of Rice yellow mottle virus genus Sobemovirus in Southwest , Nigeria. *Trends in Applied Sciences Research,* 6: 1301-1323.

Onasanya, A., Joseph, A., Olafolaji, D.B., Ekperigin, M.M., Sere, Y., Nwilene, F.E., Kiepe, P. and Onasanya, A. (2012). RYMV Serological detection in insect vector, distribution and transmission to rice cultivars. *Trends in Applied Sciences Research,* 7: 46-56.

Onwughalu, J. T., Abo, M.E., Okoro, J.K., Onasanya, A. and Sere, Y. (2010). The effect of Rice yellow mottle virus infection on the performance of rice (*Oryza sativa* L.) relative to time of infection under screenhouse condition. *Journal of Applied Science,* 10: 1341-1344.

Onwughalu, J. T., Abo, M. E., Okoro, J. K., Onasanya, A. and Sere, Y. (2011). Rice yellow mottle virus infection and reproductive losses in rice *(Oryza sativa* Linn.) *Trends in Applied Science Research,* 6: 182-189.

Onyishi, G. C., Ajagu, C. O., Omucha, E. R., Okperie, E. O. and Dialoke, S. A. (2010). Evaluation of the performance of upland rice cultivars as affected by fertilizer levels in a clay loam ultisol. *The Nigerian Agricultural Journal,* 41(1): 71-76.

Opakla, N., Fauquent, C. M., Johnson, J. Beachy, R. N. and Yeager, K. (1995). Three dimensional structure analysis of *RYMV*. In 1st International symposium on RYMV, Mbe, 18-22 September 1995 WARDA/ADRAQ, Bouake Cote d'Ivoire.

Ou, S. H. (1985). Rice Disease 2nd edition. Kew Commonwealth Mycological Institute, England.

Pinel-Galzi, A. and Fargette, D. (2006). First report of rice yellow mottle virus in rice in Uganda. *Plant Disease,* 90: 683.

Pinel, A., N'Guerssan,. P., Bousalem, M. and Fargette, D. (2000). Molecular variability of geographical distinct isolates of rice yellow mottle virus in Africa. *Archieves of Virology,* 145**:**1621-1638.

Pinto, Y. M., Rossan, A. and Baulcombe, D . (1999). Resistance to rice yellow mottle virus (RYMV) in cultivated African rice varieties containing RYMV transgenes. *Nature Biotechnology*, 17: 702 – 707.

Pinto, Y. M. (2000). Transgenic resistance to Rice yellow mottle virus disease: highlighting some of the issues facing the potential introduction of biotechnological product into Africa. *Agricultural Biotechnology Newsletter,* 2**:**1-4.

Pixley, K.V., Boote, K.J., Shokes, F.M. and Corbert, D.W. (1990). Disaeses progression and leaf area dynamics of four peanut genotypes differing in resistance to late leafspot. *Crop Science,* 30(4): 789- 796.

Raymundo, S. A. (1980). Disese of rice in Sierra Leone: Technical bulletin No.1 Rokupr, Sierra Leone Rice Research station.

Raymundo, S. A. and Buddenhagen, I. W. (1976). A rice disease in West Africa *International Rice Commission Newslette,r* 29:51-53.

Raymundo, S. A. and Konteh, I. K. (1980). Distribution, importance, screening method and varietals reaction to rice pale yellow mottle disease. *International Rice Commission newsletter,r* 29**:**51-53.

Raymundo, S. A., Buddenhaghen, I. W., Fomba, S. N. and Akinbbo- Betts, D. T. (1979). Recent advances in knowledge of rice viruses and resistance to a beetle transmitted mottle of rice in West Africa. In seminar proceedings No. 6, Rice breeding and varietals improvement II West Africa rice development association, pp 203-212, September 13-17, 1979.

Reckhaus, P. M. and Adamou, I. (1986). Rice disease and their economic importance in Niger. *FAO Plant Protection Bulletin,* 34**:**77-82.

Reckhaus, P. M. and Adriamasintseheno, H. E. (1995). Development of an IPM strategy to fight RYMV and constraint to its implementation in Madagascar; paper presented at the 1st International Symposium on RYMV 18-22 Sept., 1995 Mbe, WARDA/ADRAQ, Bouake Cote d'Ivoire.

Reckhaus, P. M. and Adriamasintseheno, H. E. (1997). Rice yellow mottle virus in Madagascar and its epidemiology in north west of the Island. *Journal of Plant Disease Protection,* 104(3): 289-295.

Reckhaus, P. M. and Randrianangaly, S. (1990). Rice yellow mottle virus (RYMV) on rice in Madagascar. *International Rice Research Newsletter*,15: 30.

Rossel, H. V. and Thottappilly, G. (1985). Virus disease of important food crops in tropical Africa. IITA publication series, IITA, Ibadan, Nigeria 67 pp.

Rossel, H. W. and Thottappilly, G. (1988). Control of virus disease in Africa's major food crops through breeding for resistance. In: Virus Disease of plants in Africa (Williams, A. O., Mbiele, A.L. and Nkouka, N. (eds)), pp.169-187 OAU/STRC, Scientific publications Lagos, Nigeria.

Rossel, H. W., Thottappilly, G. Adenti, A. A. and Alam, K. Z. (1982a). A New record of rice yellow mottle virus disease in Nigeria. *International Rice Commission Newsletter,* 29: 51-53.

Rossel, H. W., Thottappilly, G. and Buddenhagen, I.W. (1982b). Occurrence of rice yellow mottle in virus in two important rice growing areas of Nigeria *FAO Plant Protection Bulletin.* 31:137-139.

Salaudeen, M. T. (2007). Sero-distribution, varietal resistance and wild host of Rice yellow mottle virus genus Sobemovirus in North Western Nigeria. Unpublished M.Sc. Thesis. Ahmadu Bello University, Zaria, Nigeria. pp. 130.

Salaudeen, M. T., Banwo, O. O., Kashina, B. D. and Alegbejo, M. D. (2008a). Preliminary studies on the serotypes and sero-distribution of Rice yellow mottle

sobemovirus In Northern Nigeria. *Biological and Environmental Sciences Journal for the Tropics, 5*(1): 23-25.

Salaudeen, M.T., Banwo, O. O., Kashina, B. D. and Alegbejo, M. D. (2008b). Effect of Rice yellow mottle Sobemovirus on yield in some rice cultivars. *Biological and Environmental Sciences Journal for the Tropics,* 5(1):27-34.

Salaudeen, M.T., Banwo, O. O., Kashina, B. D. and Alegbejo, M. D. (2008c). Possible wild hosts of Rice yellow mottle Sobemovirus in Northern Nigeria. *Nigerian Journal of Weed Science,* 21: 67-71.

Sarra, S. and Peters, D. (2003). Rice yellow mottle virus is transmitted by Cows, Donkeys, and Grass cuts in irrigated rice crops. *Plant Disease,* 87: 804 -808.

Sarra, S., Oevering, P., Guinda, S. and Peters, D. (2004). Wind-mediated spread of rice yellow mottle virus RYMV in irrigated rice crops. *Plant Pathology,* 53**:**143-148.

Sarra, S., (2005). Novel insight in the transmission of rice yellow mottle virus in irrigated rice. Ph.D. thesis. WASeningen University. The Netherlands, 112 pp.

SAS (1999) (Staistical Analysis System, Institute Inc), SASTAT programme. Cary North Carolina, SAS Institute Inc. 1999.

Sasaya, T., Shimizu, T., Nazu, Y., Nishiguichi, M., Inouuya, N. and Kuganazawa, H. (1997). Biological, serological and molecular variabilities of Clover yellow vein virus. *Phytopathology,* 133: 255-263.

Schalbroeck, J. J. (2001). Rice *(Oryza sativa L)* In: Raemaekers R.H. (eds). Crop production in tropical Africa Directorate General for International Cooperation (DALC) IPP 59-78.

Seghal, O. P. (1981). Southern bean mosaic virus group. In Handbook of plant virus infections, comparative Diagnosis (E. Karstak, ed) pp190-121. Elsvier/North Holland Biomedical Press Amsterdam.

Sere, Y. (1991). Phytopathlogie du riz synthesis des activities: 1990 In: Rapport d'activites du programme Riz Doc. Roneot. INERA Ouagadaugua 72-79.

Séré, Y., Onasanya, A., Afolabi, A. S. and Abo, M. E. (2005). Evaluation and potential of double immunodifusion gel essay for serological characterization of Rice yellow mottle virus isolates in West Africa. *African Journal of Biotechnology,* 4 (2): 197-205.

Séré, Y., Onasanya, A., Akator, K., Afolabi, A. S. and Abo, M. E. (2007). Serological differentiation indices and phylogenetic analysis of Rice yellow mottle virus isolates in Cote d`Ivoire. *Journal of Biological Sciences,* 7(7): 1147-1154.

Sere, Y., Onasanya, A., Nwilene, F. E., Abo, M. E. and Akator, K. (2008). Potential of insect vector screening method for development of durable resistant cultivars

to Rice yellow mottle virus disease. *International Journal of Virology,* 4: 41-47.

Shaner, G. (1981). Effect of environment on fungal leaf blight of small grains. *Annual Review of Phytopathology,* 19: 273-296.

Shoyinka, S. A. (1988). Cereal viruses in Africa, In: Virus disease of plants in Africa (Williams, A. O. *et al. (eds*) OUA/STRC. Scientific publication Lagos, Nigeria pp.225

Singh, B. N. (1995). Breeding for rice yellow mottle virus resistance. A paper presented at the 1st International Symposium of RYMV, held at WARDA, Mbe/Bouake, and 18-22 Sept. 1995.

Singh, B.N., Fagade, S., Ukwungwu, M.N., Williams, C., Jagtap, S.S., Oladimeji, O. M., Efisue, A. and Okhidieubie, O. (1997). Rice growing environment and biophysical constraints in different agro-ecological zones of Nigeria. M*eteorological Journal,* 2 (1): 35-44.

Slaton, N. A., Linscombe, S. B., Norman ,R.J., and Gbur, J.E. (2003). Seeding date effect on rice grain yield in Arkansas and Louisiana. *Agronomy Journal,* 95 (1): 218-223.

Soko, D. F., Sere, Y. and Ake, S. (2010). Effect de l'age de huit cultivars de riz sur l'expression genetique de la resistance au virus de la panachure jaune du riz . *Journal of Applied Biosciences,* 25: 1585-1593

Sorho, F., Pinel, A., Traoré, O., Bersoult, A., Ghesquière, A., Hébrard, E., Konaté, G., Séré, Y. and Fargette, D. (2005). Durability of natural and transgenic resistances in rice to Rice yellow mottle virus. *European Journal of Plant Pathology,* 112: 349-359.

Sun, H. W. Tae, S.K., Seong, W.C., Jung, G.A., Kenn, Y.C., Byung, Mozo, L., Yong, G.C., Hong, S.K., Beon, H.S., Chul, W.I. and Seong, K.J. (2006). Seperation and characterization of spikelet protein at young microspore stage in rice. *Korean Journal of Crop Science,* 51 (1):66-72.

Sy, A.A. (1994). The Integrated Pest Management Task Force (IPM-TF) monitoring Tour in Mali, November, 1994.

Sy, A.A. and Akator, K. (1993). Varietals profiles for Rice yellow mottle virus. WARDA Annual Report, 1992, 01 BP 2551 Bouake (1) Cote d'Ivoire pp 20-21.

Sy, A.A., Alluri, K. and Akator, K. (1993). Selection of RYMV resistance and estimation of RYMV induced yield loss under natural and artificial pressure. In: WARDA Annual Report for 1993. WARDA Bouake Cote d'Ivoire pp 44-45.

Taylor, D. R. (1989). Resistance of upland rice varieties to pale yellow mottle virus disease in Sierra Leone, *IRRI Newsletter,* 14**:**11.

Taylor, D. R., Fofie, A.S. and Sunna, M. (1990). Natural infection of rice yellow mottle virus on rice in Sierra Leone. *IRRI Newsletter,* 15 (5):9.

Thomas, M. D., Sissiko, I. and Sacko, M. (1996). Development of leaf anthracnose and its effect on yield and grain weight in West Africa. *Plant disease,* 89: 151-153.

Thompson, J., Higgins, O., and Gibson, T. (1994). Clustal w. improving the sensitivity of the progressive multiple sequence alignment through sequence weighting, positions gap penalties and weight matrix choice. *Nucleic Acid Research*, 2**:** 4653-4680.

Thottappilly, G. and Rossel, H.W. (1993a). Plant virus disease of importance to African Agriculture. *Journal of Phytopathology,* 134**:** 205-288.

Thottappilly, G. and Rossel, H.W. (1993b). Evaluation of resistance to Rice yellow mottle virus in *Oryza* species. *Indian Journal of Virology,* 9(1):65-73.

Thottappilly, G. Varlent, J.W.M., Rossel, H.W. and Seghal, O.P. (1992). Rottboellia yellow mottle virus. A new Sobemovirus affecting *Rotboellia cochinchinensis* (Itch grass) in Nigeria. *Annals of Applied Biology,* 112:405-415.

Thresh, J. M. (1989). Insect borne viruses of rice and the green revolution. *Tropical Pest Management* 35**:**264-272.

Thresh, J.M. (1991). The ecology of tropical plant viruses. *Plant Pathology,* 40**:**324-339.

Traore, O., Pinel, A., Fargette, D. and Konate, G. (2001). First report and characterization of Rice yellow mottle virus in Central Africa. *Plant Disease,* 85**:**920.

Traore, O., Sorho, F., Pinel, A., Abubakar, Z., Banwo, O.O., Maley, J., Herbrard, E., Winter, S., Sere, C., Konate, G. and Fargette, D. (2005). Processes of diversification and dispersion of Rice yellow mottle virus inferred from large scale and high resolution phylogeographical studies. *Molecular Ecology,* 14**:**2097-2110.

Traoré, O., Pine, A., Hébrard, E., Dieudonné Gumedzoé, M. Y., Fargette, D., Traoré S. A., and Konaté, G., (2006). Occurrence of Resistance-Breaking Isolates of Rice yellow mottle virus in West and Central Africa. *Plant Disease,* 90:259-263.

Traore, M. D., Traore, V. S., Galzi-**p**inel, A., Fargette, D.,Konate, G., Traore, A. S. and Traore, O. (2008). Abiotic transmission of Rice yellow mottle virus through soil and contact between plants. *Pakistan Journal of Biological Science,* 15 (6): 900-4.

Traore, O., Pinel-Galzi, A., Sorho, S., Rakotomalala, M., Sanga, E., Kanyeka, Z., Sere, Y., Konate, G. and Fargette, D. (2009). A reassessment of the epidemiology of Rice yellow mottle virus following recent advance in field and molecular studies. *Virus Research* ,141(2) : 258-267.

Tsuboi, T., Goto, A., Bona, B. and Kato, H. (1995). Outbreak of rice yellow mottle virus in paddy rice in Bandoma basin of Cote d'Ivoire and its epidemiological cause's paper presented at the 1st International Symposium of RYMV from 18-22 Sept. 1995, WARDA, Bouake Cote d'Ivoire.

Uzest, M., Gagara, D., Gagara, D., Dracker, M., Hebtard, E. and Gorzo, E., Candresses, T., Fereres, A., Blanc, S. (2007). A protein key to plant virus transmission at the tip of insect vector stylet. *Proceeding of National Academic Sciences*, USA. 104: 17959- 17964.

Walters, H. J. (1969). Beetle transmission of plant viruses. *Advances in virus Research,* 25: 339-363.

Walz, H. G., Schechert, A. Pernet, A., Pixley, K. V. and Geiger, H. H. (1998). A gene for resistance to Maize streak virus in the African CIMMYT maize inbred line CML202. *Molecular Breeding,* 4:147-154.

WARDA (1994). Annual Report, WARDA/ADRAQ 01 B.P. 2551, Bouake Cote d'Ivoire.

WARDA (1995). Annual Report, WARDA/ADRAQ 01 B.P. 2551, Bouake Cote d'Ivoire.

WARDA (2000) . Rice yellow mottle virus. Annual Report, 2000 Features.

Wopereis, M.C.S., Defoer, T., Idinoba, P., Diock, S. and Dugue, M. J. (2008). Participatory learning and action research for integrated rice management in inland valleys of Sub Saharan Africa. Technical Manual, Africa Rice center, Cotonou, Benin PP. 128.

Yaboue, W. N. (1989). Screening for resistance to RYMV in Cote d'Ivoire. In: Report on monitoring tours to West African countries, 1988 and 1989, IRTP, Africa pp 50-51.

Zadocks, J.C. and Shein, R.D. (1979). Epidemiology and plant disease management. Oxford University press, New York. PP. 427.

Zhang, H., Li, G., Li, W. and Song, F. (2009). Transgenic strategies for improving rice disease resistance. *African Journal of Biotechnology,* 8((9): 1735-1757.

Zouzou, M. , Kouakou,T. H., Kone, M. and Issaka, S. (2008). Screening rice (*Oryza sativa* L.) Varieties for resistance to rice yellow mottle virus. *Scientific Research and Essay,* Vol.3 (9): 216-224.

APPENDICES

Appendix I: Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2008 rainy season

Month	Days	Rainfall (mm)	Average temperature (^{o}C)	Relative humidity (%)	Sunshine hours
June	1-8	78	25.62	70.25	7.9
	9-16	11.3	27.56	66.50	7.0
	17-24	27.5	26.20	80.25	5.2
	25-2	38.5	26.25	78.00	6.1
July	3-10	24.7	25.00	80.40	5.6
	11-18	90.25	26.00	82.60	6.3
	19-26	125.7	25.40	81.50	6.0
	27-3	42.6	25.00	83.40	5.1
August	4-11	136.2	24.50	87.90	5.2
	12-19	81	21.50	81.50	4.2
	20-27	69	22.36	84.62	3.2
	28-4	116	27.00	87.63	5.5
September	5-12	43	28.00	81.75	6.1
	13-20	58.2	29.00	67.25	7.6
	21-28	43.5	30.00	76.25	6.5
	29-6	63.6	27.10	76.75	7.5
October	7-14	16.3	26.50	78.00	7.6
Mean		62.67	26.07	79.09	5.92

Appendix II: Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2009 rainy season

Month	Days	Rainfall (mm)	Average temperature (^{o}C)	Relative humidity (%)	Sunshine hours
June	1-8	30.20	28.01	50.00	8.9
	9-16	9.20	26.50	65.40	7.1
	17-24	22.00	26.00	67.00	7.4
	25-2	28.00	26.02	78.63	7.6
July	3-10	80.40	25.82	75.40	9.3
	11-18	112.82	25.94	80.13	8.3
	19-26	92.10	24.63	78.90	6.0
	27-3	159.00	25.33	81.63	5.4
August	4-11	103.00	25.60	85.13	5.3
	12-19	174.60	24.75	88.40	5.3
	20-27	99.80	23.90	79.50	6.1
	28-4	127.20	24.60	80.75	5.2
September	5-12	82.70	24.25	77.90	6.3
	13-20	71.00	26.52	77.50	6.2
	21-28	7.10	26.00	71.63	6.6
	29-6	12.80	26.08	71.75	7.0
October	7-14	87.10	26.13	72.63	6.5
Mean		76.41	25.65	75.73	6.73

Appendix III: Rainfall, average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2010 rainy season

Month	Days	Rainfall (mm)	Average temperature (^{o}C)	Relative humidity (%)	Sunshine hours
June	1-8	70.60	25.00	77.51	6.7
	9-16	38.40	26.00	81.00	6.5
	17-24	59.40	25.00	87.00	6.0
	25-2	93.30	24.50	88.25	6.7
July	3-10	79.00	23.50	90.50	6.3
	11-18	81.00	24.00	95.25	5.3
	19-26	93.00	22.00	94.50	4.7
	27-3	113.80	21.00	95.00	6.1
August	4-11	192.00	22.00	95.13	6.2
	12-19	88.60	20.50	95.00	6.0
	20-27	184.30	21.06	96.00	6.0
	28-4	131.51	22.40	95.13	6.6
September	5-12	101.80	22.25	94.00	5.2
	13-20	96.60	24.00	95.00	6.1
	21-28	95.90	24.30	90.63	7.4
	29-6	80.30	25.63	88.50	7.3
October	7-14	63.10	25.50	83.00	8.6
Mean		97.80	23.50	90.67	6.34

Appendix IV: Average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2008/2009 dry season

Month	Days	Average temperature(^{o}C)	Relative humidity (%)	Sunshine hours
December	10-17	24.70	18.75	9.3
	18-20	21.90	18.90	8.2
	21-1	22.21	16.71	9.1
January	2-9	22.63	14.13	9.2
	10-17	24.70	16.00	9.3
	18-25	23.81	17.50	8.4
	26-2	25.40	10.00	9.4
February	3-10	26.20	10.50	9.1
	11-18	26.50	8.50	6.1
	19-26	27.56	10.40	8.4
March	27-6	27.00	7.50	7.2
	7-14	27.93	11.13	6.4
	15-22	29.44	14.13	7.7
	23-30	30.75	7.13	7.4
April	1-8	30.31	35.90	7.5
	9-16	31.50	46.13	9.9
Mean		26.44	16.46	8.27

Appendix V: Average temperature, relative humidity and Sunshine hours at 8 days interval during the period of experiment at Zaria environs, 2009/2010 dry season.

Month	Days	Average temperature(^{o}C)	Relative humidity (%)	Sunshine hours
December	10-17	24.00	18.12	9.3
	18-20	23.60	11.00	8.4
	21-1	19.00	13.00	8.7
January	2-9	22.00	13.00	9.2
	10-17	25.70	12.00	8.9
	18-25	26.70	13.00	9.1
	26-2	27.50	13.00	8.8
February	3-10	26.00	10.00	8.6
	11-18	28.00	10.00	9.8
	19-26	32.00	10.50	9.0
March	27-6	32.00	8.00	10.1
	7-14	32.44	20.00	9.7
	15-22	33.60	19.00	8.8
	23-30	33.40	7.00	9.1
April	1-8	32.00	7.25	9.6
	9-16	33.64	28.00	9.4
Mean		28.22	13.30	9.10

Appendix VI: Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	82.25333	41.12667	5.46	0.0062
Inoculation regime(A)	4	23287.36000	5821.84000	772.64**	□ .0001
Error(a)	8	71.08000	8.88500	1.18	0.3236
Cultivar (B)	9	56134.59333	6237.17704	827.76**	□ .0001
Error (b)	18	198.14667	11.00815	1.46	0.1308
Interaction (A×B)	36	2406.64000	66.85111	8.87**	□ .0001
Error (c)	72	542.52000	7.53500		
Corrected Total	149	82722.59333			

** = Significant at P = 0.01

Appendix VII: Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	41.81333	20.90667	2.16	0.1229
Inoculation regime(A)	4	35576.42667	8894.10667	918.22**	□ .0001
Error(a)	8	108.05333	13.50667	1.39	0.2137
Cultivar (B)	9	19295.09333	2143.89926	221.33**	□ .0001
Error (b)	18	377.38667	20.96593	2.16	0.0112
Interaction (A×B)	36	2234.50667	62.06963	6.41**	□ .0001
Error (c)	72	697.41333	9.68630		
Corrected Total	149	58330.69333			

** = Significant at P = 0.01

Appendix VIII: Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	148.89333	74.44667	1.04	0.3576
Inoculation regime(A)	4	33272.62667	8318.15667	116.54**	□ .0001
Error(a)	8	486.97333	60.87167	0.85	0.5600
Cultivar (B)	9	24181.12667	2686.79185	37.64**	□ .0001
Error (b)	18	1526.57333	84.80963	1.19	0.2938
Interaction (A×B)	36	5937.90667	164.94185	2.31**	0.0013
Error (c)	72	5138.89333	71.37352		
Corrected Total	149	70692.99333			

** = Significant at P = 0.01

Appendix IX: Combined analysis of Variance for the effect of RYMV on plant height in the screenhouse from 2008 to 2010 rainy seasons .

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	150.61778	75.30889	2.25	0.0886
Year (A)	2	1217.01778	608.50889	19.76**	□ .0001
Error (a)	4	122.34222	30.58556	0.99	0.4116
Inoculation regime(B)	4	89491.09778	22372.77444	726.64**	□ .0001
Error(b)	8	292.11556	36.51444	1.19	0.3075
Cultivar (C)	9	77889.96444	8654.44049	281.09**	□ .0001
Error (c)	18	603.38222	33.52123	1.09	0.3633
Interaction					
(A×B)	8	2645.31556	330.66444	10.74**	□ .0001
(A×C)	18	21720.84889	1206.71383	39.19**	□ .0001
(B×C)	36	4576.45778	127.12383	4.13**	□ .0001
(A×B×C)	72	6002.59556	83.36938	2.71**	□ .0001
Error (abc)	268	8251.54220	30.78930		
Corrected Total	449	212963.29780			

** = Significant at P = 0.01

Appendix X: Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2008/2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	151.69333	75.84667	5.79	0.0047
Inoculation regime(A)	4	32677.00000	8169.25000	623.37**	□ .0001
Error(a)	8	50.44000	6.30500	0.48	0.8657
Cultivar (B)	9	21748.30000	2416.47778	184.39**	□ .0001
Error (b)	18	599.64000	33.31333	2.54	0.0028
Interaction (A×B)	36	3068.20000	85.22778	6.50**	□ .0001
Error (c)	72	943.56000	13.10500		
Corrected Total	149	59238.83333			

** = Significant at P = 0.01

Appendix XI : Analysis of Variance for the effect of RYMV on plant height in the screenhouse during 2009/2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	40.49333	20.24667	1.88	0.1601
Inoculation regime(A)	4	34092.16000	8523.04000	791.11**	□ .0001
Error(a)	8	110.44000	13.80500	1.28	0.2668
Cultivar (B)	9	24204.82667	2689.42519	249.63**	□ .0001
Error (b)	18	367.37333	20.40963	1.89	0.0299
Interaction (A×B)	36	2694.10667	74.83630	6.95**	□ .0001
Error (c)	72	775.69333	10.77352		
Corrected Total	149	62285.09333			

** = Significant at P = 0.01

Appendix XII: Combined analysis of Variance for the effect of RYMV on plant height in the screenhouse 2008/2009 and 2009/2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	168.00000	84.00000	7.11	0.0011
Year (A)	1	16.80333	16.80333	1.42^{ns}	0.2348
Error (a)	2	24.18667	12.09333	1.02	0.3617
Inoculation regime(B)	4	66726.51333	16681.62833	1411.13**	□ .0001
Error(b)	8	93.16667	11.64583	0.99	0.4494
Cultivar (C)	9	45782.89667	5086.98852	430.32**	□ .0001
Error (c)	18	744.33333	41.35185	3.50	0.0001
Interaction					
(A×B)	4	42.64667	10.66167	0.90^{ns}	0.4642
(A×C)	9	170.23000	18.91444	1.60	0.1187
(B×C)	36	5380.48667	149.45796	12.64**	□ .0001
(A×B×C)	36	381.82000	10.60611	0.90^{ns}	0.6389
Error (abc)	170	2009.64670	11.82150		
Corrected Total	299	121540.73000			

** = Significant at P = 0.01
Ns = Not significant

Appendix XIII: Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	2.17333333	1.0866667	3.08	0.0523
Inoculation regime(A)	4	390.2933330	97.5733333	276.15**	□ .0001
Error(a)	8	3.2266667	0.4033333	1.14	0.3467
Cultivar (B)	9	32.4600000	3.6066667	10.21**	□ .0001
Error (b)	18	13.1600000	0.7311111	2.07	0.0159
Interaction (A×B)	36	47.4400000	1.3177778	3.73**	□ .0001
Error (c)	72	25.4400000	0.3533333		
Corrected Total	149	514.1933333			

** = Significant at P = 0.01

Appendix XIV: Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	0.3733333	0.1866667	0.54	0.5828
Inoculation regime(A)	4	351.2400000	87.81,00000	255.90**	□ .0001
Error(a)	8	1.9600000	0.2450000	0.71	0.6784
Cultivar (B)	9	22.5400000	2.5044444	7.30**	□ .0001
Error (b)	18	16.9600000	0.9422222	2.75**	0.0013
Interaction (A×B)	36	24.0933333	0.6692593	1.95*	0.0081
Error (c)	72	24.7066667	0.3431481		
Corrected Total	149	441.8733333			

** = Significant at P = 0.01
* = Significant at P = 0.05

Appendix XV: Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	1.4533333	0.7266667	2.43	0.0951
Inoculation regime(A)	4	425.8000000	106.4500000	356.15**	□ .0001
Error(a)	8	1.6800000	0.21,00000	0.70	0.6882
Cultivar (B)	9	20.8000000	2.3111111	7.73**	□ .0001
Error (b)	18	10.6800000	0.5933333	1.99	0.0216
Interaction (A×B)	36	33.4000000	0.9277778	3.10**	□ .0001
Error (c)	72	21.5200000	0.2988889		
Corrected Total	149	515.3333333			

** = Significant at P = 0.01

Appendix XVI: Combined analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	1.617778	0.808889	2.17	0.1164
Year (A)	2	385.631111	192.815556	516.91**	□ .0001
Error (a)	4	2.362222	0.595556	1.60	0.1755
Inoculation regime(B)	4	1161.762222	290.441111	778.62**	□ .0001
Error(b)	8	1.782222	0.222778	0.60	0.7799
Cultivar (C)	9	38.231111	4.247901	11.39**	□ .0001
Error (c)	18	17.582222	0.976790	2.62	0.0005
Interaction					
(A×B)	8	5.568889	0.696111	1.87*	0.0655
(A×C)	18	37.568889	2.087160	5.60**	□ .0001
(B×C)	36	68.146667	1.892963	5.07**	□ .0001
(A×B×C)	72	36.786667	0.510926	1.37*	0.0393
Error (abc)	268	99.968889	0.373018		
Corrected Total	449	1857.031111			

** = Significant at P = 0.01
* = Significant at P = 0.05

Appendix XVII: Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2008/2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	1.0133333	0.506667	1.31	0.2766
Inoculation regime(A)	4	271.2000000	67.8000000	175.09**	□ .0001
Error(a)	8	4.1200000	0.5150000	1.33	0.2428
Cultivar (B)	9	29.1,000000	3.2333333	8.35**	□ .0001
Error (b)	18	6.3200000	0.3511111	0.91	0.5728
Interaction (A×B)	36	47.2000000	1.3111111	3.39**	□ .0001
Error (c)	72	27.8800000	0.3872222		
Corrected Total	149	386.8333333			

** = Significant at P = 0.01

Appendix XVIII: Analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse during 2009/2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	0.0533333	0.0266667	0.09	0.9155
Inoculation regime(A)	4	366.4666667	91.6166667	303.70**	□ .0001
Error(a)	8	3.2133333	0.4016667	1.33	0.2421
Cultivar (B)	9	29.4666667	3.2740741	10.85**	□ .0001
Error (b)	18	9.0133333	0.5007407	1.66	0.0679
Interaction (A×B)	36	33.4000000	0.9277778	3.08**	□ .0001
Error (c)	72	21.7200000	0.3016667		
Corrected Total	149	463.3333333			

** = Significant at P = 0.01

Appendix XIX: Combined analysis of Variance for the effect of RYMV on the number of tillers per plant in the screenhouse, 2008/2009 and 2009/2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	0.3466667	0.1733333	0.52	0.5971
Year (A)	1	6.7500000	6.7500000	20.15**	□ .0001
Error (a)	2	0.7200000	0.3600000	1.07	0.3438
Inoculation regime(B)	4	631.2333333	157.8083333	470.99**	□ .0001
Error(b)	8	6.3866667	0.7983333	2.38	0.0185
Cultivar (C)	9	54.3500000	6.0388889	18.02**	□ .0001
Error (c)	18	8.9200000	0.4955556	1.48	0.1027
Interaction					
(A×B)	4	6.4333333	1.6083333	4.80*	0.0011
(A×C)	9	4.2166667	0.4685185	1.40^{ns}	0.1923
(B×C)	36	71.5000000	1.9861111	5.93**	□ .0001
(A×B×C)	36	9.1,000000	0.2527778	0.75^{ns}	0.8397
Error (abc)	170	56.9600000	0.3350588		
Corrected Total	299	856.9166667			

** = Significant at P = 0.01
* = Significant at P = 0.05
Ns = Not significant

Appendix XX: Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	13.77333	6.88667	4.56	0.0137
Inoculation regime(A)	4	2990.76000	747.69000	494.92**	□ .0001
Error(a)	8	24.56000	3.07000	2.03	0.0544
Cultivar (B)	9	36893.12667	4099.23630	2713.39**	□ .0001
Error (b)	18	76.89333	4.27185	2.83	0.0009
Interaction (A×B)	36	1705.10667	47.36407	31.35**	□ .0001
Error (c)	72	108.77333	1.51074		
Corrected Total	149	41812.99333			

** = Significant at P = 0.01

Appendix XXI: Analysis of Variance for the effect of RYMV on days to 50 % flowering in the s creenhouse during 2009 rainy season .

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	5.29333	2.64667	1.46	0.2402
Inoculation regime(A)	4	3266.33333	816.58333	448.95**	□ .0001
Error(a)	8	9.30667	1.16333	0.64	0.7419
Cultivar (B)	9	38759.90000	4306.65556	2367.74**	□ .0001
Error (b)	18	62.44000	3.46889	1.91	0.0286
Interaction (A×B)	36	1146.60000	31.85000	17.51**	□ .0001
Error (c)	72	130.96000	1.81889		
Corrected Total	149	43380.83333			

** = Significant at P = 0.01

Appendix XXII: Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	129.64000	64.82000	0.97	0.3823
Inoculation regime(A)	4	5515.77333	1378.94333	20.73**	□ .0001
Error(a)	8	560.22667	70.02833	1.05	0.4056
Cultivar (B)	9	42001.17333	4666.79704	0.17**	□ .0001
Error (b)	18	1128.62667	62.70148	0.94	0.5324
Interaction (A×B)	36	2955.16000	82.08778	1.23^{ns}	0.2220
Error (c)	72	4788.84000	66.51167		
Corrected Total	149	57079.44000			

** = Significant at P = 0.01 Ns =Not significant

Appendix XXIII: Combined analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	63.0933	31.5467	1.34	0.2639
Year (A)	2	1801.4533	900.7267	38.22**	□ .0001
Error (a)	4	85.6133	21.4033	0.91	0.4596
Inoculation regime(B)	4	11417.4533	2854.3633	121.12**	□ .0001
Error(b)	8	186.9067	23.3633	0.99	0.4430
Cultivar (C)	9	112104.8089	12456.0899	28.56**	□ .0001
Error (c)	18	388.0178	21.5565	0.91	0.5611
Interaction					
(A×B)	8	355.4133	44.4267	1.89*	0.0624
(A×C)	18	5549.3911	308.2995	13.08**	□ .0001
(B×C)	36	3606.0133	100.1670	4.25**	□ .0001
(A×B×C)	72	2200.8533	30.5674	1.30*	0.0731
Error (abc)	268	6315.7022	23.5661		
Corrected Total	449	144074.7200			

** = Significant at P = 0.01
* = Significant at P = 0.05

Appendix XXIV: Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2008/2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	6732.8933	3366.4467	1.05	0.3535
Inoculation regime(A)	4	15764.0000	3941.0000	1.23^{ns}	0.3038
Error(a)	8	24988.4400	3123.5550	0.98	0.4596
Cultivar (B)	9	49366.1667	5485.1296	1.72^{ns}	0.1003
Error (b)	18	57507.7733	3194.8763	1.00	0.4690
Interaction (A×B)	36	118760.6667	3298.9074	1.03^{ns}	0.4417
Error (c)	72	229770.8933	3191.2624		
Corrected Total	149	502890.8333			

Ns = Not Significant

Appendix XXV: Analysis of Variance for the effect of RYMV on days to 50 % flowering in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	6.77333	3.38667	2.01	0.1416
Inoculation regime(A)	4	3277.13333	819.28333	486.01**	□ .0001
Error(a)	8	23.02667	2.87833	1.71	0.1113
Cultivar (B)	9	37483.23333	4164.80370	2470.61**	□ .0001
Error (b)	18	36.82667	2.04593	1.21	0.2740
Interaction (A×B)	36	1242.46667	34.51296	20.47**	□ .0001
Error (c)	72	121.37333	1.68574		
Corrected Total	149	42190.83333			

** = Significant at P = 0.01

Appendix XXVI: Combined analysis of variance for the effect of RYMV on days to 50 % flowering in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	3554.46000	1777.23000	0.12	0.3299
Year (A)	1	320.33333	320.33333	0.20^{ns}	0.6543
Error (a)	2	3185.20667	1592.60333	1.00	0.3700
Inoculation regime(B)	4	12934.00000	3233.50000	2.03*	0.0923
Error(b)	8	12596.44000	1574.55500	0.99	0.4465
Cultivar (C)	9	81759.06667	9084.34074	5.71**	□ .0001
Error (c)	18	29165.27333	1620.29296	1.02	0.4426
Interaction					
(A×B)	4	6107.13333	1526.78333	0.96^{ns}	0.4316
(A×C)	9	5090.33333	565.59259	0.36^{ns}	0.9544
(B×C)	36	63323.26667	1758.97963	1.10^{ns}	0.3289
(A×B×C)	36	56679.86667	1574.44074	0.99^{ns}	0.4948
Error (abc)	170	270686.62000	1592.2742		
Corrected Total	299	545402.00000			

** = Significant at P = 0.01
* = Significant at P = 0.05
Ns = Not significant

Appendix XXVII: Analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse during 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	57.7600	28.8800	0.27	0.7622
Inoculation regime(A)	4	152329.2000	38082.3000	359.36**	□ .0001
Error(a)	8	567.8400	70.9800	0.67	0.7163
Cultivar (B)	9	26252.4333	2916.9370	27.53**	□ .0001
Error (b)	18	2957.7067	164.3170	1.55	0.0979
Interaction (A×B)	36	27848.5333	773.5704	7.30**	□ .0001
Error (c)	72	7630.0267	105.9726		
Corrected Total	149	217643.5000			

** = Significant at P = 0.01

Appendix XXVIII: Analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	144.33333	72.16667	3.08	0.0519
Inoculation regime(A)	4	63287.82667	15821.95667	676.02**	□ .0001
Error(a)	8	106.73333	13.34167	0.57	0.7990
Cultivar (B)	9	213331.22667	2370.13630	101.27**	□ .0001
Error (b)	18	1245.13333	69.17407	2.96	0.0006
Interaction (A×B)	36	10571.50667	293.65296	12.55**	□ .0001
Error (c)	72	1685.13333	23.40463		
Corrected Total	149	98371.89333			

** = Significant at P = 0.01

Appendix XXIX: Analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	5.853333	2.926667	2.50	0.0891
Inoculation regime(A)	4	5851.800000	1462.950000	1250.19**	□ .0001
Error(a)	8	27.480000	3.435000	2.94	0.0068
Cultivar (B)	9	2567.333333	285.259259	243.77**	□ .0001
Error (b)	18	49.746667	2.763704	2.36	0.0054
Interaction (A×B)	36	1426.866667	39.635185	33.87**	□ .0001
Error (c)	72	84.253333	1.170190		
Corrected Total	149	10013.333333			

** = Significant at P = 0.01

Appendix XXX: Combined analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse from 2008 to 2010 rainy seasons..

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	98.2933	49.1467	1.01	0.3661
Year (A)	2	105453.6933	52726.8467	1082.12**	□ .0001
Error (a)	4	109.6533	27.4133	0.56	0.6900
Inoculation regime(B)	4	171065.5200	42766.3800	877.70**	□ .0001
Error(b)	8	210.8400	26.3550	0.54	0.8252
Cultivar (C)	9	32375.9756	3597.3306	73.83**	□ .0001
Error (c)	18	1084.8178	60.2677	1.24	0.2312
Interaction					
(A×B)	8	50403.3067	6300.4133	129.30**	□ .0001
(A×C)	18	17775.0178	987.5010	20.27**	□ .0001
(B×C)	36	20323.3689	564.5380	11.59**	□ .0001
(A×B×C)	72	19522.5378	271.1602	5.57**	□ .0001
Error (abc)	268	13058.3956	48.7254		
Corrected Total	449	431482.4200			

** = Significant at P = 0.01

Appendix XXXI: Analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse during 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	792.4800	396.2400	13.43	□ .0001
Inoculation regime(A)	4	107664.0933	26916.0233	912.12**	□ .0001
Error(a)	8	836.3867	104.5483	3.54	0.0016
Cultivar (B)	9	27879.7933	3099.7548	105.04**	□ .0001
Error (b)	18	675.7867	37.5437	1.27	0.2322
Interaction (A×B)	36	11417.6400	317.1567	10.75**	□ .0001
Error (c)	72	2124.6800	29.5094		
Corrected Total	149	151408.8600			

** = Significant at P = 0.01

Appendix XXXII: Analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	73.9733	36.9867	0.56	0.5725
Inoculation regime(A)	4	105658.8933	26414.7233	401.48**	□ .0001
Error(a)	8	322.6267	40.3283	0.61	0.7642
Cultivar (B)	9	26364.1933	2929.3548	44.52**	□ .0001
Error (b)	18	1401.6267	77.8681	1.18	0.2976
Interaction (A×B)	36	15917.7733	442.1604	6.72**	□ .0001
Error (c)	72	4737.1067	65.7931		
Corrected Total	149	154476.1933			

** = Significant at P = 0.01

Appendix XXXIII: Combined analysis of Variance for the effect of RYMV on number of grains per panicle in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	343.22667	171.61333	9.88	□ .0001
Year (A)	1	20435.25333	20435.25333	1177.01**	□ .0001
Error (a)	2	457.14667	228.57333	13.17	□ .0001
Inoculation regime(B)	4	80201.21333	20050.30333	1154.84**	□ .0001
Error(b)	8	461.10667	57.63833	3.32	0.0015
Cultivar (C)	9	19942.74667	2215.86074	127.63**	□ .0001
Error (c)	18	356.97333	19.83185	1.14	0.3159
Interaction					
(A×B)	4	33143.94667	8285.98667	477.25**	□ .0001
(A×C)	9	10253.61333	1139.29037	65.62**	□ .0001
(B×C)	36	8176.98667	227.13852	13.08**	□ .0001
(A×B×C)	36	4551.18667	126.42185	7.28**	□ .0001
Error (abc)	170	2951.54670	17.36200		
Corrected Total	299	181274.94670			

** = Significant at P = 0.01

Appendix XXXIV: Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	41.078100	20.539050	8.41	0.0005
Inoculation regime(A)	4	6689.002933	1672.250733	684.84**	□ .0001
Error(a)	8	33.907067	4.238383	1.74	0.1047
Cultivar (B)	9	2041.516683	226.835187	92.90**	□ .0001
Error (b)	18	95.743567	5.319087	2.18	0.0107
Interaction (A×B)	36	918.254400	25.507067	210.45**	□ .0001
Error (c)	72	175.809600	2.441800		
Corrected Total	149	9995.312350			

** = Significant at P = 0.01

Appendix XXXV: Analysis of Variance for the effect of RYMV on the paddy yield in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	36.903333	18.451667	16.62	0.7792
Inoculation regime(A)	4	9567.276667	2391.819167	2154.34**	□ .0001
Error(a)	8	10.563333	1.320417	1.19	0.7409
Cultivar (B)	9	2227.435000	247.492778	222.92**	□ .0001
Error (b)	18	36.930000	2.051667	1.85	□ .0001
Interaction (A×B)	36	824.023333	22.889537	20.62**	0.0847
Error (c)	72	79.936670	1.110230		
Corrected Total	149	12783.06833			

** = Significant at P = 0.01

Appendix XXXVI: Analysis of Variance for the effect of RYMV on the paddy yield in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	5.083333	2.541667	1.62	0.2057
Inoculation regime(A)	4	8308.560000	2077.140000	1321.15**	□ .0001
Error(a)	8	25.800000	3.225000	2.05	0.0521
Cultivar (B)	9	2340.801667	260.089074	165.43**	□ .0001
Error (b)	18	69.083333	3.837963	2.44	0.0040
Interaction (A×B)	36	762.240000	21.173333	13.47**	□ .0001
Error (c)	72	113.200000	1.572220		
Corrected Total	149	11624.76833			

** = Significant at P = 0.01

Appendix XXXVII: Combined analysis of Variance for the effect of RYMV on paddy yield in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	1.13303	0.56652	0.28	0.7530
Year (A)	2	322.10343	161.05172	80.74**	□ .0001
Error (a)	4	81.93173	20.48293	10.27	□ .0001
Inoculation regime(B)	4	24350.26431	6087.56608	3051.98**	□ .0001
Error(b)	8	10.82536	1.35317	0.68	0.7105
Cultivar (C)	9	6197.18223	688.57580	345.21**	□ .0001
Error (c)	18	95.58752	5.31042	2.66	0.0004
Interaction					
(A×B)	8	214.57529	26.82191	13.45**	□ .0001
(A×C)	18	412.57112	22.92062	11.49**	□ .0001
(B×C)	36	1867.06258	51.86285	26.00**	□ .0001
(A×B×C)	72	637.45516	8.85354	4.44**	□ .0001
Error (abc)	268	534.56069	1.99463		
Corrected Total	449	34725.25245			

** = Significant at P = 0.01

Appendix XXXVIII: Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	2.994533	1.497267	0.57	0.5676
Inoculation regime(A)	4	8647.259067	2161.814767	824.06**	□ .0001
Error(a)	8	6.318133	0.789767	0.30	0.9633
Cultivar (B)	9	2157.352067	239.705785	91.37**	□ .0001
Error (b)	18	64.564133	3.586896	1.37	0.1751
Interaction (A×B)	36	958.771600	26.632544	10.15**	□ .0001
Error (c)	72	188.883200	2.623380		
Corrected Total	149	12026.14273			

** = Significant at P = 0.01

Appendix XXXIX: Analysis of Variance for the effect of RYMV on paddy yield in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	10.189200	5.094600	3.65	0.0310
Inoculation regime(A)	4	9570.688400	2392.672100	1712.77**	□ .0001
Error(a)	8	9.346800	1.168350	0.84	0.5738
Cultivar (B)	9	2671.513067	196.834785	212.49**	□ .0001
Error (b)	18	59.976133	3.332007	2.39	0.0049
Interaction (A×B)	36	1102.855600	30.634878	21.93**	□ .0001
Error (c)	72	100.58120	1.396960		
Corrected Total	149	13525.15040			

** = Significant at P = 0.01

Appendix XL: Combined analysis of Variance for the effect of RYMV on paddy yield in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	9.82207	4.91103	2.71	0.0697
Year (A)	1	2.34083	2.34083	1.29^{ns}	0.2577
Error (a)	2	3.36167	1.68083	0.93	0.3981
Inoculation regime(B)	4	18194.97580	4548.74395	2506.20**	□ .0001
Error(b)	8	7.15160	0.89395	0.49	0.8604
Cultivar (C)	9	4773.26430	530.36270	292.21**	□ .0001
Error (c)	18	113.96860	6.33159	3.49	□ .0001
Interaction					
(A×B)	4	22.97167	5.74292	3.16 *	0.0154
(A×C)	9	55.60083	6.17787	3.40**	0.0007
(B×C)	36	2008.49887	55.79164	30.74**	□ .0001
(A×B×C)	36	53.12833	1.47579	0.81^{ns}	0.7644
Error (abc)	170	308.54940	1.81500		
Corrected Total	299	25553.63397			

** = Significant at P = 0.01
* = Significant at P = 0.05
Ns = Not significant

Appendix XLI: Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	381.05039	190.52519	3.87	0.0254
Inoculation regime(A)	4	68201.43662	17050.35916	345.95**	□ .0001
Error(a)	8	423.10427	52.88803	1.07	0.3916
Cultivar (B)	9	8852.04518	983.56058	19.96**	□ .0001
Error (b)	18	1775.52579	98.64032	2.00	0.0204
Interaction (A×B)	36	7949.76255	220.82674	4.48**	□ .0001
Error (c)	72	3548.59076	49.28598		
Corrected Total	149	91131.51556			

** = Significant at P = 0.01

Appendix XLII: Analysis of Variance for the effect of RYMV on the paddy yield loss in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	168.43180	84.21590	8.40	0.0005
Inoculation regime(A)	4	98596.09756	24649.02439	2458.54**	□ .0001
Error(a)	8	114.59029	14.32379	1.43	0.1995
Cultivar (B)	9	13383.90503	1487.10056	148.33**	□ .0001
Error (b)	18	573.87808	31.88212	3.18	0.0003
Interaction (A×B)	36	8033.18309	233.14397	22.26**	□ .0001
Error (c)	72	721.86450	10.02590		
Corrected Total	149	121591.95030			

** = Significant at P = 0.01

Appendix XLIII: Analysis of Variance for the effect of RYMV on the paddy yield loss in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	12.88085	6.44042	0.33	0.7219
Inoculation regime(A)	4	84355.98929	21088.99732	1072.09**	□ .0001
Error(a)	8	369.35776	46.16972	2.35	0.0266
Cultivar (B)	9	13073.88955	1452.65439	73.85**	□ .0001
Error (b)	18	699.48254	38.86014	1.98	0.0224
Interaction (A×B)	36	7844.95557	217.91543	11.08**	□ .0001
Error (c)	72	1416.3064	19.6709		
Corrected Total	149	107772.8619			

** = Significant at P = 0.01

Appendix XLIV: Combined analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	105.4822	52.7426	1.81	0.1653
Year (A)	2	3322.2550	1666.1275	57.24**	□ .0001
Error (a)	4	456.8778	114.2195	3.92	0.0041
Inoculation regime(B)	4	248827.3666	62206.8416	2137.10**	□ .0001
Error(b)	8	258.5242	32.3155	1.11	0.3564
Cultivar (C)	9	29217.2811	3246.3646	111.53**	□ .0001
Error (c)	18	1583.2330	87.9574	3.02	□ .0001
Interaction					
(A×B)	8	2326.1569	290.7696	9.99**	□ .0001
(A×C)	18	6092.5587	338.4755	11.63**	□ .0001
(B×C)	36	17065.8354	474.0510	16.29**	□ .0001
(A×B×C)	72	6762.0658	93.9176	3.23**	□ .0001
Error (abc)	268	7800.9432	29.1080		
Corrected Total	449	323828.5828			

** = Significant at P = 0.01

Appendix XLV: Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	0.06557	0.03278	0.00	0.9986
Inoculation regime(A)	4	86296.17183	21574.04296	932.82**	□ .0001
Error(a)	8	47.51008	5.93876	0.26	0.9775
Cultivar (B)	9	16551.93400	1839.10378	79.52**	□ .0001
Error (b)	18	500.11171	27.78398	1.20	0.2835
Interaction (A×B)	36	9151.27420	254.20206	10.99**	□ .0001
Error (c)	72	1665.20500	23.1278		
Corrected Total	149	114212.27240			

** = Significant at P = 0.01

Appendix XLVI: Analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	24.37151	12.1575	1.10	0.3371
Inoculation regime(A)	4	96798.98307	24199.74577	2192.64**	□ .0001
Error(a)	8	119.86741	14.98343	1.36	0.2299
Cultivar (B)	9	17198.64617	1910.96069	173.14**	□ .0001
Error (b)	18	438.13813	24.34101	2.21	0.0096
Interaction (A×B)	36	10846.25536	101.28487	27.30**	□ .0001
Error (c)	72	794.6493	11.0368		
Corrected Total	149	126220.9190			

** = Significant at P = 0.01

Appendix XLVII: Combined analysis of Variance for the effect of RYMV on paddy yield loss in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons .

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	11.6858	5.8429	0.37	0.6923
Year (A)	1	0.8374	0.8374	0.05^{ns}	0.8185
Error (a)	2	12.7513	6.3757	0.40	0.6695
Inoculation regime(B)	4	182823.7009	45705.9252	2883.41**	□ .0001
Error(b)	8	83.0124	10.3765	0.65	0.7307
Cultivar (C)	9	33647.1373	3738.5708	235.85**	□ .0001
Error (c)	18	787.7398	43.7633	2.76	0.0003
Interaction					
(A×B)	4	271.4540	67.8635	4.28 **	0.0025
(A×C)	9	103.4429	11.4937	0.73^{ns}	0.6855
(B×C)	36	19508.4024	541.9001	34.19**	□ .0001
(A×B×C)	36	489.1272	13.5869	0.86^{ns}	0.7005
Error (abc)	170	2694.7294	15.8513		
Corrected Total	299	240434.0207			

** = Significant at P = 0.01
* = Significant at P = 0.05
Ns = Not significant

Appendix XLVIII: Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	2.073733	1.036867	1.44	0.2437
Inoculation regime(A)	4	5462.267733	365.566933	1896.39**	□ .0001
Error(a)	8	3.272267	0.409033	0.57	0.8006
Cultivar (B)	9	2036.994400	226.332711	314.31**	□ .0001
Error (b)	18	37.927600	2.107089	2.93	0.0007
Interaction (A×B)	36	1599.981600	44.443933	61.72**	□ .0001
Error (c)	72	51.846400	0.720089		
Corrected Total	149	9194.363733			

** = Significant at P = 0.01

Appendix XLIX: Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	1.083333	0.541667	0.34	0.7155
Inoculation regime(A)	4	4774.360000	1193.590000	741.27**	□ .0001
Error(a)	8	15.800000	1.975000	1.23	0.2962
Cultivar (B)	9	2236.535000	248.503889	154.33**	□ .0001
Error (b)	18	87.350000	4.852778	3.01	0.0005
Interaction (A×B)	36	1024.506667	4.852778	17.67**	□ .0001
Error (c)	72	115.933333	1.610185		
Corrected Total	149	8255.568333			

** = Significant at P = 0.01

Appendix L: Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	189.00000	94.50000	0.73	0.4873
Inoculation regime(A)	4	79318.57333	19829.64333	152.36**	□ .0001
Error(a)	8	1198.66667	149.83333	1.15	0.3406
Cultivar (B)	9	18485.57333	2053.95259	15.78**	□ .0001
Error (b)	18	2464.86667	136.93704	1.05	0.4164
Interaction (A×B)	36	17041.56000	473.37667	3.64**	□ .0001
Error (c)	72	9370.80000	130.15000		
Corrected Total	149	128069.04000			

** = Significant at P = 0.01

Appendix LI: Combined analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	68.88458	34.44229	0.75	0.4718
Year (A)	2	31003.37551	15501.68776	339.08**	□ .0001
Error (a)	4	123.27249	30.81812	0.67	0.6105
Inoculation regime(B)	4	59081.36836	14770.34209	23.08**	□ .0001
Error(b)	8	390.65964	48.83246	1.07	0.3857
Cultivar (C)	9	14814.35336	1646.03926	6.00**	□ .0001
Error (c)	18	703.60698	39.08928	0.86	0.6339
Interaction					
(A×B)	8	30473.83271	3809.22909	83.32**	□ .0001
(A×C)	18	7944.74938	441.37497	9.65**	□ .0001
(B×C)	36	9849.02142	273.58393	5.98**	□ .0001
(A×B×C)	72	9817.02684	136.34760	2.98**	□ .0001
Error (abc)	268	12252.19630	45.71720		
Corrected Total	449	176522.34760			

** = Significant at P = 0.01

Appendix LII: Analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse during 2008/2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	26.723333	13.361667	12.22	□ .0001
Inoculation regime(A)	4	5081.640000	1270.41,0000	1162.16**	□ .0001
Error(a)	8	30.160000	3.770000	3.45	0.0020
Cultivar (B)	9	2565.748333	285.083148	260.79**	□ .0001
Error (b)	18	43.576667	2.420926	2.21	0.0093
Interaction (A×B)	36	1475.493333	40.985926	37.49**	□ .0001
Error (c)	72	78.706667	1.093148		
Corrected Total	149	9302.048333			

** = Significant at P = 0.01

Appendix LIII: Analysis of Variance for the effect of RYMV on threshing percentage the screenhouse during 2009/2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	7.893333	3.946667	4.88	0.0103
Inoculation regime(A)	4	5681.066667	1420.266667	1756.23**	□ .0001
Error(a)	8	4.173333	0.521667	0.65	0.7373
Cultivar (B)	9	2298.566667	255.396296	315.81**	□ .0001
Error (b)	18	70.373333	3.909630	4.83	□ .0001
Interaction (A×B)	36	1310.533333	36.403704	45.01**	□ .0001
Error (c)	72	58.226667	0.808704		
Corrected Total	149	9430.833333			

** = Significant at P = 0.01

Appendix LIV: Combined analysis of Variance for the effect of RYMV on threshing percentage in the screenhouse, 2008/2009 and 2009/2010 dry seasons .

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	16.66167	8.33083	0.25	□ .0001
Year (A)	1	18275.40750	18275.40750	546.92**	□ .0001
Error (a)	2	84.03500	42.01750	1.26	□ .0001
Inoculation regime(B)	4	77489.85333	19372.46333	579.75**	□ .0001
Error(b)	8	191.99667	23.99958	0.72	0.0015
Cultivar (C)	9	19727.24083	2191.91565	5.60**	□ .0001
Error (c)	18	741.22167	41.17898	1.23	0.3159
Interaction					
(A×B)	4	33250.68000	312.67000	48.77**	□ .0001
(A×C)	9	9202.70083	1022.52231	30.60**	□ .0001
(B×C)	36	10577.51333	293.81981	8.79**	□ .0001
(A×B×C)	36	6815.75333	189.32648	5.67**	□ .0001
Error (abc)	170	5680.58500	33.41520		
Corrected Total	299	182053.64920			

** = Significant at P = 0.01

Appendix LV: Analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	6.790000	3.395000	8.09	0.0007
Inoculation regime(A)	4	1149.040000	287.260000	684.71**	□ .0001
Error(a)	8	3.260000	0.407500	0.97	0.4653
Cultivar (B)	9	3122.406667	346.934074	826.95**	□ .0001
Error (b)	18	20.243333	1.124630	2.68	0.0016
Interaction (A×B)	36	186.293333	5.174815	12.33**	□ .0001
Error (c)	72	30.206667	0.419537		
Corrected Total	149	4518.240000			

** = Significant at P = 0.01

Appendix LVI: Analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	9.823333	4.911667	7.04	0.0016
Inoculation regime(A)	4	1331.756667	332.939167	477.46**	□ .0001
Error(a)	8	6.193333	0.774167	1.11	0.3667
Cultivar (B)	9	2694.681667	299.409074	429.37**	□ .0001
Error (b)	18	52.943333	2.941296	4.22	□ .0001
Interaction (A×B)	36	116.643333	3.240093	4.65**	□ .0001
Error (c)	72	50.206667	0.697315		
Corrected Total	149	4262.248333			

** = Significant at P = 0.01

Appendix LVII: Analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	19.053333	9.526667	10.10	□ .0001
Inoculation regime(A)	4	1175.373333	293.843333	311.49**	□ .0001
Error(a)	8	17.546667	2.193333	2.33	0.0280
Cultivar (B)	9	2956.773333	328.530370	348.27**	□ .0001
Error (b)	18	22.146667	1.230370	1.30	0.2115
Interaction (A×B)	36	331.960000	9.221111	9.78**	□ .0001
Error (c)	72	67.920000	0.943333		
Corrected Total	149	4590.773333			

** = Significant at P = 0.01

Appendix LVIII: Combined analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	20.034444	10.017222	11.99	0.4718
Year (A)	2	157.887778	78.943889	94.51*	□ .0001
Error (a)	4	15.632222	3.908056	4.68	0.6105
Inoculation regime(B)	4	3643.374444	910.843611	1090.40**	□ .0001
Error(b)	8	17.515556	2.189444	2.62	0.3857
Cultivar (C)	9	8673.582778	963.731420	1153.80**	□ .0001
Error (c)	18	29.298889	1.627716	1.95	0.6339
Interaction					
(A×B)	8	12.795556	1.599444	1.91**	□ .0001
(A×C)	18	100.278889	5.571049	6.67**	□ .0001
(B×C)	36	499.692222	13.880340	16.62**	□ .0001
(A×B×C)	72	135.204444	1.877840	2.26**	□ .0001
Error (abc)	268	223.85222	0.835270		
Corrected Total	449	13529.14944			

** = Significant at P = 0.01

Appendix LIX: Analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse during 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	2.443333	1.221667	1.22	0.3007
Inoculation regime(A)	4	684.193333	171.048333	171.06**	□ .0001
Error(a)	8	13.006667	1.625833	1.63	0.1325
Cultivar (B)	9	2770.335000	302.259444	302.29**	□ .0001
Error (b)	18	78.390000	4.355000	4.36	□ .0001
Interaction (A×B)	36	71.406667	1.983519	1.98**	0.0069
Error (c)	72	71.993333	0.999907		
Corrected Total	149	3641.768333			

** = Significant at P = 0.01

Appendix LX: Analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	12.623333	6.311667	10.33	0.0001
Inoculation regime(A)	4	936.306667	234.076667	382.98**	□ .0001
Error(a)	8	4.393333	0.549167	0.90	0.5225
Cultivar (B)	9	3277.081667	364.120185	595.74**	□ .0001
Error (b)	18	65.143333	3.610974	5.92	□ .0001
Interaction (A×B)	36	103.093333	2.863704	4.69**	□ .0001
Error (c)	72	44.006667	0.611204		
Corrected Total	149	4442.648333			

** = Significant at P = 0.01

Appendix LXI: Combined analysis of Variance for the effect of RYMV on 1,000 grain weight in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	12.185000	6.092500	6.65	0.0017
Year (A)	1	19.253333	19.253333	21.00**	□ .0001
Error (a)	2	2.881667	1.440833	1.57	0.2107
Inoculation regime(B)	4	1609.953333	402.488333	439.05**	□ .0001
Error(b)	8	11.206667	1.400833	1.53	0.1507
Cultivar (C)	9	5865.053333	651.672593	710.86**	□ .0001
Error (c)	18	109.881667	6.104537	6.66	□ .0001
Interaction					
(A×B)	4	10.546667	2.636667	2.88*	0.0244
(A×C)	9	132.363333	14.707037	6.04**	□ .0001
(B×C)	36	126.746667	3.520741	3.84**	□ .0001
(A×B×C)	36	47.753333	1.326481	1.45*	0.0627
Error (abc)	170	155.845000	0.916735		
Corrected Total	299	8103.670000			

** = Significant at P = 0.01

Appendix LXII: Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	9.6933	4.8467	1.03	0.3631
Inoculation regime(A)	4	231728.6400	57932.1600	12281.5**	□ .0001
Error(a)	8	69.8400	8.7300	1.85	0.0815
Cultivar (B)	9	308.9067	34.3230	7.28**	□ .0001
Error (b)	18	88.1733	4.8985	1.04	0.4302
Interaction (A×B)	36	730.2933	20.2859	4.30**	□ .0001
Error (c)	72	339.6267	4.7170		
Corrected Total	149	233275.1733			

** = Significant at P = 0.01

Appendix LXIII: Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2009 rainy season .

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	101.3333	50.6667	2.75	0.0704
Inoculation regime(A)	4	215619.0000	53904.7500	2929.90**	□ .0001
Error(a)	8	822.0000	102.7500	5.58	□ .0001
Cultivar (B)	9	15317.3333	1701.9259	92.51**	□ .0001
Error (b)	18	418.6667	23.2593	1.56	0.2376
Interaction (A×B)	36	17894.3333	497.0648	27.02**	□ .0001
Error (c)	72	1324.6667	18.3981		
Corrected Total	149	251497.3333			

** = Significant at P = 0.01

Appendix LXIV: Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	4.4800	2.2400	0.08	0.9189
Inoculation regime(A)	4	217988.6267	54497.1567	2059.79**	□ .0001
Error(a)	8	298.2533	37.2817	1.41	0.2075
Cultivar (B)	9	7982.3267	886.9252	33.52**	□ .0001
Error (b)	18	479.6533	26.6474	1.01	0.4626
Interaction (A×B)	36	10558.9733	293.3048	11.09**	□ .0001
Error (c)	72	1904.9467	26.4576		
Corrected Total	149	239217.2600			

** = Significant at P = 0.01

Appendix LXV Combined analysis of Variance for the effect of RYMV incidence in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	14.5733	7.2867	0.43	0.6499
Year (A)	2	6840.2533	3420.1267	202.62*	□ .0001
Error (a)	4	100.9333	25.2333	1.49	0.2047
Inoculation regime(B)	4	648887.0756	162221.7689	9610.34**	□ .0001
Error(b)	8	646.9378	80.8672	4.79	□ .0001
Cultivar (C)	9	17558.6422	1950.9602	115.58**	□ .0001
Error (c)	18	575.0711	31.9484	1.89	0.0166
Interaction					
(A×B)	8	16449.1911	2056.1489	121.81**	□ .0001
(A×C)	18	6049.9244	366.1069	19.91**	□ .0001
(B×C)	36	21867.1911	607.4220	35.98**	□ .0001
(A×B×C)	72	7316.4089	101.6168	6.02**	□ .0001
Error (abc)	268	4523.8178	16.8799		
Corrected Total	449	730830.0200			

** = Significant at P = 0.01

Appendix LXVI : Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	212.3333	106.1667	152	0,2249
Inoculation regime(A)	4	186202.6667	46550.6667	668.01**	□ .0001
Error(a)	8	499.3333	62.4167	0.90	0.5248
Cultivar (B)	9	48010.1667	5334.4630	76.55**	□ .0001
Error (b)	18	2004.3333	111.3519	1.60	0.0837
Interaction (A×B)	36	22870.6667	635.2963	9.12 **	□ .0001
Error (c)	72	5017.3333	69.6852		
Corrected Total	149	264816.8333			

** = Significant at P = 0.01

Appendix LXVII: Analysis of Variance for the effect of RYMV incidence in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	135.0533	67.5267	12.69	□ .0001
Inoculation regime(A)	4	205140.3733	512885.0933	9634.69**	□ .0001
Error(a)	8	381.5467	47.6933	8.96	□ .0001
Cultivar (B)	9	23844.0067	2649.3341	497.72**	□ .0001
Error (b)	18	122.8133	6.8230	1.28	0.2258
Interaction (A×B)	36	12006.0267	333.5007	62.65**	□ .0001
Error (c)	72	383.2533	5.3230		
Corrected Total	149	242013.0733			

** = Significant at P = 0.01

Appendix LXVIII: Combined analysis of Variance for the effect of RYMV incidence in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	172.5267	86.2633	2.11	0.1244
Year (A)	1	7027.6800	7027.6800	171.92**	□ .0001
Error (a)	2	174.8600	87.4300	2.14	0.1210
Inoculation regime(B)	4	386919.4867	96729.8717	2366.30**	□ .0001
Error(b)	8	464.2733	58.0342	1.42	0.1914
Cultivar (C)	9	68570.3867	7618.9319	186.38**	□ .0001
Error (c)	18	995.0733	55.2819	1.35	0.1617
Interaction					
(A×B)	4	4423.5513	1105.8883	27.05**	□ .0001
(A×C)	9	3283.7867	364.8652	8.93**	□ .0001
(B×C)	36	27981.6467	777.2513	19.01**	□ .0001
(A×B×C)	36	6895.6467	191.5457	4.69**	□ .0001
Error (abc)	170	6949.2667	40.8780		
Corrected Total	299	513857.5867			

** = Significant at P = 0.01

Appendix LXIX: Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2008 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	109.8178	54.9089	2.85	0.0642
Inoculation regime(A)	4	118106.4653	29526.6163	1533.96**	□ .0001
Error(a)	8	367.1644	45.896	2.38	0.0244
Cultivar (B)	9	3828.9654	425.4406	22.10**	□ .0001
Error (b)	18	368.5705	20.4761	1.06	0.4049
Interaction (A×B)	36	2202.6008	61.1834	3.18**	□ .0001
Error (c)	72	1385.8967	19.2486		
Corrected Total	149	126369.4809			

** = Significant at P = 0.01

Appendix LXX: Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2009 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	101.3333	50.6667	2.75	0.0704
Inoculation regime(A)	4	215619.0000	53904.7500	2929.90**	□ .0001
Error(a)	8	822.0000	102.7500	5.58	□ .0001
Cultivar (B)	9	15317.3333	1701.9259	92.51**	□ .0001
Error (b)	18	418.6667	23.2593	1.26	0.2376
Interaction (A×B)	36	17894.3333	497.0648	27.02**	□ .0001
Error (c)	72	1324.6667	18.3981		
Corrected Total	149	251497.3333			

** = Significant at P = 0.01

Appendix LXXI: Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2010 rainy season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	3.8933333	1.9466667	8.40	0.0005
Inoculation regime(A)	4	990.1333333	247.5333333	1067.64**	□ .0001
Error(a)	8	4.1066667	0.5133333	2.21	0.0360
Cultivar (B)	9	113.0666667	12.5629630	54.19**	□ .0001
Error (b)	18	1.9733333	0.1096263	0.47	0.9618
Interaction (A×B)	36	43.4666667	1.2074074	5.21**	□ .0001
Error (c)	72	16.693333	0.2318520		
Corrected Total	149	1173.333333			

** = Significant at P = 0.01

Appendix LXXII: Combined analysis of Variance for the effect of RYMV severity index in the screenhouse from 2008 to 2010 rainy seasons.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	115.8087	57.9043	2.08	0.1268
Year (A)	2	6009.3739	3004.6870	107.90*	□ .0001
Error (a)	4	322.2222	80.5555	2.90	0.0226
Inoculation regime(B)	4	324533.9068	81133.4767	2915.99**	□ .0001
Error(b)	8	312.6750	39.0844	1.40	0.1944
Cultivar (C)	9	22647.8762	2516.4307	90.44**	□ .0001
Error (c)	18	560.3302	31.1295	1.12	0.3334
Interaction					
(A×B)	8	2144.7588	268.0948	9.64**	□ .0001
(A×C)	18	1974.9606	109.7200	3.94**	□ .0001
(B×C)	36	9004.8154	250.1338	8.99**	□ .0001
(A×B×C)	72	4016.7869	55.7887	2.01**	□ .0001
Error (abc)	268	7456.7462	27.8237		
Corrected Total	449	379100.2607			

** = Significant at P = 0.01

Appendix LXXIII: Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	271.31782	135.65891	6.87	0.0019
Inoculation regime(A)	4	93586.62982	23396.65746	1185.49**	□ .0001
Error(a)	8	202.38836	25.29854	1.28	0.2666
Cultivar (B)	9	13133.15508	1459.23945	73.94**	□ .0001
Error (b)	18	683.19934	37.95552	1.94	0.0270
Interaction (A×B)	36	4786.01852	132.94496	6.74**	□ .0001
Error (c)	72	1420.98360	19.73590		
Corrected Total	149	114083.69260			

** = Significant at P = 0.01

Appendix LXXIV: Analysis of Variance for the effect of RYMV severity index in the screenhouse during 2009/ 2010 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	146.1953	73.0976	4.36	0.0163
Inoculation regime(A)	4	119195.8154	29798.9539	1776.57**	□ .0001
Error(a)	8	701.2605	87.6576	5.23	□ .0001
Cultivar (B)	9	17404.0346	1913.7816	115.29**	□ .0001
Error (b)	18	474.1544	26.3419	1.57	0.0917
Interaction (A×B)	36	7000.0819	194.4467	11.59**	□ .0001
Error (c)	72	1207.6765	16.7733		
Corrected Total	149	146129.2186			

** = Significant at P = 0.01

Appendix LXXV: Combined analysis of Variance for the effect of RYMV severity index in the screenhouse, 2008/ 2009 and 2009/ 2010 dry seasons

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	25.5158	12.7579	0.60	0.5500
Year (A)	1	8824.1972	8824.1972	415.01**	□ .0001
Error (a)	2	391.9974	195.9987	9.22	0.0002
Inoculation regime(B)	4	209348.1828	52337.0457	2461.43**	□ .0001
Error(b)	8	377.9978	47.2497	2.22	0.0281
Cultivar (C)	9	29991.1292	3332.3477	156.72**	□ .0001
Error (c)	18	696.9810	38.7212	1.82	0.0262
Interaction					
(A×B)	4	3434.2624	858.5656	40.38**	□ .0001
(A×C)	9	546.0605	60.6734	2.85*	0.0037
(B×C)	36	9829.8002	273.0500	12.84**	□ .0001
(A×B×C)	36	1956.3003	54.3417	2.56**	□ .0001
Error (abc)	170	3614.6839	21.2628		
Corrected Total	299	269037.1084			

** = Significant at P = 0.01

Appendix LXXVI: Analysis of variance of RYMV incidence 6 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.200	0.100	0.4737	0.6302
Treatment	9	44.786	4.976	23.572**	0.0001
Error	18	3.800	0.2111		
Total	29	48.786			

** = Significant at P = 0.01

Appendix LXXVII : Analysis of variance of RYMV incidence 8 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	4.350	2.175	2.802	0.0872
Treatment	9	186.71	20.746	26.728**	0.0001
Error	18	13.971	0.7762		
Total	29	205.03			

** = Significant at P = 0.01

Appendix LXXVIII: Analysis of variance of RYMV incidence 10 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	2.400	1.200	2.250	0.1342
Treatment	9	341.43	37.936	71.130**	0.0001
Error	18	9.600	0.5333		
Total	29	353.43			

** = Significant at P = 0.01

Appendix LXXIX: Analysis of variance of RYMV incidence 12 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	6.150	3.075	5.497	0..0137
Treatment	9	1009.9	112.21	200.67**	0.0001
Error	18	10.068	0.5593		
Total	29	1026.1			

** = Significant at P = 0.01

Appendix LXXX : Analysis of variance of RYMV incidence 14 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	9.600-0	4.800	8.308	0.0028
Treatment	9	11409.0	1267.7	2194.0**	0.0001
Error	18	10.400.0	0.5778		
Total	29	11429.0			

** = Significant at P = 0.01

Appendix LXXXI: Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.1807	0.0903	0.7870	0.4702
Treatment	9	888.45	98.766	860.06**	0.0001
Error	18	2.0660	0.1144		
Total	29	890.69			

** = Significant at P = 0.01

Appendix LXXXII: Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.1120	0.5560	1.8780	0.1816
Treatment	9	6653.3	739.26	2497.5**	0.0001
Error	18	5.3280	0.2960		
Total	29	6659.8			

** = Significant at P = 0.01

Appendix LXXXIII: Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.8820	0.4410	0.9452	0.4071
Treatment	9	2973.5	330.39	708.28**	0.0001
Error	18	8.3980	0.4666		
Total	29	2982.7			

** = Significant at P = 0.01

Appendix LXXXIV: Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	11.744	5.6720	4.9730	0.0191
Treatment	9	3864.7	429.41	363.63**	0.0001
Error	18	21.256	1.1810		
Total	29	3897.7			

** = Significant at P = 0.01

Appendix LXXXV: Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	5.4000	2.7000	2.8190	0.0861
Treatment	9	2809.2	312.13	325.89**	0.0001
Error	18	17.240	0.9578		
Total	29	2831.8			

** = Significant at P = 0.01

Appendix LXXXVI : Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Bomo during 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	134737	67369	1.074	0.3624
Treatment	9	4491284	499032	7.958**	0.0001
Error	18	1128724	62707		
Total	29	5754745			

** = Significant at P = 0.01

Appendix LXXXVII: Analysis of variance of RYMV incidence 6 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	5.00	2.500	0.1617	0.8519
Treatment	9	1966.7	218.52	14.132**	0.0001
Error	18	278.33	15.463		
Total	29	2250			

** = Significant at P = 0.01

Appendix LXXXVIII: Analysis of variance of RYMV incidence 8 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	61.667	30.853	0.8473	0.4450
Treatment	9	2817.5	313.06	8.603**	0.0001
Error	18	655.00	36.389		
Total	29	3534.2			

** = Significant at P = 0.01

Appendix LXXXIX: Analysis of variance of RYMV incidence 10 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	11.667	5.833	0.3865	0.6849
Treatment	9	5300.8	583.98	39.025**	0.0001
Error	18	271.67	15.093		
Total	29	5584.2			

** = Significant at P = 0.01

Appendix XC: Analysis of variance of RYMV incidence 12 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	81.667	40.833	1.332	0.2887
Treatment	9	4740.8	526.76	17.187**	0.0001
Error	18	551.67	30.648		
Total	29	5374.2			

** = Significant at P = 0.01

Appendix XCI: Analysis of Variance of RYMV incidence 14 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	121.67	60.833	1.031	0.3766
Treatment	9	6803.3	755.93	12.816**	0.0001
Error	18	1061.7	58.981		
Total	29	7986.7			

** = Significant at P = 0.01

Appendix XCII: Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.3993	0.1996	0.5868	0.5664
Treatment	9	3410.3	378.92	1113.7**	0.0001
Error	18	6.124	0.3402		
Total	29	3416.8			

** = Significant at P = 0.01

Appendix XCIII: Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	88.749	44.374	0.8381	0.4487
Treatment	9	4089.3	454.37	8.5820**	0.0001
Error	18	953.01	52.945		
Total	29	5131.1			

** = Significant at P = 0.01

Appendix XCIV: Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	110.02	55.010	0.8098	0.4605
Treatment	9	4706.5	522.95	7.6980**	0.0001
Error	18	1222.8	67.933		
Total	29	6039.3			

** = Significant at P = 0.01

Appendix XCV: Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	46.722	23.361	0.7490	0.5751
Treatment	9	4872.4	541.38	17.357**	0.0001
Error	18	561.42	31.190		
Total	29	5480.5			

** = Significant at P = 0.01

Appendix XCVI: Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	78.324	39.162	0.8423	0.4470
Treatment	9	4245.4	471.71	10.145**	0.0001
Error	18	836.92	46.496		
Total	29	5160.7			

** = Significant at P = 0.01

Appendix XCVII: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Bomo during 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	89740	44870	1.121	0.3477
Treatment	9	8001237	889026	22.206**	0.0001
Error	18	720634	40035		
Total	29	8811611			

** = Significant at P = 0.01

Appendix XCVIII: Analysis of Variance of RYMV incidence 6 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.0897	0.0448	0.3797	0.6894
Treatment	9	167.41	18.601	157.34**	0.0001
Error	18	2.128	0.1182		
Total	29	169.63			

** = Significant at P = 0.01

Appendix XCIX: Analysis of Variance of RYMV incidence 8 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	161.67	80.833	3.770	0.0218
Treatment	9	2780.0	308.89	18.230**	0.0001
Error	18	305.00	16.944		
Total	29	3246.7			

** = Significant at P = 0.01

Appendix C: Analysis of Variance of RYMV incidence 10 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	20.000	10.00	0.4130	0.6742
Treatment	9	4550.8	505.65	20.377**	0.0001
Error	18	446.67	24.815		
Total	29	5017.5			

** = Significant at P = 0.01

Appendix CI: Analysis of Variance of RYMV incidence 12 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	15.000	7.500	0.3361	0.7189
Treatment	9	4250.8	472.31	21.166**	0.0001
Error	18	401.67	22.315		
Total	29	4667.5			

** = Significant at P = 0.01

Appendix CII: Analysis of Variance of RYMV incidence 14 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	81.667	40.833	1.569	0.2354
Treatment	9	7236.7	804.07	30.904**	0.0001
Error	18	468.33	26.019		
Total	29	7786.7			

** = Significant at P = 0.01

Appendix CIII: Analysis of Variance of RYMV Severity index 6 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.5010	0.7507	1.4840	0.2531
Treatment	9	2987.8	331.88	656.22**	0.0001
Error	18	9.1040	0.5058		
Total	29	2997.6			

** = Significant at P = 0.01

Appendix CIV: Analysis of Variance of RYMV Severity index 8 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	3.0840	1.5420	1.6680	0.2128
Treatment	9	2978.9	330.99	362.38**	0.0001
Error	18	16.441	0.9134		
Total	29	2998.5			

** = Significant at P = 0.01

Appendix CV: Analysis of Variance of RYMV Severity index 10 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	6.0080	3.0040	3.8540	0.0405
Treatment	9	5002.7	555.80	718.08**	0.0001
Error	18	14.031	0.7795		
Total	29	5022.8			

** = Significant at P = 0.01

Appendix CVI: Analysis of Variance of RYMV Severity index 12 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	11.483	5.7420	1.6300	0.2236
Treatment	9	4429.2	491.45	139.49**	0.0001
Error	18	63.417	3.5290		
Total	29	4498.2			

** = Significant at P = 0.01

Appendix CVII: Analysis of Variance of RYMV Severity index 14 WAS at Bomo 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.4000	0.7000	1.4650	0.2573
Treatment	9	2978.9	330.99	692.77**	0.0001
Error	18	8.6000	0.4778		
Total	29	2988.9			

** = Significant at P = 0.01

Appendix CVIII: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Bomo during 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	19877	9938.4	0.3722	0.6944
Treatment	9	6677165	741907	27.786**	0.0001
Error	18	480614	26701		
Total	29	7177656			

** = Significant at P = 0.01

Appendix CIX: Analysis of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	32.067	16.033	1.029	0.3776
Treatment	9	180.16	20.018	1.284^{NS}	0.3003
Error	18	280.60	15.589		
Total	29	492.60			

** = Significant at P = 0.01

Appendix CX: Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.788	0.8940	1.083	0.3598
Treatment	9	399.70	44.411	53.776**	0.0001
Error	18	14.865	0.8259		
Total	29	416.35			

** = Significant at P = 0.01

Appendix CXI: Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	9.021	4.510	9.795	0.0013
Treatment	9	3212.5	356.94	775.19**	0.0001
Error	18	8.288	0.4605		
Total	29	3229.8			

** = Significant at P = 0.01

Appendix CXII: Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	16.968	8.484	1.764	0.1998
Treatment	9	12637.0	1403.5	291.78**	0.0001
Error	18	86.583	4.810		
Total	29	1273.5			

** = Significant at P = 0.01

Appendix CXIII: Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.757	0.8759	1.771	0.1935
Treatment	9	10399.0	1155.4	2336.4**	0.0001
Error	18	8.902	0.4945		
Total	29	10411.0			

** = Significant at P = 0.01

Appendix CXIV: Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.5680	0.7840	1.8990	0.1676
Treatment	9	887.11	98.568	238.73**	0.0001
Error	18	7.4320	0.4129		
Total	29	896.11			

** = Significant at P = 0.01

Appendix CXV: Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.0320	0.0160	0.6429	0.5379
Treatment	9	3290.4	365.60	14689.0**	0.0001
Error	18	0.4480	0.0248		
Total	29	3290.9			

** = Significant at P = 0.01

Appendix CXVI: Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.5120	0.2560	2.0140	0.1624
Treatment	9	2090.5	232.27	1827.3**	0.0001
Error	18	2.2880	0.1271		
Total	29	2093.3			

** = Significant at P = 0.01

Appendix CXVII: Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	3.7060	1.8530	2.9550	0.7777
Treatment	9	3065.9	340.65	543.27**	0.0001
Error	18	11.287	0.6270		
Total	29	3080.9			

** = Significant at P = 0.01

Appendix CXVIII; Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	2.2320	1.1160	4.8660	0.2040
Treatment	9	2508.1	278.68	1215.2**	0.0001
Error	18	4.1280	0.2293		
Total	29	2514.5			

** = Significant at P = 0.01

Appendix CXIX: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Sayen Gobirawa during 2008 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	36767	18383	0.2330	0.7945
Treatment	9	5834326	648258	8.216**	0.0001
Error	18	1420180	78899		
Total	29	7291273			

** = Significant at P = 0.01

Appendix CXX: Analysis of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.000	0.000	0.000	0.9999
Treatment	9	2720.8	302.31	11.661**	0.0001
Error	18	466.67	25.926		
Total	29	3187.5			

** = Significant at P = 0.01

Appendix CXXI: Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.667	0.8333	0.0431	0.9580
Treatment	9	3234.2	359.35	18.569**	0.0001
Error	18	348.33	19.352		
Total	29	3584.2			

** = Significant at P = 0.01

Appendix CXXII: Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	5.00	2.500	0.1139	0.8930
Treatment	9	3407.5	378.61	17.253**	0.0001
Error	18	395.0	21.944		
Total	29	3807.5			

** = Significant at P = 0.01

Appendix CXXIII: Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	101.67	50.833	2.041	0.1589
Treatment	9	4224.2	469.35	18.844**	0.0001
Error	18	448.33	24.907		
Total	29	4774.2			

** = Significant at P = 0.01

Appendix CXXIV: Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	15.00	7.500	0.3103	0.7370
Treatment	9	4057.5	450.83	18.655**	0.0001
Error	18	435.00	24.167		
Total	29	4507.5			

** = Significant at P = 0.01

Appendix CXXV: Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	22.866	11.433	0.2004	0.8202
Treatment	9	1274.5	141.61	2.4830*	0.0481
Error	18	1036.7	67.040		
Total	29	2324.1			

* = Significant at P = 0.05

Appendix CXXVI: Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	197.66	98.821	2.6820	0.0956
Treatment	9	4019.2	446.58	12.118**	0.0001
Error	18	663.36	36.853		
Total	29	4080.2			

** = Significant at P = 0.01

Appendix CXXVIII: Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	49.331	24.665	0.5259	0.5999
Treatment	9	4148.9	460.99	9.8280**	0.0001
Error	18	844.28	46.904		
Total	29	5042.5			

** = Significant at P = 0.01

Appendix CXXIX: Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	25.084	12.542	0.5910	0.5612
Treatment	9	3160.4	351.16	16.546**	0.0001
Error	18	382.01	21.223		
Total	29	3567.5			

** = Significant at P = 0.01

Appendix CXXX: Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	114.28	57.138	3.6300	0.0474
Treatment	9	3098.4	344.27	21.871**	0.0001
Error	18	283.34	15.741		
Total	29	3496.1			

** = Significant at P = 0.01

Appendix CXXXI: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Sayen Gobirawa during 2009 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	2464.5	1232.2	0.0272	0.9732
Treatment	9	8262262	918029	20.253**	0.0001
Error	18	815886	45327		
Total	29	9080613			

** = Significant at P = 0.01

Appendix CXXXII: Analyses of Variance of RYMV incidence 6 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	11.298	5.649	6.815	0.0063
Treatment	9	191.15	21.239	25.624**	0.0001
Error	18	14.920	0.8289		
Total	29	217.37			

** = Significant at P = 0.01

Appendix CXXXIII: Analysis of Variance of RYMV incidence 8 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	2.069	1.035	1.296	0.2979
Treatment	9	264.98	29.998	37.585**	0.0001
Error	18	14.366	0.7981		
Total	29	286.42			

** = Significant at P = 0.01

Appendix CXXXIV: Analysis of Variance of RYMV incidence 10 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.092	0.5459	0.7616	0.4814
Treatment	9	4700.4	522.27	728.65**	0.0001
Error	18	12.902	0.7168		
Total	29	4714.4			

** = Significant at P = 0.01

Appendix CXXXV: Analysis of Variance of RYMV incidence 12 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.9915	0.4957	0.4517	0.6436
Treatment	9	7348.2	816.14	743.93**	0.0001
Error	18	19.734	1.057		
Total	29	7368.7			

** = Significant at P = 0.01

Appendix CXXXVI: Analysis of Variance of RYMV incidence 14 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	1.059	0.5293	0.7370	0.4924
Treatment	9	7354.3	817.24	1137.7	0.0001
Error	18	12.928	0.7182		
Total	29	7368.3			

** = Significant at P = 0.01

Appendix CXXXVII: Analysis of Variance of RYMV Severity index 6 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	0.4693	0.2347	0.5368	0.5937
Treatment	9	2304.4	256.04	595.65**	0.0001
Error	18	7.8690	0.4372		
Total	29	2312.7			

** = Significant at P = 0.01

Appendix CXXXVIII: Analysis of Variance of RYMV Severity index 8 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	0.0314	0.0157	0.5652	0.7084
Treatment	9	3193.6	354.84	127.50**	0.0001
Error	18	0.5009	0.0278		
Total	29	3194.1			

** = Significant at P = 0.01

Appendix CXXXIX: Analysis of Variance of RYMV Severity index 10 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	10.869	5.4330	1.2900	0.2995
Treatment	9	4141.9	460.77	109.42**	0.0001
Error	18	75.800	4.2110		
Total	29	4233.6			

** = Significant at P = 0.01

Appendix CXL: Analysis of Variance of RYMV Severity index 12 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	11.659	5.8330	0.9292	0.4130
Treatment	9	4667.5	518.61	82.600**	0.0001
Error	18	113.00	6.2780		
Total	29	4792.1			

** = Significant at P = 0.01

Appendix CXLI: Analysis of Variance of RYMV Severity index 14 WAS at Sayen Gobirawa 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	5.6000	2.8000	1.6580	0.2183
Treatment	9	6912.6	768.07	454.78	0.0001**
Error	18	30.400	1.6890		
Total	29	6948.6			

** = Significant at P = 0.01

Appendix CXLII: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Sayen Gobirawa during 2010 rainy season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	227239	113619	0.7764	0.4749
Treatment	9	10264212	1140468	7.7930**	0.0001
Error	18	2634060	146337		
Total	29	13125511			

** = Significant at P = 0.01

Appendix CXLIII: Analyses of Variance of RYMV incidence 6 WAS at Nasarawan Buhari 2008/ 2009 dry season.

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	81.67	40.83	1.515	0.2464
Treatment	9	3680.0	408.87	15.175**	0.0001
Error	18	485.0	26.94		
Total	29	4246.67			

** = Significant at P = 0.01

Appendix CXLIV: Analysis of Variance of RYMV incidence 8 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	15.0	7.5	0.4736	0.6304
Treatment	9	6117.5	679.722	42.929**	0.0002
Error	18	285.0	15.833		
Total	29	6417.5			

** = Significant at P = 0.01

Appendix CXLV: Analysis of Variance of RYMV incidence 10 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	61.67	30.833	2.9469	0.0781
Treatment	9	7574.17	841.574	80.4330**	0.0001
Error	18	188.33	10.463		
Total	29	7824.17			

** = Significant at P = 0.01

Appendix CXLVI: Analysis of Variance of RYMV incidence 12 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	41.67	20.83	0.9183	0.4170
Treatment	9	8634.17	959.35	42.289**	0.0002
Error	18	408.33	22.69		
Total	29	9084.00			

** = Significant at P = 0.01

Appendix CXLVII: Analysis of Variance of RYMV incidence 14 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	16.447	8.2240	5.119	0.0174
Treatment	9	8769.8	974.43	606.5**	0.0001
Error	18	28.919	1.6070		
Total	29	8815.2			

** = Significant at P = 0.01

Appendix CXLVIII: Analysis of Variance of RYMV Severity index 6 WAS at Nasaeawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	1.800	0.9000	1.328	0.2898
Treatment	9	1074.200	119.3500	176.100**	0.0001
Error	18	12.200	0.6778		
Total	29	1088.200			

** = Significant at P = 0.01

Appendix CXLIX : Analysis of Variance of RYMV Severity index 8 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	12.193	6.097	0.7704	0.4775
Treatment	9	1780.90	187.870	25.001**	0.0023
Error	18	142.44	7.913		
Total	29				

** = Significant at P = 0.01

Appendix CL: Analysis of Variance of RYMV Severity index 10 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	100.66	50.332	0.5870	0.5663
Treatment	9	4070.3	452.25	5.2740**	0.0014
Error	18	1543.4	85.744		
Total	29	5714.3			

** = Significant at P = 0.01

Appendix CLI: Analysis of Variance of RYMV Severity index 12 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	407.81	203.91	2.345	0.1244 NS
Treatment	9	6233.8	692.64	8.967	0.0001**
Error	18	1584.8	86.936		
Total	29	8206.4			

** = Significant at P = 0.01

Appendix CLII: Analysis of Variance of RYMV Severity index 14 WAS at Nasarawan Buhari 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	23.353	11.677	0.1724	0.9430 NS
Treatment	9	4331.8	481.31	7.1050	0.0002**
Error	18	1219.3	67.738		
Total	29	5574.4			

** = Significant at P = 0.01

Appendix CLIII: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Nasarawan Buhari during 2008/ 2009 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	22765.67	113825.8	3.134	0.0679
Treatment	9	13435124.83	1492792	41.102**	0.0001
Error	18	653739.67	36318.87		
Total	29	14316516.17			

** = Significant at P = 0.01

Appendix CLIV: Analysis of Variance of RYMV incidence 6 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	10.414	5.207	16.148	0.0001
Treatment	9	1119.0	124.40	385.79**	0.0001
Error	18	5.804	0.3224		
Total	29	1135.818			

** = Significant at P = 0.01

Appendix CLV: Analysis of Variance of RYMV incidence 8 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	12.850	6.4250	9.3870	0.0016
Treatment	9	7118.1	790.90	115.56**	0.0001
Error	18	12.319	0.6844		
Total	29	7143.3			

** = Significant at P = 0.01

Appendix CLVI: Analysis of Variance of RYMV incidence 10 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.5611	0.2806	0.2595	0.7743
Treatment	9	8513.0	945.90	874.98**	0.0001
Error	18	19.459	1.0810		
Total	29	8533.1			

** = Significant at P = 0.01

Appendix CLVII: Analysis of Variance of RYMV incidence 12 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.6231	0.3116	0.3929	0.6870
Treatment	9	8255.8	917.64	1157.1**	0.0001
Error	18	14.275	0.7430		
Total	29	8273.7			

** = Significant at P = 0.01

Appendix CLVIII: Analysis of Variance of RYMV incidence 14 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P r□ F
Replication	2	0.6904	0.3829	0.6873	0.5646
Treatment	9	7763.5	861.50	955.61**	0.0001
Error	18	16.227	0.9015		
Total	29	7770.4			

** = Significant at P = 0.01

Appendix CLIX: Analysis of Variance of RYMV Severity index 6 WAS at Nasarawan Buhari during 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	1.330	0.6651	0.0064	0.9936
Treatment	9	3070.7	341.86	3.3150*	0.0146
Error	18	1886.0	103.11		
Total	29	4934.1			

* = Significant at P = 0.05

Appendix CLX: AnalysIs of Variance of RYMV Severity index 8 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	18.378	9.189	0.1246	0.8836
Treatment	9	3248.4	360.93	4.8940**	0.0021
Error	18	1327.6	73.754		
Total	29	4594.4			

** = Significant at P = 0.01

Appendix CLXI: Analysis of Variance of RYMV Severity index 10 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	11.526	5.763	0.1169	0.8903
Treatment	9	4838.5	537.61	10.908**	0.0001
Error	18	887.17	49.287		
Total	29	5737.2			

** = Significant at P = 0.01

Appendix CLXII: Analysis of Variance of RYMV Severity index 12 WAS at Nasarawan Buhari during 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	P □ F
Replication	2	29.436	14.718	0.2485	0.7841
Treatment	9	5210.1	578.90	9.6940**	0.0001
Error	18	1074.9	59.715		
Total	29	6314.4			

** = Significant at P = 0.01

Appendix CLXIII: Analysis of Variance of RYMV Severity index 14 WAS at Nasarawan Buhari 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	373.77	186.89	1.500	0.2498
Treatment	9	4242.3	471.43	3.783*	0.0078
Error	18	2243.0	124.61		
Total	29	6859.6			

* = Significant at P = 0.05

Appendix CLXIV: Analysis of Variance for the effect of RYMV on paddy yield of rice cultivars at Nasarawan Buhari during 2009/ 2010 dry season

Source of variance	Degree of freedom	Sum of square	Mean square	F Value	Pr □ F
Replication	2	87037	43519	2.617	0.1006
Treatment	9	3039591	337732	20.307**	0.0001
Error	18	299367	16631		
Total	29	3425995			

** = Significant at P = 0.01

Appendix CLXV: Correlation co -efficient for the screenhouse experiment in 2008 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.4670	1.00									
V3	-0.0495	0.4049	1.00								
V4	-0.4872	0.3741	0.1258	1.00							
V5	-0.0246	0.0596	0.4003	-0.5009	1.00						
V6	-0.1955	0.0770	0.1533	-0.4700	0.5919	1.00					
V7	0.4447	-0.3600	-0.1152	-0.3691	0.1209	0.0778	1.00				
V8	0.6991*	-0.5167	0.0292	-0.1646	0.0646	-0.3904	0.3803	1.00			
V9	-0.3847	0.4268	0.0724	-0.1031	0.3772	0.8017**	-0.3510	0.6165	1.00		
V10	0.3635	0.1201	-0.1853	-0.4462	0.2630	0.1747	-0.4700	0.3680	0.2264	1.00	
V11	0.4441	-0.4266	0.3415	-0.3671	0.5577	-0.1266	0.2992	0.7531*	0.4316	0.1671	1.00
V12	-0.6606*	0.3630	-0.2438	0.6609*	-0.5210	0.0829	-0.3651	-0.5072	0.3899	-0.1347	-0.8140
V13	-0.6562*	0.5118	-0.2778	0.5243	-0.3520	0.1536	-0.4500	-0.7399*	0.5515	-0.1970	-0.9286
V14	0.0493	0.1900	0.5689	-0.0510	0.4492	0.4494	0.0101	0.3337	0.3866	0.4084	0.4579

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at p ≤ 0.01
* = Significant at p ≤ 0.05

Appendix CLXVI: Correlation co -efficient for the screenhouse experiment in 2009 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.4436	1.00									
V3	-0.7059*	0.6864*	1.00								
V4	-0.8115**	0.4376	0.5883	1.00							
V5	0.4363	-0.0850	-0.6051	-0.4411	1.00						
V6	0.0308	0.3038	-01180	0.4520	0.0652	1.00					
V7	0.4007	-0.5780	-0.4731	-0.4600	0.1496	-0.0711	1.00				
V8	0.1171	0.2045	0.1306	-0.0711	0.0652	0.0227	-0.1230	1.00			
V9	-0.8279**	0.7616*	0.8418**	0.6831*	-0.4081	0.0810	-0.7130*	0.1672	1.00		
V10	0.6825*	-0.6521*	-0.6900	-0.4710	0.2703	0.0960	.0.8947**	-0.2721	-0.8917**	1.00	
V11	0.6025	-0.6491*	-0.6680*	-0.6310	0.5166	-0.3494	0.5432	-0.0751	-0.8399**	0.6800*	1.00
V12	-0.8089**	0.6185	0.8091**	0.6881*	-0.5270	0.1104	-0.5360	0.1940	0.9474**	-0.7039*	-0.9002**
V13	-0.8117**	0.6065	0.8114**	0.6591*	-0.5191	0.0864	-0.5110	0.1813	0.9464**	-0.7733*	-0.8735**
V14	0.0451	0.2331	0.0345	0.3462	-0.1432	-0.0823	0.1232	0.2341	0.3421	0.2314	-0.2310

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXVII: Correlation co -efficient for the screenhouse experiment in 2010 rainy season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.7163*	1.00									
V3	-0.1436	0.3889	1.00								
V4	0.7028*	0.5882	-0.1883	1.00							
V5	0.3321	-0.2775	0.0789	-0.3619	1.00						
V6	-0.5576	0.8251**	0.3610	0.4492	0.0048	1.00					
V7	0.7110*	-0.5793	0.0680	-0.5532	0.2461	-0.1487	1.00				
V8	0.8662**	-0.6791*	0.0518	-0.6634*	0.3551	-0.4173	0.8003**	1.00			
V9	-0.8106**	0.8794**	0.1238	0.6475*	-0.3076	0.5498	-0.8738**	-0.9029**	1.00		
V10	0.7279*	-0.6132	-0.1870	-0.6471*	0.1872	-0.3014	0.7936*	0.8621**	-0.8259**	1.00	
V11	0.8937**	-0.7718*	-0.1099	-0.6268*	0.5706	-0.5389	0.6978*	0.8648**	-0.8464**	0.6258*	1.00
V12	-0.8686**	0.8693**	0.2083	0.7014*	-0.5484	0.5877	-0.7663*	-0.8856**	0.9197**	-0.7573*	-0.9512**
V13	-0.8567**	0.7851*	0.0763	0.7914*	-0.4831	0.5544	-0.7528*	-0.9337**	0.8994**	-0.8273**	-0.9038**
V14	-0.4380	0.1204	0.5378	0.1608	0.5403	0.3754	0.3110	0.4404	-0.0014	0.2802	0.4539

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXVIII: Correlation co -efficient for the screenhouse experiments in 2008, 2009 and 2010 rainy seasons combined analysis

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.6480	1.00									
V3	0.3121	.0.6822*	1.00								
V4	-0.7405*	0.5794	0.3827	1.00							
V5	0.0602	0.1417	0.0026	-0.5479	1.00						
V6	-0.4679	0.4781	0.3563	0.1400	0.4750	1.00					
V7	0.6311*	-0.6071	-0.2512	-0.4957	0.2026	-0.1014	1.00				
V8	0.6716*	-0.7126*	0.2511	-0.5981	0.2581	-0.4721	0.7553*	1.00			
V9	-0.7464*	0.8366**	0.0476	0.6031	-0.1249	0.6544*	-0.7104*	-0.8640**	1.00		
V10	0.6690*	-0.5728	0.3378	-0.5673	0.1450	0.3322	0.8821**	0.8544**	-0.8073**	1.00	
V11	0.5400	-0.6737*	0.1572	-0.6399*	0.5665	0.3510	0.5369	0.8620**	-0.8021**	0.5989	1,00
V12	-0.7305*	0.7480*	0.3541	0.7709*	-0.4994	0.4156	-0.6644*	-0.8517**	0.9096**	-0.7322×	-0.92
V13	0.6977*	0.7945*	0.3428	0.7364*	0.4363	0.4373	0.6533*	-0.8588*	0.9304*×	-.0.8065××	-0.89
V14	-0.0578	0.1228	0.5487	0.1607	0.5318	0.3751	.0.3101	0.4563	-0.4012	0.2766	0.443

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXIX: Correlation co -efficient for the screenhouse experiment in 2008/2009 dry season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.3276	1.00									
V3	-0.2511	0.1004	1.00								
V4	-0.6843*	0.0336	0.2290	1.00							
V5	0.5266	-0.2410	-0.2350	-0.7130*	1.00						
V6	-0.4964	0.3434	-0.0571	0.0678	0.3092	1.00					
V7	0.2572	0.0115	0.3546	-0.4611	-0.0941	-0.2591	1.00				
V8	0.6855*	0.0556	0.2563	-0.7051*	0.1578	-0.4911	0.8324**	1.00			
V9	-0.7787*	0.1636	0.0370	0.7409*	-0.3778	0.3766	-0.6800*	-0.8441**	1.00		
V10	0.5836	-0.2175	-0.2431	-0.6901*	-0.2099	0.3411	0.6214*	0.6894*	-0.7685*	1.00	
V11	0.7859*	-0.3906	0.1294	-0.5191	0.3651	-0.6451*	0.3948	0.6941*	-0.7002*	0.3039	1.00
V12	-0.8738**	0.5058	0.0279	0.6837*	-0.4031	0.6037	-0.5731	-0.7900*	0.8585**	-0.6957*	-0.8810**
V13	-0.8566**	0.3795	0.2573	0.7810*	-0.3731	0.5519	-0.6011	-0.8060**	0.8785**	-0.8368**	-0.7441*
V14	0.0757	-0.014	0.6842*	-0.3360	0.3701	0.1311	0.5023	0.4844	-0.3564	0.0811	0.4011

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXX: Correlation co -efficient for the screenhouse experiment in 2009/2010 dry season

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.7325*	1.00									
V3	-0.4739	0.4250	1.00								
V4	-0.4911	0.3882	0.4881	1.00							
V5	0.4725	-0.4331	0.0201	-0.6390*	1.00						
V6	-0.4895	0.4811	0.1210	-0.2347	0.3802	1.00					
V7	0.1710	-0.1611	0.0401	-0.3085	0.0880	-0.3431	1.00				
V8	0.6435*	-0.4341	-0.1411	-0.4546	0.1918	-0.5461	0.8351**	1.00			
V9	-0.8007**	0.6271*	0.3810	0.5568	-0.2721	0.5633	-0.6810*	-0.9421**	1.00		
V10	0.4354	-0.5041	-0.4161	-0.1895	-0.0541	-0.5831	0.6238*	0.6679*	-0.7316*	1.00	
V11	0.8677**	-0.7211*	-0.2516	-0.5264	0.5708	-0.4710	0.3749	0.7767*	-0.8182**	0.4421	1.00
V12	-0.9176**	0.8361**	0.4071	0.5846	-0.5321	0.4966	-0.4260	-0.7810*	0.9061**	-0.6241*	-0.9371**
V13	-0.9855**	0.7271*	0.4031	0.5828	-0.6810*	0.2967	-0.1131	-0.5861	0.7332*	-0.3291	-0.8941**
V14	0.1081	-0.0800	0.5510	-0.2984	0.5802	0.1609	0.5085	0.4900	-0.2884	0.0233	0.4539

V1 = Plant height
V2 = Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXXI: Correlation co -efficient for the screenhouse experiments in 2008/2009 and 2009/2010 dry seasons combined analysis

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
V1	1.00										
V2	-0.5220	1.00									
V3	0.0665	0.6500*	1.00								
V4	-0.7105*	0.4095	-0.0964	1.00							
V5	0.4454	-0.4384	-0..5490	-0.7203*	1.00						
V6	-0.5464	0.3410	0.0008	- 0.0062	0.3342	1.00					
V7	0.2982	-0.0082	0.2591	-0.4134	-0.0876	-0.3025	1.00				
V8	0.6029	-0.4154	0.6431	-0.5748	0.3078	-0.2030	0.6155	1.00			
V9	-0.8690**	-0.3611	-0.2126	0.7766*	-0.3156	0.5681	-0.6716*	-0.6882*	1.00		
V10	0.6326*	-0.2428	-0.0001	-0.6882*	0.1321	-0.4364	0.6342*	0.5431	-0.8009**	1.00	
V11	0.6287*	-0.2425	0.1212	-0.3608	0.3809	-0.4739	0.1165	0.3834	-0.5079	0.1724	1.00
V12	-0.9138**	-.06646**	0.0640	0.7427*	-0.4707	0.5699	-0.5185	-0.5688	0.9247**	-0.7163*	-0.6070
V13	-0.9071**	0.6168*	0.052	0.7707*	-0.3696	0.5085	-0.5714	-0.5413	0.9614**	-0.8174**	-0.5207
V14	0.0994	-0.9747	0.2747	0.2979	0.4827	0.1452	0.5080	0.5550	-0.2851	0.0880	0.3007

V1 = Plant height
V2= Reduction in plant height
V3 = Number of tillers per plant
V4 = Reduction in number of tillers per plant
V5 = Number of Days to 50% flowering
V6 = Increase in days to 50% flowering
V7 = Number of grain per panicle
V8 = Paddy yield
V9 = Paddy yield loss
V10 = Threshing percentage
V 11 = 1,000 grain weight
V 12 = Disease incidence
V 13 = Disease severity index
V14 = Age of plant (weeks)
* * = *Significant* at $p \leq 0.01$
* = Significant at $p \leq 0.05$

Appendix CLXXII: Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Bomo from 2008 to 2010 rainy seasons

	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1	1.00								
V2	-0.9929**	1.00							
V3	-0.9478**	0.9034**	1.00						
V4	0.4357	-0.3261	-0.6999*	1.00					
V5	0.9235**	-0.8716**	-0.9976**	0.7475**	1.00				
V6	-0.9452**	0.9772**	0.7917**	-0.1179	-0.7477**	1.00			
V7	-0.8550**	0.7875**	0.9757**	-0.8393**	-0.9885**	0.6388*	1.00		
V8	0.0913	0.0271	-0.4041	0.9361**	0.4663	0.2387	-0.6946*	1.00	
V9	-0.2223	0.1053	0.5215	-0.9744**	-0.6792*	-0.1082	0.6957*	0.9912**	1.00

V1 = Plant height
V2 = Number of tillers per plant
V3 = Number of Days to 50% heading
V4 = Number of grain per panicle
V5 = Paddy yield
V6 = Threshing percentage
V7 =1,000 grain weight
V8 = Disease incidence
V 9 = Disease severity index

* * = *Significant* at p ≤ 0.01
* * = *Significant* at p ≤ 0.05

Appendix CLXXIII: Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Sayen Gobirawa from 2008 to 2010 rainy seasons

	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1	1.00								
V2	0.2475	1.00							
V3	0.2875	-0.4447	1.00						
V4	0.1055	-03652	0.3553	1.00					
V5	0.1240	0.6519*	-0.0165	0.4443	1.00				
V6	-0.1603	0.2093	-0.2813	-0.9865**	-0.5625	1.00			
V7	-0.1841	-0.0814	0.1003	-0.8505**	-0.7122**	0.9138**	1.00		
V8	-0.6516*	0.2914	-0.8356**	-0.6518*	-0.4736	0.6080	0.3653	1.00	
V9	-0.3827	0.7001*	-0.6973*	-0.7396**	-0.1841	0.6551*	0.3766	0.8521**	1.00

V1 = Plant height
V2 = Number of tillers per plant
V3 = Number of Days to 50% heading
V4 = Number of grain per panicle
V5 = Paddy yield
V6 = Threshing percentage
V7 =1,000 grain weight
V8 = Disease incidence
V 9 = Disease severity index

* * = *Significant* at p ≤ 0.01
* = *Significant* at p ≤ 0.05

Appendix: CLXXIV: Combined correlation coefficient for field experiment of RYMV incidence, severity index and paddy yield components at Nasarawan Buhari for 2008/ 2009 and 2009/ 2010 dry seasons

	V1	V2	V3	V4	V5	V6	V7	V8	V9
V1	1.00								
V2	-0.2119	1.00							
V3	-0.8293**	0.2061	1.00						
V4	-0.0752	0.7064**	0.1447	1.00					
V5	-0.2752	-0.1903	0.2952	0.2249	1.00				
V6	-0.8137**	0.1681	0.6893*	0.0678	0.0628	1.00			
V7	-0.9133**	0.1934	0.6884*	0.0197	0.1626	0.7024**	1.00		
V8	-0.8263**	0.0584	0.7556**	-0.0245	0.2092	-0.7524**	-0.7798**	1.00	
V9	0.2431	0.1616	-0.4023	0.6533*	-0.0191	-0.1334	0.0055	-0.1859	1.00

V1 = Plant height
V2 = Number of tillers per plant
V3 = Number of Days to 50% heading
V4 = Number of grain per panicle
V5 = Paddy yield
V6 = Threshing percentage
V7 =1,000 grain weight
V8 = Disease incidence
V 9 = Disease severity index

* * = *Significant* at $p \leq 0.01$
* = *Significant* at $p \leq 0.05$

Appendix CLXXV: Phosphate buffer 0.01M (pH 7.4):

Component	Quantity
Dibasic potassium phosphate ($K_2HPO_{4)}$	13.62 g
Di-sodium hydrogen orthophosphate anhydrous ($Na_2HPO_4.2H_2O$)	17.81 g

NB : The above chemicals were dissolved in 1,000ml of distilled water; the pH of the solution was adjusted to 7.4 using concentrated sodium hydroxide (NaOH).

Appendix CLXXVI: Phosphate buffered Saline (PBS), pH 7.4:

Component	Quantity
Sodium chloride (NaCl)	8.0 g
Monobasic potassium phosphate ($KH_2PO_{4)}$	0.2 g
Dibasic sodium phosphate (Na_2HPO_4)	1.19 g
Potassium chloride (KCl)	0.2 g

Sodium azide (NaN_2)	0.2 g

NB: The above chemicals were dissolved in 900ml of distilled water and stirred on a magnetic stirrer for 5 minutes in a beaker. The pH of the solution was adjusted to 7.4 using concentrated sodium hydroxide (NaOH). The solution was made up to one litre with distilled water.

Appendix CLXXVII: Phosphate buffered Saline Tween (PBS-T)

Component	Volume
Phosphate buffered saline (PBS)	999.5 ml
Tween-20 .	0.5 ml

NB: Mixed and stirred with a plastic stick.

Appendix CLXXVII: Sample extraction buffer (pH 7.4)

Component	Volume/Quantity
Phosphate buffered Saline-Tween 20 (PBS-T 20)	1 Litre
Polyvinyl pyrrolidone (PVP).	20 g

NB: Mixed and stirred with a plastic stick.

Appendix CLXXVIII: Conjugate or antibody buffer:

Component	Volume/Quantity
Sample extraction buffer	100 ml
Egg-albumen (Sigma A-5253)	2 g

NB: Mixed and stirred with a plastic stick.

Appendix CLXXIX: Carbonate buffer or Coating buffer 0.1 M (pH 9.6):

Component	Quantity
Sodium carbonate ($Na_2 CO_3$)	1.59 g
Sodium bicarbonate ($NaHCO_3$)	2.93 g
Sodium azide ($NaN_{2)}$	0.20 g

NB: The above chemicals were dissolved in 900ml of distilled water and stirred on magnetic stirrer for 5 minutes in a beaker. The pH of the solution was adjusted to 9.6 using concentrated hydrochloric (HCl), the solution volume was made up to one litre (1 L) with distilled water and sterilized by autoclaving

Appendix CLXXX: Substrate buffer or Diethanolamine buffer (pH 9.8)

Component	Volume/Quantity
Diethanolamine	97 ml
Sodium azide (NaN_3)	0.2 g

NB: The above chemical compounds were dissolved in 600 ml of distilled water in a beaker and stirrer on a magnetic stirrer for 5 minutes. The solution was adjusted to pH 9.8 with concentrated hydrochloric (HCl) acid and then the volume was made up to one litre with distilled water.