Protection Technologies of Rice: Activities, Achievements and Aspirations

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SUMMARY

Crop Protection Division at NRRI is emphasizing on host plant resistance research using apt screening methodology for different insect pest and diseases. Studies on crop loss estimation, ecology, epidemiology, toxicology and integrated pest management (IPM) are integral components of investigation of the division since its inception. Methodology for large scale screening like uniform blast nursery (UBN) developed by the Division has been adopted worldwide. More than 1,25,000 genotypes were screened to find out novel sources of resistance against rice pests. Scientists have identified resistant genotypes against bacterial leaf blight (BLB) and brown plant hopper (BPH) which were used to find out novel genes. Novel quantitative trait loci (qBph4.3 and qBph4.4) associated with BPH resistance in the rice landrace "Salkathi" has been identified. Research on yield loss estimation and ecology of pests is being carried out here to understand the dynamics of rice pests. The scientists are also working on evaluation of different pesticides, use of biocontrol agents and indigenous technical knowledge (ITK) to offer options to farmers for the best pest management options. Developed IPM technologies are well accepted by the farmers. The contribution of the division in rice crop protection science is reflected through the quality publications by the scientists. The division is adopting new tools and techniques such as genomics, proteomics, genome editing, nanotechnology and space technology to provide more accurate and precise options to the farmers to tackle the complex and emerging pest situations in rice production systems.

1. INTRODUCTION

Pests, comprising of insects, diseases and nematodes are major constraints in increasing the productivity of rice in all ecosystems. The insect pest scenario of rice in India from 1965-2000 shows a gradual increase in the number of insect species from three during 1965 to twenty-one pests by 2017 (Jena et al. 2018). Likewise, brown spot and blast were the only prominent diseases in early 1960s, but additional ten diseases became economically important by 2017. The overall increase in number of economically important pests within a span of 52 years rings a bell of caution for analysing and identifying the factors responsible for such increase and also to bridge the gaps of management system so that the varieties can yield to their maximum potential. On an average, farmers loose 37 % of their rice yield to pests and diseases, and these losses can range between 24 and 41 % depending on the production situation (Sparks et al. 2012). At the national level, stem borers account for 30% of the losses while plant hoppers, gall midge, leaf folder and other pests are responsible for about 20%, 15%, 10% and 25%, respectively (Krishnaiah and Varma 2013).

Division has worked on various aspects of crop protection strategies and came out with technologies, products and processes to minimise the ever-challenging problems of rice pests. Presently, the Division is working to fulfil the current and upcoming challenges with following objectives:

- Exploration of new sources of donors for multiple resistance against different insect pests and diseases of rice and unravelling the mechanism thereof;
- Discerning the ever-changing bio-ecology of rice insect pests and diseases for climate smart protection strategies;
- Bio-intensive approaches for pest management in rice as a key component of Integrated Pest Management (IPM) technologies;
- Optimization of chemical pesticide-use for management of rice pests in different eco-systems and understanding the extent of pesticide pollution in rice ecosystems and its effects.

Scientists at NRRI, Cuttack has carried out investigations to understand the biology and ecology of major insect pests like stem borers, brown plant hopper (BPH), white backed plant hopper (WBPH) and gall midge. Epidemiology of diseases like blast and brown spot with physiological specialization enabling to forecast different diseases of common occurrence are also being studied by Plant Pathologists in the Division. Valuable resistant donors against these insect pests and diseases were identified at this institute and have been widely used by researchers in the country and abroad. The objective of the chapter is to revisit the work done by the Division in past, elaborate the impacts of the research to farming community and rice sciences at large and identify the future work plan to deal with new challenges in rice pest management.

2. GENESIS OF THE DIVISION

The outbreak of devastating epiphytotic brown spot disease of rice (*Helminthosporium* spp.) in the then Bengal province in 1942 caused heavy loss in rice production leading to Great Bengal Famine of 1943. The need to establish a national institute was felt for undertaking rice research on crop protection as well as on all aspects of rice, and thus the Central Rice Research Institute (CRRI) came into existence in 1946. The present day Crop Protection Division of the institute was started with two separate divisions namely, Entomology and Pathology. It was here that the concept of multi-locational evaluation of accessions to find out resistant genotypes was conceptualised in early 1950s and started with testing donors of blast resistance in different states for understanding the variability of blast fungus. A separate coordinated programme on this was initiated later. Methodology for large scale screening for blast resistance was developed and practiced at NRRI. The protocol has been adopted world over as Uniform Blast Nursery technique and is being widely used even today. Over the years, the division became stronger in the field of crop protection to tackle new challenges. The present format of Crop Protection Division came into shape in the year 2008 consisting of scientists from four disciplines, namely Entomology, Pathology, Nematology and Agricultural Chemicals. Presently the division has 21 scientists, 10 technical staffs, 2 skilled support staffs and one administrative staff, working relentlessly to manage the crop pests to achieve higher yield.

3. ACTIVITIES OF THE DIVISION

The Crop Protection Division is conducting basic, strategic and applied research on integrated management of rice pests to improve rice productivity, quality and profitability. Scientists from different disciplines of the division are involved in multidisciplinary research in collaboration with scientists of other divisions as well as from other institutes to generate basic and advance knowledge on relevant aspects. The Division is actively engaged in different major aspects of rice protection sciences e.g. (1) identification of genotypes with novel genes/QTLs against rice pests; (2) predicting the biology and severity of different pests in anticipated climate change scenario; environment friendly pest management using predators, parasitoids, microbial agents and plant based products for minimising the use of chemical pesticide. Major thrust has been given on multiple pest resistant genotypes, pest modelling and forecasting, tri-trophic interaction of rice, pests and predators/parasites under climate change, novel molecules and eco-friendly formulations for the management of field and stored grain pest. The Division is also involved in designing, validating and popularising pest-specific and ecology-based IPM modules for the farmers to ensure sustainability and profitability.

4. ACHIEVEMENTS

The Division has identified resistance donors against different pests and developed novel technologies to address the pest damages. Few important technologies are mentioned below:

4.1. Multi-use formulation of Trichoderma spp.

This technology relates to the development of talc based formulations of *Trichoderma* (Rice-Vit) to be used as a potential biofertilizer and biocontrol

Fig. 1. Effect of *Trichoderma* seed treatment on rice growth.

agent for direct seeded rice variety (Fig. 1). *Trichoderma* strains were isolated from novel habitats like tree bark, decaying woods etc. These products are safe to handle and cost effective. These may be used as invaluable input in the present day organic agriculture.

4.1.1. Alternate Energy (Solar) Light Trap (AELT)

Alternate Energy Light Trap comprising of light trap unit for attracting insects, a collector unit and an energy harnessing unit for harnessing alternative energy (sunlight) for powering the light trap unit (Fig. 2). The trap catches flying insects like leaf folder, stem borer moths, hoppers and other insects, thereby reduce population and subsequent progenies in the fields. No electricity and manpower is required to operate the device. The device reduces the usage of toxic chemical pesticide in the agricultural fields. It is an eco-friendly insect pest management device for cereals, pulses, oil seeds, vegetables, fruits and other fields of horticultural crops including plantation crops.

Fig. 2. Alternate energy light trap.

4.1.2. IPM module for rainfed upland ecology

Seed treatment (with fungicides), application of herbicide (pre-emergence) at 3 days after sowing and need based application of pesticide at maximum infestation and installation of pheromone traps for YSB resulted in effectively reducing crop damage by rice pests with highest B/C ratio.

4.1.3. IPM module for deepwater ecology

Cultural practices (deep summer ploughing, burning of stubbles), seed treatment with bactericides and any fungicides in water suspension for 6 hrs and basal application of granular pesticides reduced crop damage due to different pests (mainly BLB and yellow stem borer) and increased yield.

4.1.4. IPM module (bio-intensive) for irrigated ecology

Seed treatment and foliar spray of neem oil (0.5%) against hispa and leaf folder; soil application of neem and *Milletia pinnata* (karanja) seed powder at the beginning of infestation against yellow stem borer and gall midge and spray of extract of water pepper leaves for BPH and gundhi bug were recommended.

4.1.5. IPM module for scented rice

Foliar spray of tetracycline and Copper oxychloride against BLB, neem oil (1%), Karanja oil (1%) and water pepper leaf extract for BPH, mixed seed powder of neem, *Milletia pinnata* (karanja), or *Strychnosnux-vomica* (kochila) and kochila seed extract significantly controlled yellow stem borer.

4.1.6. riceXpert App

It is an android based mobile application (app.) and is presently tri-lingual (English, Hindi and Odia). The App will provide better diagnosis and management of insect pests, diseases, nematodes, weeds and nutrient deficiencies in rice to farmers. The App has other features like rice varieties, agricultural implements, news, expert consultation, weather information, rice news, government schemes and advisory services like Pest Solution and Fertilizer Calculator etc. Farmers can use this App as a diagnostic tool in their rice fields and make customize queries for quick solution of their problems through text, picture and voice that would be addressed by NRRI experts on real time basis (Mohapatra et al. 2018).

4.1.7. Indigenous Technical Knowledge (ITK) modules

The bio-intensive IPM was demonstrated in tribal areas of Odisha by NRRI, Cuttack, and was found most effective, economic and socially acceptable method of pest management for tribal farmers. Further, this was found to be the only feasible method of rice pest management for the farmers of unfavourable low land ecosystem. At the same time, ITK based IPM modules have the potency to reduce the pesticide load in irrigated ecosystem by preventing unnecessary pesticide application through proper monitoring and by the application of botanical products as an alternate to pesticides.

4.2. *Knowledge generation*

4.2.1. Host plant resistance

Various disciplines of the division always endeavored to find out new sources of resistance against different insect pests and diseases of rice. Large number of germplasm were screened over the years to find out novel donors against the rice pests. As per our annual reports of 1950-2018, the overall work has been summarized in Table 1 and 2.

Concerted efforts for identifying source of resistance started at Central Rice Research Institute, Cuttack in 1948. Since then, mechanism of resistance is being understood in rice. The antixenosis and antibiosis were studied in depth to understand the mechanism of resistance in rice pests. The yellow stem borer resistant variety, TKM 6, exhibited highest antibiosis as far as the larval survival and growth are concerned. In addition, susceptible cultivar Jaya possessed

Table 1. Varietal/landraces/genotypes screened against different insect pest at NRRI.

Insect pest	Scientific name	No. of genotypes screened	Number of resistant genotypes	Notable accession
Brown Plant hopper (BPH)	*Nilaparvata lugens*	14001	582	Salkathi, Dhobanumberi, Assamchudi, Baiganmanji, Champa, Champeisiali, Balibhanjana-T, Ganjeijota-P, Jalakanthi, Banaspati, Panidubi, Harishankar
White backed plant hopper (WBPH)	*Sogatella furcifera*	2365	60	AC 34222, AC 34264, AC 38468, AC 42425, AC 34270, Kalakalam, Malata, Babel, Lachha, Tripti
Gall Midge (GM)	*Orseolia oryzae*	15160	567	Aganni, INRC 3021, ARC 5984, Kakai (K1417), ARC 6248, IC 121824, IC 199557, IC 199558, IC 121850A1, B-127, B-140, B-143, B181, B-182
Yellow stem borer (YSB)	*Scirpophaga incertulas*	9606	88	TKM 6, SLO 12, B-514-32, B–506-2-18, B-2-12-14, Nalihazara, Dahijhil, Kendrajhali, Kusuma, Champeisali, Kanelaka, Achinha and Bahalmali
Green leaf hopper	*Nephotettix virescens*	772	30	Vikramarya, Nidhi, Samalai, Saraswati, Daya, Lalat and Radhi
Leaf folder	*Cnaphalocrocis medinalis*	1292	45	ARC14539B, GEB 24, HB 349, Raminad st3, Bundei, Harisankar, Sunakathi, Surjana, Juli and Sana chinamala
Gundhi bug	*Leptocorisa acuta*	161	9	CR 44-82, RR 50-3, TR 13-600, Badshabhog, Hamsa, CR 544-148-82,
Hispa	*Dicladispa armigera*	20	4	MO 1, MTU 15, Doddakhare and SR 26B
Aphid	*Rhopalosiphum rufiabdominale*	85	6	ZA/BCP-20, ZA/BCP-24, ZA/BCP-26, ZA/BCP-27, ZA/BCP-28, ZA/BCP- 32
Mite	*Steneotarsonemus spinki*	13	4	Vanaprabha, Heera, Annada and Vandana
Total	**43475**	**1395**		

Table 2. Varietal/landraces/genotypes screened against different diseases at NRRI.

Diseases	Genotypes screened	No. of resistant donors*	Notable accession
Blast	27954	3146 (R)	Zenith, Tetep, Tadukan,Dular, IR64, Sumit, Abhishek, Savitri, Co25, Co26, IR8
Brown spot	18220	1903 (R)	Co20, Bhagirathi, Sarala, Jyothi, PTB4, BAM10, Sudhir, Ashoka, ARC5846, HRC 702
Bacterial leaf blight	22837	1134 (R)	IR32, IR34, Naveen, Tetep, Tadukan, Dular, Zenith, CRHR 45, AC36369, CRHR 48
Sheath blight	13951	433 (MR)	CR BoroDhan 2, CR Dhan 801, CRHR 41, Sabita, Tarori Basmati, Sumit, Pusa-33,Ghanteswari, Tulajapur-1, IR-62

*R, Resistance; MR, Moderately resistance

higher amounts of total and reducing sugars, amino acids and starch whereas the resistant TKM 6 and PTB 18 had more amount of total phenols (Padhi and Rao 1978). It was found that the resistant gene, Gm4 identified from PTB10 was an ideal candidate for deployment in gene pyramiding (Mohaptra et al. 2014). Gene pyramiding of gall midge resistance genes (Gm1, Gm4) into an elite cultivar, Improved Tapaswini was completed. Out of the ten gene pyramids, ITGP7 (IT+Gm1+Gm4) showed high levels of resistance similar to resistant controls (Das et al. 2018).

NRRI has developed a polymerase chain reaction (PCR) based assay that distinguished five different biotypes of the Asian gall midge (biotype 1 to biotype 5). Five diagnostic PCR products were isolated, cloned, sequenced and converted to sequence characterized amplified regions (SCARs). It was found that Cuttack (Odisha) populations were found to be distinctly different from those of Warangal and Raipur (Behura et al. 2002). An important study established a karyological sexual dimorphism in rice gall midge. Six chromosomes are present in the metaphase ganglionic cells of larvae populations generating males and eight chromosome populations generating females (Sahu et al. 1996).

Salkathi and Dhobanumberi showed promising antibiosis against BPH; further novel quantitative trait loci associated with brown plant hopper resistance in the rice landrace Salkathi has been identified (qBph4.3 and qBph4.4.) (Mohanty et al. 2017). Utilizing these resistant accessions, different genotypes have been developed in the back ground of popular rice varieties

Tapaswini, Pusa 44 and Samba mashuri. Some genotypes like CR 2711-76, CR2712-227, CR2711-114, CR 2711-139, CR 2711-149, CR2712-2, CR 2712-11-1, CR 2712-11-13, CR 2712-229, CR 2713-8, CR 2714-2 were identified as highly resistant to BPH out of which CR2711-114, CR 2711-76, 2711-139, CR 2711-149, CR 3005-77-2, CR 3005-230-5 and CR 3006-8-2 were found highly promising in the co-ordinated trials of IIRR (earlier DRR), Hyderabad, (CRRI, 2013; AICRIP, DRR, 2006-2010). Cultivar CR2711-76 developed with the introgression of resistance from genotype Dhobanumberi in the background of high yielding cultivar Tapaswini at NRRI Cuttack, India, has a single dominant gene, Bph31.

The Division has identified highly tolerant variety "CR-1014" against sheath blight disease. This particular variety performed good against sheath blight over the years. Efforts were put into to identify new QTLs or genes present in it. The Division also actively participated in the developing of BLB resistance gene pyramided variety Jalamagna.

The variability in reaction of blast resistant accessions at different locations suggested the possible existence of different physiological races of the blast fungus. By 1964, the existence of 22 races of the blast fungus were classified using the international set of differentials. Later on, isolates of *P. oryzae* collected from different parts of India during the period 1962–68 were analysed and reported the occurrence of 31 pathogenic races of *P. oryzae* (Padmanabhan et al. 1970). Three varieties Tetep, Tadukan and Zenith were found resistant to all the races identified in India. Similarly, pathogenic specialization in bacterial blight pathogen was established. A set of Indian rice differentials were constituted and 6 pathotypes were identified (Nayak et al. 2008).

The genetic diversity at twenty-four most significant blast resistance gene loci using twenty-eight gene specific markers were investigated in landraces originated from nine diverse rice ecologies of India. The landraces harbour a range of five to nineteen genes representing blast resistance allele with the frequency varied from 4.96% to 100%. Five markers viz; K3957, Pikh, Pi2–i, RM212 and RM302 were strongly associated with blast disease with the phenotypic variance of 1.4% to 7.6% (Yadav et al. 2019). The genetic diversity of eighty released rice varieties of the institute (NRVs) were studied by screening them using molecular markers linked to twelve major blast resistance (R) genes. Out of seventeen markers, only five markers, 195R-1, Pi9-i, Pita3, YL155/YL87 and 40N23r corresponded to three broad spectrum *R* genes viz. Pi9, Pita/Pita2 and Pi5 were found to be significantly associated with the blast disease with explaining phenotypic variance from 3.5% to 7.7% (Yadav et al. 2017). Similarly, major blast resistance genes were investigated in landraces originating from north-eastern India. The genetic frequencies of the 18 major blast resistance genes were between 6.2% and 27.4%. Association analysis identified six markers, CRG4_2, RM72, tk59-2, pi21_79-3, RM1233 and RM6648 which are significantly associated with blast disease and explained a phenotypic variance of 1.1–6.5% (Susan et al. 2019). The associated genes could be used in marker-assisted rice breeding programmes for gene pyramiding to develop rice varietal resistance against blast disease.

4.2.2. Ecology and epidemiology

The pre-monsoon rains in India during April and May initiate gall midge activity in rice stubbles, self-sown rice, and other hosts leading to extensive damage to early planted rice crop. (Prakasa Rao 1975). In case of delayed monsoon, however, the late-planted crop suffers. Insect activity oscillates between last week of August and first week of October. Pest proliferates in active tillers of susceptible rice cultivars irrespective of planting time (Prakasa Rao et al. 1971). Depending on the severity of gall midge attack, yield loss was estimated between 3-70% (Chatterji et al. 1976) and was also estimated percent increase in gall midge incidence reduced the crop yield by 0.4-0.5% (Reddy 1967).

Stem borer occurs in both the wet and dry seasons. In the wet season, stem borer incidence is intense during October-November resulting in white ear head damage at the flowering stage, while in the dry season, the pest incidence occurs from February to April infesting the rice both at vegetative and heading stages. The stem borer incidence was negligible at the vegetative stage while the white ear head incidence was recorded as high as up to 22.6% (Jaya) and 27.2% (Padma) (Annual report, 1974). NRRI has developed a simple method of forecasting appearance of first brood of yellow stem borer, by either recording soil temperature at 5 cm depth in field (appearance of first brood of stem borer is correlated to soil temperature reaching 19°C at 5 cm depth) or by regular examination of the stubbles of the harvested crop for over-wintering larvae during December-January (Prakasa Rao 1984).

Hot and humid conditions with stagnant water in the fields with a maximum temperature of 28 to 29°C and humidity range of 85 to 90% were favourable for the incidence of leaf hoppers and plant hoppers. Rice hispa was abundant when temperature is in the range of 28 to 33°C with a relative humidity of 75 to 98%. During flowering season in October-November, prevalence of temperature between 27 and 28°C with a relative humidity of 80-82% favoured gundhi bug incidence.

Investigation on nematodes of rice and rice soils commenced in 1963 at this institute. Sampling methods and optimum time for survey and assessment of nematode fauna in rice and rice soil were devised (Israel et al. 1966; Das and Rao 1971). The nematode parasites of rice were identified and research started with identification of nematode resistant rice varieties and their mechanism of resistance (Jena and Rao 1971).

Four new nematodes viz. *Heterodera oryzae, Meloidogyne graminicola, Caloosiahetero cephala* and *Trichodorus* spp. were reported from rice. In 1978, *Heterodera oryzicola*, a new cyst nematode species infecting rice was identified and reported from Kerala, India (Rao and Jayaprakash 1978). The symptom of nematode injury in rice and losses due to their infestation were determined. The losses ranged from 20 to 23% in young crop. The principal nematode problems were identified. Population dynamics of rice nematodes in relation to soil factors were studied. Alternate hosts of rice nematodes were identified. Nematode management through crop rotation was studied and found that crop rotation with jute and soil population of *Hirschmanniella mucronata* were considerably reduced below threshold levels (Rao et al. 1984).

Two species of rice tarsonemid mites, *Steneotarsonemus spinki* and *Tarsonemus cuttacki* were found to be regular pest deteriorating paddy seed quality. For the first time in India, rice tarsonemid mite, *Tarsonemus cuttacki* was isolated from stored paddy from CRRI godowns (Rao and Prakash 1984). They also reported this mite from the infected panicles/grains. Biology of this mite was studied by Ghosh et al. (1993). For first time in India, population of *S. spinki* were recorded in rice ratoons, stubbles paddy field and weed, *Cynodon dactylon* (Rao and Prakash 1992).

4.2.3. Screening methodologies

No standard methods were available in the beginning for assessing the reaction of genotype to the major diseases like blast and brown spot. The need for evaluating the genetic stocks for blast resistance was felt as early as in 1955 in the sixth meeting of International Rice Commission working party on rice production and protection in which CRRI was an important member and played a vital role. CRRI, as a partof the three-member committee (Ceylon, India and Japan) set up by Food and Agricultural Organisation (FAO) in 1959 played a significant role in designing and developing the popular Uniform Blast Nursery technique for large scale testing and evaluation of genotypes for blast resistance that has been adopted and is still being practiced world-wide (Padmanabhan 1979).

Division’s role in the establishment of the coordinated rice improvement programme in India traced to the multi-location trials used to be conducted to find out resistance donor against both brown spot and blast from its inception. The resistant varieties were tested in 46 centres all over India consecutively for three years during 1955-58. This was a significant precursor for the formulation of multi-location trials for evaluation of resistant donors and breeders’ material (Padmanabhan 1979).

Pathologists of the division have standardized false smut pathogen isolation method (PSA media, 26±1°C for 21 days) and artificial inoculation technique (2 ml spore solution was injected in each tiller at late booting stage and the plant should be kept at 25±1°C for 5 days) to screen genotypes against this pathogen (NRRI Newsletter. 2016. 37(2):17). An artificial inoculation technique to screen large number of germplasm for their resistance against bakane was also stadardized. Inoculation of hot water treated seeds (52 °C for 10 min) with microconidial suspension @ 1.50 x 10^5/ml for 24 hours followed by drying the seeds for 4-6 hours and sowing in sterilized soil in trays under glass house conditions resulted in rapid development of disease symptoms. This technique is very useful for large scale screen of genotypes within 20-30 days.

Initially, the primary emphasis was put on developing a dependable screening method for assessing reaction of large population of plant material against bacterial blight and sheath blight. The methods like clipping the leaves and spraying the plants with the bacterial suspension or dipping the clipped leaves into the bacterial suspension led to development of now popular clip inoculation technique. A cut-leaf inoculation technique was developed in this institute for assessing reaction to sheath blight was successful and results were comparable to field screening (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

4.2.4. Leads in bio-agents and plant products

The role of indigenous parasitoids in the control of stem borer and gall midge and other pests of rice was studied and the period of activity and the extent of parasitization by important egg, larval and pupal parasitoids were determined. *Colluiris sp*. a carabid beetle and adults of *Casnoidea indica* was recorded for 1st time as predators on immature stages of gall midge and leaf folders. *Platygaster oryzae* (solitary), a parasitoid of gall midge was recorded for the first time during 1986.

Leaves of *Vitex negundo, Lippia geminta, Aegle marmelos, Ocimum canum,* crude extracts of garlic and pyrethrum found to be effective in protecting the stored paddy grains insects (Prakash and Rao 1996). A promising grain protectant “2-heptatriacontanone” was isolated and identified from begunia, *Vitex negundo*, leaves and evaluated against grain boring insects in stored rice (Prakash et al. 1990). Strong antifeedant action was observed by neem bark decoction to leaf eating larvae of leaf folder and cutworm. Aqueous and ethanolic extracts and essential oil preparations from leaves of *Agele marmelos and Ocimum sanctum* were toxic to blast fungus (Rout et al. 2013 and 2014).

Trichoderma isolated from tree bark is being used as growth promoter and kills soil and seed borne pathogens (patent file no. 1240/KOL/2015). First time it was proved that *Trichoderma erinaceum* obtained from tree bark could be incorporated in integrated rice crop management both as biocontrol agent and biofertilizer (Swain et al., 2018). Similarly, *Beauveria bassiana,* was found to kill *Nilaparvata lugens* (brown plant hopper), *Nephotetix virescens* (green leaf hopper), *Scirpophaga incertulas, Chilo auricilius, etc*. *Parnara* and *Sesamia* NPV viruses were isolated and characterized. The *Parasitorhabditis* sp. nematode was reared on an artificial diet developed for the purpose (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

Insect juvenile hormone, ZR-777 was found to inhibit metamorphosis of green leafhopper. ZR-515 at 0.5% concentration impaired embryonic development in *Angoumois* grain moth, a stored grain pest. Rice yellow stem borer (*Scirpophaga incertulas*) and rice leaf folder (*Cnapholocrocis medinalis*) were monitored by using dry funnel sleeve traps baited with 9 Z-hexdecenol and 11 Z-hexadecenol in 1:3 rati on and 13 Z-octadecenyl acetate and 11 Z-hexadecenyl acetate in 10:1 ratio, respectively (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

4.2.5. IPM and pesticides

Scientists of the division evaluated large number of pesticides to give recommendation to the farmers to manage rice pests. Recently, seed treatment of rice with thiamethoxam showed positive effects on seed emergence, increased plant root and shoot biomass (Annamalai et al., 2018). Seed treatment with chlorantraniliprole had shown no negative effect on seed emergence, shoot and root parameters (NRRI Annual Report 2017-18), no dead heart damage was reported till 40 days after seed treatment. Besides the bio-efficacy of the pesticides, resurgence of different pests was also investigated. For example, application of synthetic pyrethroids viz., decamethrin, cypermethrin, tetramethrin as foliar spray had shown yellow stem borer resurgence; a first time reported in India. Similarly, application of sub-lethal doses of phosphamidon continuously for 3 BPH generations resulted in females to lay more eggs than the control, with increament ranging from 3 to 11 times (Fifty Years of Rice Research at CRRI (1945-1995), CRRI, Cuttack, India, 1996).

Detailed investigation was carried out to know the persistence of different pesticides (pretilachlor, imidacloprid, fipronil, chlorantraniliprole, bispyribac sodium etc.) in rice ecosystem. In-vitro experiment has been carried out for number pesticides namely butachlor, bispyribac sodium, chlorantraniliprole, fipronil etc. to understand their distribution in different environmental matrices and effects on soil microbes. For example, chlorpyriphos degradation was faster under elevated CO_2 (Adak et al. 2016). Changes in microbial diversity indices confirmed that imidacloprid application significantly affected distribution of microbes. The extent of negative effect of imidacloprid depends on dose and exposure time (Mahapatra et al. 2017). Pretilachlor did not harm the soil microbes at field dose but microbes were affected at higher dose (Sahoo et al. 2016). Non-target effect of continuous application (7 seasons) of chlorpyrifos had no significant effect on population of heterotrophic aerobic, anaerobic, oligotrophic and copiotrophic bacteria, whereas, population of asymbiotic aerobic nitrogen fixer, nitrifiers, denitrifiers, gram positive and spore-forming bacteria were significantly reduced by nearly 0.25–2 fold in chlorpyriphos treatment (Kumar et al. 2017).

Indigenous green synthesis of silver nanoparticles (Ag-NPs) mediated by rice plant extracts has been undertaken by the division for the first time. They were characterized by UV-Vis spectrophotometer, FT-IR, DLS, SEM-EDS etc.

The synthesized Ag-NPs were effective against rice diseases *Xanthomonas oryzae* and *Rhizoctonia solani (*NRRI Annual Report 2015-16).

Use of phosphine in quarantine is limited in India, being a part of all India collaborative project, scientists came into conclusion that both phosphine formulations (77.5% G (Granule) & 56 % Tablet) were effective. Exposure to phosphine for 7 days can be recommended in quarantine to kill major store grain pests of rice. Seven days degassing period is safe for human consumption as phosphine residue in the rice samples was found to be within the MRL (<0.1 ppm). Based on the results, phosphine gas can be recommended for quarantine (NRRI Annual Report 2017-18).

5. PUBLICATIONS

Division of Crop protection has made tremendous progress not only in terms of research but also communicating the same for scientific fraternity through quality research journals with better NAAS score or impact factor. Over the years' not only total number of publications have increased but also publications in journals having higher NAAS score (>8) also increased. Last year (2017-18), divisional scientists have published total of 30 publications of which 11 publications are having NAAS score greater than 8. Few of the journals in which scientists have published with higher score are; Chemosphere, Microbiological Research, Ecotoxicology and Environmental Safety, Bulletin of Environmental Contamination and Toxicology, Biological Control, PLoS One, etc.

6. HUMAN RESOURCE DEVELOPMENT

Developing human resource is one of the important priorities of the Division. Since its inception Division has taken a keen interest in guiding various masters and doctoral students. Because of competent scientists and well established laboratories students from various universities are taking up their research at Crop Protection Division. Over the years, number of students who had taken up their research at Division and awarded degrees have increased. Till today, there are 11 doctoral and 32 master students awarded/pursuing with their degrees who took up their research at this division. Beside this, division imparts training to different stakeholders of rice farming namely, agricultural officers, farmers, etc. on integrated pest management.

7. LINKAGES

The division of crop protection is working vibrantly with various international and national agencies. Division is working in collaboration with IRRI Philippines through different projects. There is a strong convergence mode of research with other division of the institute. There have been collaborations with different ICAR institutes. Since, pesticides are one of the thrust area of the Division, we are working in close association with the various private partners too.

8. IMPACTS

The resistance of BLB in one of the wild rice accessions of *O. longistaminata* (earlier designated as O. *barthii*) was first identified at CRRI (Devadath, 1983). Dr. Khush took it to IRRI, from where it was taken to the University of California-Davis where the Xa21 gene was identified and cloned for developing BLB-resistant rice varieties (Patra et al. 2016). If we Google search with a key word "xa21 gene" 10,900 results which contain the particular key word are being retrieved as on 20.04.2019.

The bio-intensive IPM system has been introduced in the tribal areas by CRRI, Cuttack, through a DST Project (2007-2011). The application of insecticides in irrigated ecosystem, an unnecessary expenditure of about Rs. 800-1800/- during 2007 and 2008 besides polluting the environment by killing earthworms, was dropped by about 70% of the farmers during 2009 and 2010 and they have opted for botanical applications, particularly oil application against BPH (Annual report SP/TSP/2006).

Location specific package of practice for integrated pest management (IPM) in Mahanga block, Cuttack district, Odisha during 2013-2016 recorded tremendous adoption by farmers. The number of damaging pests decreased from 2012 to 2017 and even if more pests were observed during years like 2013, 2015 and 2016, their intensity decreased as protection strategy was taken at initial incidence. The overall protection cost (only material cost) was reduced by 91% by the year 2017 as compared to that of 2012. Yield increase was realized from an average of 3.70 tha^{-1} during 2012 to 5.83 tha^{-1} during 2016 with about 57.6% increase over the first year. The technologies like seed treatment, pest monitoring and application methods were adopted by the farmers of the nearby villages (Jena et al. 2017).

The *Trichoderma* based formulation Rice-Vit developed at ICAR-NRRI is having multifaceted impact on crop health. The *Trichoderma* sp. has been isolated from tree bark and having excellent plant growth promoting characters as well as it is having the capability to control the soil and seed borne pathogens (Swain et al. 2018). The formulation has been tested in Hazaribagh under drought condition and it has been recorded that the *Trichoderma* treated paddy gave 12% higher yield than that of the control one (NRRI Annual Report 2017). The formulation has been tested in Chandol of Kendrapara district in farmers field where higher yield and total biomass of paddy was recorded in treated plants. So, this formulation is having tremendous potentiality for better crop health management.

"riceXpert", the mobile app is having more than 22,000 users covering India (73%), Philippines (9%), Indonesia (3%), Pakistan (2%), Nigeria (1%) and other counties (12%). More than 1500 queries relating to rice insect pest, disease, weed, variety, farm implement, nutrient toxicity/deficiency and other aspects of rice have been received from the Indian users through e-rice advisory module of the app covering almost all rice growing states of India and the queries are being addressed by the panel of experts from and the solutions are being sent to them through SMS. Perusal of the month-wise statistics on the year 2018 downloads of riceXpert app revealed that August (1583) month recorded the highest users of the riceXpert app followed by September (1236) and October (1110).

9. ASPIRATIONS

The pioneering work of the division to identify the resistant donors based on rigorous phenotyping has to be translated into identification of genes/QTLs for resistance and their possible integration into elite variety which are underway and need to be further strengthened. Use of genome editing techniques will be amalgamated to obtain pest free rice crops. Proteomics and metabolomics techniques will be applied to understand plant-pest-natural enemies' interaction. Deeper understanding in molecular diagnosis to detect pathogen at initial stage can help framers to save the crop. Use of space technology in developing forecasting model would make the technology more precise and accurate. Nanotechnology would help to reduce the doses of pesticides and may help for targeted pesticide application. Site specific IPM modules incorporating ICTs will be developed to entrust farmers in decision making for better pest management. Novel pest management strategies like new biocontrol agents, RNAi techniques, novel peptides, chemical elicitors should be given importance.

10. CONCLUSIONS

The Division has screened more than 1,25,000 genotypes against number of disease and insect pests. Two genotypes, Salkathi and Dhobanumberi, have shown resistance against BPH. Similarly, the resistant genotype *Oryza longistaminata* against bacterial blight, has been dissected to identify novel gene *Xa21*. Division's role in phenotyping is worldwide acknowledged. The Division is associated with development of Uniform blast nursery, novel screening techniques related to host plant resistance and many others. Two products as patents, IPM technologies, ITKs have reached to farmers. Work on botanicals, biocontrol agents are widely accepted. Dissemination of rice technologies through riceXpertis is playing critical role to provide information at farmer's doorstep. The Division has amalgamated new technologies to counter the challenges posed by ever-changing pest scenario.

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