1. PROGRESS AND TRENDS OF VIRUS RESEARCH IN INDIA

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India is a vast country with diverse agroclimatic zones and a wide range of crops. They are subjected to the infection of a large number of diseases, many of which are viral in nature. Since the earliest record of spike disease of sandal (now considered to be a mycoplasmal disease) by Coleman[1] many virus and mycoplasmal diseases have been recorded. The earlier accounts were faithful records of host range, transmission and distribution of virus diseases. In the recent years, however, other aspects such as purification, serology, epidemiology etc. have also been taken up. The present account is intended to bring into focus the various aspects of research on virus diseases of crops in our country.

Legumes

The legumes are affected by a number of virus diseases, causing mosaic, mottling, leaf curl and sterility, which are as follows:-

I. Viruses transmitted mechanically as well as by aphids.

1. Common bean mosaic virus on beans (*Phaseolus vulgarias*)[2], urid (*P. mungyo*)[3], cowpea (*Vigna sinensis*)[4].
2. Broad bean mosaic virus on broad bean (*Vicia faba*)[5,6].
3. Cowpea mosaic viruses–
   Catjang mosaic (*Vigna catjang*)[7-9].
   Cowpea mosaic[10] also described as Banding mosaic[11] Necrosis[11] is serologically distinct from banding mosaic. In both the cases the virus particles are isometric[10,11].
4. Common pea mosaic virus on common Pea (*Pisum sativum*)[12].
5. Soybean mosaic virus on soybean (*Glycine max*)[13,14].
6. Leaf crinkle on urid[15,16], cowpea[17].
7. Methi wilt mosaic virus on methi (*Trigonella foenum—graecum*)[18].
8. Berseem mosaic virus on berseem (*Trifolium aleaxndrianum*, unpblished) resembles alfalfa mosaic virus.

II. Viruses transmitted by white flies (*Bemisia trbaci*) only.

Yellow mosaic on; *Dolichos lablab*[19], mung (*P. aureus*)[20] double bean (*P. lunatus*)[21], urid[22], soybean[23], cowpea[13].

III. Virus transmitted by mites (*Aceria cajani*)

Sterility disease of pigeon pea (*Cajanus cajans*)[24]. Narayanaswamy and Ramakrishnan[25] suspected some nematodes as the vactor.

IV. Viruses transmitted only mechanically (no vectors known).

1. Virus isolates considered to be strains of TMV;
   A typical bean mosaic[26].

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Cowpea mosaic[11].
Dolichos enation mosaic[27,28].

2. Virus isolates considered to be strains of tobacco ring spot virus.
   Top necrosis of guar[29].
   Bud blight of soybean[23].
3. Leaf curl disease of urid and mung[30].
4. A mechanically transmitted mosaic disease on pigeon pea reported by Bisht and Bannerjee[31] also called yellow mosaic of pigeon pea[22].
5. A top necrosis disease of cowpea[11].
6. Runner bean mosaic virus (*Phaseolus multiflorus*)[32].

Most of the viruses listed above are seed transmitted and hence attempts have been made to detect their presence in the seeds. Indexing of detached and macerated embryos on local lesion hosts such as *Chenopodium amaranticolor* or *C. murale* gave results within 6–7 days. Phatak and Summanwar[33] distinguished between healthy and cowpea mosaic virus affected cowpea seeds based on seed morphology. The fluorescent stain, acridine orange was used to detect viral infection in cowpea embryos, which on microscopic examination, showed characteristic red fluorescence[34]. Employing embryo culture technique, Mishra *et al*[35] demonstrated the deleterious effects of mosaic infection on embryos of runner bean.

Cereals and Millets

RICE (*Oryza sativa*):

Three important leaf hopper transmitted diseases recorded on rice crop in India[36,37] are:–

1. Rice tungro virus (RTV) occurs in many regions of the country[38–43]. The virus is transmitted by *Nephotettix virescens, N. nigropictus,* though not so efficient a vector, transmits RTV strains differentially (unpublished). Five strains of the virus have been recorded from different regions in India[44,45], all of which are considered to belong to the 'S' strain reported from the Philippines.
2. Grassy stunt disease incident and its vector are recorded in epidemic form from Kerala, Madras and Orissa[46–49]. Etiological studies undertaken at the IARI, New Delhi, did not evidence the presence of mycoplasma like bodies in ultra thin sections of diseased leaves (unpublished).
3. Orange leaf is transmitted by *Inazuma dorsalis*[37].

WHEAT (*Triticum* spp.):

1. The mosaic streak disease on wheat is reported to be the same as Chirke disease of large cardamom[50]. The virus is sap and aphid transmitted and has spherical virions of 40 nm diameter[51].
2. Another virus disease 'Eastern wheat striate' reported on wheat and barley varieties[52] is only leaf hopper transmitted and has virus like particles of 40 nm diameter.
3. Maize streak virus on wheat has also been recorded[53].

MAIZE (*Zea mays*):

1. The mosaic disease on maize[54], sap and aphid transmitted, infects many grasses except sugarcane. Flexuous virions measuring 554×27–35 nm and two types of cellular inclusions are associated with the disease[55,56].
2. A mosaic disease transmitted by the *Peregrinus maidis* and causing chlorotic stripes[57] is reported to be caused by maize mosaic virus I—a member of the Rhabdovirus group[58].
3. Another virus disease causing vein enations on maize leaves, besides stunting has

been recorded recently. It is transmitted by *Cicadulina intoila* and infects wheat, rice, oats, sorghum, sugarcane, ragi etc. and is designated as 'maize vein enation virus'[59].

JOWAR (*Sorghum vulgare*):

Jowar is affected by a chlorosis disease, which is transmissible only by a fulgorido vector, *Peregrinus maidis*[60].

BARLEY AND OATS (*Hordeum vulgare* and *Avena sativa*):

Two virus diseases, barley yellow dwarf[61-63] and barley mosaic[64], occur in India. Both the diseases are sap and aphid transmitted, the latter having spherical virions 40 nm.

PEARL MILLET (*Pennisetum typhoides*):

A sap and aphid transmitted mosaic[65] and a leaf hopper transmitted streak mosaic[66] are recorded. Both viruses have a wide host range, the former including rice and are considered to be strains of sugarcane mosaic virus and maize streak virus, respectively.

RAGI (*Eleusine coracana*):

A mosaic disease was described from Mysore and Poona which is transmitted by sap and aphids and is transmissible to maize and sorghum[67-69].

Vegetables

CUCURBITS: The virus diseases on cucurbits are:-

I. Sap and aphid transmitted virus diseases.

1. Cucumber mosaic virus—Cucumis virus I (Cucumo virus group) isolated from melon[70]; snakegourd (*Trichosanthes anguina*)[71,72] vegetable marrow (*Cucurbita pepo*)[73] and pumpkin (*C. maxima*)[74,75]. Spherical virions with average diameter of 27–29 nm were reported for on three of the above isolates[71,73,75]. The two latter isolates are seed borne. Raj and Chohan[76] and Sharma and Chohan[77] found that transmission of vegetable marrow virus infection could be eliminated from seeds of vegetable marrow by hot air (70°C for 2 days or 40°C for 4 weeks) or hot water (55°C for 60 min.) treatments.
2. Water melon mosaic virus (Potyvirus group) reported from vegetable marrow[78,79,75]; ash gourd (*Benincasa hispida*)[80]; pumpkin[81] and bottle gourd[72]. These isolates are highly unstable and have flexuous virions of the dimension, 720–860[81,75,73].

II. Sap transmissible virus diseases with no vectors (Tobacco virus group):-

1. Cucumber green mottle mosaic virus (Cucumis virus 2) reported from bottle gourd:-
   (a) Cucumis virus 2 B[82,83].
   (b) Cucumis virus 2 C[84-89]. Vasudeva[90] also isolated cucumis virus 2 C from *Lagenaria leucantha.*
   Shankar[71], Raychaudhuri[75] and Rao[73] reported the isolates from bottle gourd; water melon[71,75] and muskmelon (*Cucumis melo*)[75] as Cucumis virus 2.
   The virus is stable and many of the isolates are shown to be serologically related to tobacco mosaic virus[91,75,73]. Rod shaped virions with average dimension of 280 nm have been reported[73,75,91,92,93].
2. Cucumis virus 3 has rod shaped virions of 300 nm[94] and distant serological relation with TMV[95]. It is reported from bottle gourd (*Lagenaria siceraria*)[96] and tori (*Luffa acutangula*)[97,83,98].

III. Non sap transmissible and white fly (*Bemisia tabaci*) transmitted virus disease.

Yellow vein mosaic of vegetable marrow[99] and pumpkin yellow vein mosaic virus[100]. The latter affects *Cucurbita pepo, C. pepo* cv. medullosa, *C. moschcata* and *C. maxima.*

IV. Other viruses which have not been placed in any of the above groups due to inadequate information.

Water melon mosaic virus on water melon[101].
Pumpkin mosaic virus on pumpkin[102].
Bitter gourd mosaic virus on bitter gourd[103].
Kakri mosaic virus on kakri[75].
Tori mosaic virus on tori[104,75].
Melon mosaic virus on melon[98].

AMARANTHS (*Amaranthus* spp.):

A severe mosaic disease has been reported[105–107] causing mosaic mottling and yellowing of veins, transmitted by sap and aphids. The flexuous virions measuring 700–725× 14 nm were isolated.

BHINDI (*Abelmoschus esculentus*):

The yellow vein mosaic disease reported from various parts of the country[108,109] is transmissible by *Bemisia tabaci* on a number of hosts. Control of the disease to a limited extent is suggested in certain localities by roguing diseased plants and use of insecticides[110–112].

CHILLI (*Capsicum* spp.):

Mosaic and leaf curl are the chief virus diseases on chilli crop. Mosaic disease of chilli is reported to be caused by at least six viruses, namely:–

1. Chilli mosaic virus[113, 114].
2. Tobacco mosaic virus strains[115–117].
3. A virus causing necrosis on chilli[118].
4. Cucumber mosaic virus[119].
5. Potato virus X[120].
6. A strain of potato virus Y[121].

Swaminathan[122] recorded mitotic disturbance, delayed embryo sac development and inability of virus to infect functional gametes which might be the reasons for the non-seed transmissibility of the virus, besides suspected presence of an inhibitor in the embryo sac.

Ramakrishnan *et al*[123] studied the reaction of a number of chilli varieties to TMV, whereas Alagianagalingum[124] found that the rhizosphere of TMV infected chilli plants supported a large number of fungi and bacteria.

Chilli leaf curl virus on chlli[125] is the same as the tobacco leaf curl virus transmitted by white flies but not by sap. A severe strain described from Delhi, besides inducing enations on the under surface of the leaves infects 'Puri Red' and 'Puri Orange' varieties of chilli[126].

BRINJAL (*Solanum melongena*):

Moasic like symptoms are caused by a number of viruses viz.:–

1. Tobacco mosaic virus strain[127–130].
2. Cucumber mosaic virus strain[127, 131, 129, 130].
3. Tobacco etch virus[132].
4. Brinjal ring mosaic virus[130].
5. Brinjal crinkle mosaic virus[130].

6. Brinjal mosaic virus[130].
7. A seed transmitted virus resembling BMV[130] has also been reported[133,134].

LETTUCE (*Lactuca sativa*):

Two mosaic diseases are recorded. Lettuce mosaic disease caused by lettuce mosaic virus is sap and aphid transmitted[135]. Vasudeva *et al*[136] reported another disease designated as yellow mosaic disease which is also sap inoculable and seed transmissible.

SPINACH (*Spinacea oleracea*):

A sap and aphid transmitted mosaic virus disease was reported[137] for the first time.

TOMATO (*Lycopersicon esculentum*):

Among a number of diseases occurring on tomato, leaf curl virus disease, transmitted by white flies is the most important one[138,139]. The causal virus is the same as tobacco leaf curl virus and has a very wide host range. A number of strains of tobacco leaf curl virus have been described[140–142].

The mosaic disease prevalent in the country is caused by a number of viruses:–

1. Tobacco mosaic virus strains—Tomato aucuba virus[143,129]. This strain is carried through seeds as contaminant[144].
2. Potato virus X[79].
3. A symptomless virus[145].
4. Tomato black ring spot virus[146].

Mosaic viruses of onion and raddish have also been recorded[147,148].

Oil Seed and Fibre Crops

MUSTARD (*Brassica* spp.):

1. Mosaic disease identified as Turnip virus I, on *B. juncea* cv. rugosa[149,150].
2. Sarson mosaic on *B. campestris* cv. sarson, restricted to sarson[151].

SAFFLOWER (*Carthamus tinctorius*):

1. Mosaic disease, sap and aphid transmitted[152].
2. Mosaic disease belonging to TMV group[153].

GROUNDNUT (*Arachis hypogea*):

I. Diseases transmitted only by grafting.

1. Mosaic[154].
2. Bud necrosis[155–157].

II. Diseases transmitted by grafting and seed.

1. Bunchy top[158].
2. Ring mottle[158].

III. Diseases transmitted by grafting and aphids.

1. Mosaic[159,160].
2. Chlorosis[158]. *A. craccivora* transmits this disease in a persistent manner.
3. Singh and Gupta[161] reported a rosette virus, a complex of virus strains, namely normal chlorotic rosette, mosaic and mottling. The chlorotic rosette is transmitted by the vector *Helothrips indicus*.

JUTE (*Corchorus trilocularis*):

Chlorosis of jute transmitted by white flies[162,163], is reported to have two strains[164].

SANNHEMP (*Crotolaria juncea*):

1. Mosaic caused by strains of TMV[165,166].
2. Mosaic virus with spherical virus particles[167,168].

Plantation Crops

SMALL CARDAMOM (*Eletteria cardamomum*):

'Katte' (or marble or mosaic) disease is prevalent throughout the cardamom growing regions of Southern India. The virus is transmitted by banana aphid, but not by sap and infects only *Amomum cannaecarpum*[169–171]. 13 additional aphid species are reported as its vector[171].

LARGE CARDAMOM (*Amomum sbulatum*):

Chirke disease causes small mosaic streaks on leaves[172,173]. The disease is sap inoculable and transmitted by a number of aphids[174].

MULBERRY (*Morus alba*):

1. Mosaic—mechanically and aphid transmitted[175,176]. The virus particles are reported to be rods measuring 544×27–35 nm[177].
2. Yellow net—mostly occurs in low bushes and is transmitted by *Bemisia* sp.[178].

PINEAPPLE (*Ananas comosus*):

A wilt disease, transmitted by mealy bugs, is recorded from Coorg (Karnataka)[179].

CASSAVA (*Manihot utilissima*):

The white fly transmitted cassava mosaic is a major problem in Kerala. Besides, euphorbaceous hosts, Menon and Raychaudhuri[180] reported cucumber to be an additional host.

COCONUT (*Cocus nucifera*):

The root wilt disease of coconut produces yellowing and slow wilting of foliage. Cowpea seedlings produce diagnostic symptoms[181]. Summanwar *et al*[182] isolated rod shaped virions (320–360×24–25 nm) from infected leaves and transmitted the disease to herbaceous hosts. Shanta *et al*[183] however do not conform to the above findings. The disease is reproducible by means of mechanical transmission[184] and also transmissible through soil and insects like *Stephanitis typicus*[185,186]. The presence of nematode species *Longidoru* and *Xiphinema* in the coconut root soil, is considered to be of interest[187].

CITRUS (*Citrus* spp.):

1. Die Back or decline is considered to be a complex disease where association of tristeza virus, greening pathogen and certain deuteromycetous fungi has been demonstrated[188].
2. Tristeza was first recorded from Bombay and has since been reported from all over the country. The virus is principally transmitted by aphid species mainly *Toxoptera citricidus*[189–191]. Capoor[192] recorded Kagzi lime as the indicator host.
3. Exocortis: This disease causes scaling of the bark and is only graft transmitted[193,194].
4. Psorosis: Ahlawat *et al*[195] have indicated the occurrence of this disease in Kalimpong region.

BANANA (*Musa* sp.):

1. A mosaic disease of cultivated Cavendish banana caused by a strain of cucumber

mosaic virus was recorded from Poona[169]. The virus is sap transmitted to only *Cucumis sativus* and by aphids to banana.

2. Bunchy top virus is not sap transmissible but transmitted by banana aphid (*Pentalonia nigronervosa*) in a circulative manner[197].

PAPAYA (*Carica papaya*):

1. Mosaic: Capoor and Varma[198] reported a mosaic disease from Bombay having different strains[199,200].
2. Distortion ring spot virus: Apocarpy and double fruit formation was also reported[201].
3. Leaf curl: Nariani[202] proved it to be caused by leaf curl virus of tobacco.

TOBACCO (*Nicotiana* sp.):

1. In India, tobacco is mainly grown in Andhra Pradesh and mosaic is the most commonly occuring virus disease which affects the quality of the leaves[203].
2. Leaf curl is an important white fly transmitted virus having a wide host range and many strains[204,205].

SUGARCANE (*Saccharum officinarum*):

Sugarcane is an important cash crop. The numerous viruses occuring on sugarcane bring about degeneration and decay of the seed setts by their repeated vegetative propagation.

1. Mosaic disease of sugarcane was observed as early as 1921 and studied in detail by Chona and Rafay[206]. The virus is sap inoculable and transmitted by the aphid vectors, namely, *Rhopalosiphum maidis* and *Schizaphis graminum*[207].
2. Ratoon stunting disease occurs in many regions of the country[208], which might have escaped the notice earlier because of lack of any clear symptom. The disease is readily transmissible mechanically and in nature through harvesting implements[209] and results in progressive degeneration of the seed sett stocks. The disease can be controlled effectively by hot air treatment at 54°C for 8 hours or hot water treatment at 50°C for 2 hours[210,211].

Tuber Crops

POTATO (*Solanum tuberosum*):

The potato crop was introduced into India by Western traders about 3 decades ago and the work on potato viruses for the production of disease free stocks was initiated at the Indian Agricultural Research Institute and its substation at Simla[212-214]. With the subsequent establishment of Central Potato Research Institute, Simla, the research work on potato viruses and development of virus free seed stocks has further enhanced. The common viruses infecting potatoes are:–

1. Potato virus X (PVX) first isolated by Vasudeva and Lal[215]. Nine strains of PVX has been reported from India[216-220]. *Capsicum pendulum* has been found to be a superior assay plant[221]. Production of PVX local lesions in *Capsicum* sp. is cytoplasmically controlled[222]. PVX infected plants are more susceptible to early blight than the healthy ones[223].
2. Potato virus Y (PVY) first isolated by Vasudeva and Lal[224] from several varieties and transmitted by *Myzus persicae*. PVY infected potato plants are more susceptible to early blight[223].
3. Potato virus S and M are reported by Upreti *et al*[225]. The symptoms of S strain are present in almost all the varieties.
4. Potato virus A (PVA) is reported for the first time by Vasudeva and Ramamurthy[226] from the cultivars 'Phulwa' 'Darjeeling' and 'Red Round'. It produces mild

mosaic in potato plants. It has also been found to infect *Nicandra physaloides* in nature[227].

5. Potato virus F or G produces aucuba mosaic type of symptoms characterised by bright yellow spots on older leaves and sometimes necrosis in tuber in varieties 'Phulwa' and 'Kufri Kuber'.
6. Potato calico virus: Nagaich and Giri[228] reported it from potato and primula as a strain of alfalfa mosaic virus. This virus produces calico symptoms i.e., creamish or white yellow spots on older leaves and necrosis of both tubers and leaves. The necrotic symptoms resemble that of PVY.
7. Potato leaf roll virus (PLRV) is commonly occurring virus in the plains[229]. The yield losses are above 50% and in extreme cases even much higher[230]. Variation in the ability of *M. persicae* clones to transmit PLRV has been reported[231].
8. A tobacco mosaic virus strain was isolated from 'Phulwa' variety of potato by Phatak and Verma[232].
9. Tomato spotted wilt virus. The infection of this virus was recorded to be latent in 'Great Scot' stocks and observed to be common to tomato and dahlia plants in Nilgiris[233].

These viruses occur either singly or in combination. The most common combinations are PVX : PVY, PVX : PVA and PVX : PVS.

For controlling these viruses heat therapy seems to be the best way. Thirumalachar[234] reported cure of stored potatoes at Patna where temperature outdoor in summer is 40°C. Nagaichi and Upreti[235] reported inactivation of virus by continuous heat treatment of tubers at 35°C for 8 weeks. Alternatively, putting 'Eye-pieces' at 40–42°C for 2–4 hours and 12–20°C for the rest of the days for a total duration of 6–8 weeks was also found to be effective. Hot water treatment of whole tubers at 55°C for 15 minutes and 52°C for 25 minutes (in the case of cut tubers) was also effective[236]. PVS could not be inactivated in tubers by heat treatment. However, sprouted tips (1–2 cm) maintained at 35°C for 21 days did not show the presence of the virus.

SURAN (*Amerphophallus campanulatus*):

Capoor and Rao[237] reported from Poona a mosaic virus which is not sap inoculable, but transmissible by aphids.

Mycoplasmal Diseases

Some of the mycoplasmal diseases occurring in our country are described and others listed.

1. Little leaf of brinjal reported by Thomas and Krishnaswami[238] is transmitted by grafting and the vector *Hishimonas phycitis*. Varma *et al*[239,240] showed mycoplasma-like organisms (MLO) in ultra thin sections of phloem from stem as well as roots. Anjaneyulu and Ramakrishnan[241,242] and Varma *et al*[243] reported tetracycline therapy.
2. Citrus greening is widely prevalent in India[244,245] and is transmitted by psylla, *Diaphorina citri*[246]. Ghosh *et al*[247,248] could isolate and cultivate MLO from greening affected leaves and reproduced the disease symptoms by artificially injecting psylla with the culture[249], while Kumar *et al*[250] reported the presence of MLO by staining with fluorescein isothiocyanate labelled antiserum prepared from cultures of the organism. Nariani *et al*[251] and Capoor and Thirumalachar[252] reported tetracycline treatment, whereas Nariani *et al*[249] inactivated the pathogen by treating bud wood at 47°C for 4 hours or 45°C for 6 hours.
3. Sandal spike is spreading rapidly in the Southern part of Karnataka State. It is transmitted by grafting and the leaf hopper vector *Jassus indicus*[1,250]. Varma *et al*[239] and Hull *et al*[251] reported presence of MLO in phloem cells. Raychaudhuri *et al*[252]

found suppression of the disease symptoms with tetracycline antibiotics and benlate. Hull *et al*[252] demonstrated the presence of MLO in phloem cells of *Dodonaea viscosa* and *Ziziphus jujuba*, reported to be alternate hosts. However, Pandey *et al*[253] have recorded natural occurrence of a mycoplasmal disease of jujube plant.

4. Sugarcane grassy shoot disease is now wide spread in many provinces. Association of MLO in the seive cells of infected plants is reported by Corbett *et al*[254] and Rishi *et al*[255]. The disease is sap and aphid transmitted[256-258]. Temporary remission of disease symptoms was obtained by tetracycline treatment while complete cure of the disease in both plant and ratoon crop can be obtained by hot air treatment (54°C for 8 hours) of seed sets[259,260].
5. The potato crop is affected by three mycoplasmal diseases[261-264]. They are potato purple top roll, marginal flavescence and potato witche's broom transmitted by grafting and leaf hopper, namely, *Orosius albicinctus* and have been found to be wide spread in hills and Deccan Plateau areas. MLO have been observed in ultra thin sections and tetracycline treatment indicated recovery[265,266]. Infected tubers develop hairy sprouts in stores.
6. Rice yellow dwarf disease which was first observed in Japan, has also spread to a limited extent in India[267]. MLO have been found associated with the disease[268] The disease is transmitted by *Nephotettix* sp. and is reported to be transmitted simultaneously with RTV[269].
7. Cotton little leaf or cotton stenosis was first described by Uppal *et al*[270]. Capoor *et al*[271] reported evidences for the presence of MLO and suggested tetracycline therapy.
8. Areca (*Areca catechu*) yellow leaf was first described by Menon[272]. The MLO associated with the disease have been cultured[273].
9. Sesamum phyllody disease was reported to be graft transmitted[274] and in nature by *Orosius albicinctus*[275]. Sahambi[276] reported the pathogen vector relationship and also a very wide host range of this disease. Prasad[277] reported rickettsia like bodies in the phloem cells of sunnhemp inoculated with sesamum phyllody.

Presence of MLO was also shown in the phloem cells of *Parthenium hysterophus*[278,279] and *Cannabis sativa*[280] which are reported to be natural hosts of sesamum phyllody[276,277].

Association of MLO reported in certain other plants are:–

Justicia gendarussa[281,282]; *Mirabilis jalapa*[283,284]; *Eclipta prostata*[285,286]; *Launaea nudicaulis*[287].

Yellows-type of symptoms resembling those caused by MLO recorded on a number of crop plants are:–

Phaseolus aureus[288]; *P. mungo*[289]; Sunnhemp phyllody[290]; Tomato big bud[291,292]; Foorkey disease of large cardamom[293,294].

Tissue Culture Studies

The tissue culture techniques have been increasingly employed in plant virus studies. The cultures of a number of viruses, namely PVX, PVY, TMV*, ChMV*, SMV*, CpMV*, could be maintained for long durations by repeated sub-culturing of the calli from virus infected tissues, whereas other viruses like TrRSV*, BMV* etc. were lost during subculturing[295-298]. Mishra[299], on this basis, suggested a type culture collection for maintenance of some of the viruses. The infectivity of the virus infected leaf callus was always higher as compared to callus cultures obtained from other plant parts (unpublished). On induction of morphogenesis, the caulogenic growths gave higher infectivity titre[300].

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* ChMV: chilli mosaic virus; SMV: sunnhemp mosaic virus
CpMV: cow pea mosaic virus, TMV: tobacco mosaic virus,
TrRSV: tropaeslum ring spot virus, BMV: burseem mosaic virus

Padma *et al*[301] reported decrease in incubation period of launaea mosaic virus on its local lesion host when the inoculum was prepared from differentiating and non-differentiating leaf callus culture.

A large number of chemicals such as purine and pyrimidine analogues, growth regulators, tannic acid, aflatoxins, surfactants, plant extracts, phenols, antibiotics etc.[302,303,298,304-301] have been screened after incorporating them in tissue culture media to study their antiviral activity. Sodium lauryl sulphate completely inactivated cowpea mosaic virus in cowpea calli[307]. Similarly, incorporation of S^{35} in the medium reduced the infectivity of the callus cultures to 80%[311]. Abscisic acid also reduced the infectivity of the tissue besides inducing rhizogenic growth (unpublished).

The studies on embryo culture have already been discussed. The attempts to develop meristem cultures were discussed, techniques for culturing meristems of tropaeolum, carnations and chrysanthemum and for obtaining virus free plantlets from infected potato eyebuds[312-314] have been described. Hendre *et al*[315] obtained mosaic virus free sugarcane plants from excised shoot apices of sugarcane by culturing on modified White's medium. Mishra and Quak[316] also reported a similar technique for growing proliferating meristem cultures of carnation where indefinite number of plantlets could be obtained.

Subbarayudu *et al*[317] demonstrated transmission of TMV through hyphae of *Pythium debaryanum* when the latter was fed on tobacco calli.

Studies on Inhibition and Chemotherapy of Plant Viroses

Presence of viral inhibitors have been reported from many plants such as chilli, datura, potato, black nightshed, carnation etc.[318-321] In this respect, the extracts from medicinal plants have been an object of special interest and indicated presence of some excellent viral inhibitors in the form of alkaloids, phenols, quinons etc.[312,323-328,298]. Prophylactic sprays of crude plant extracts (inhibition 89–95%) on transplanting material was also attempted[329] at CTRI. A number of organic compounds have been screened *in vivo* or *in vitro* as also by incorporating them in tissue culture medium. Compounds like thiouracil, nitrouracil, tannic acid compounds, alkaloids inhibited viruses like PVX, PVY, ChMV, etc.[326,330,331]. The work done on growth regulators in connection with their use as viral inhibitors and chemotherapeutants has been reviewed[332,333]. Similarly, enzymes[334,335], surfactants[298,335,336], inorganic salts like that of cadmium[337], phenols, quomarins and abscisic acid[338,,339], systemic pesticides[340,341], homeopathic drugs[342] have been reported to inhibit the viral infectivity *in vitro* and hindered the infection with a number of viruses. Stam F. 34, Knoxwee, Comparol and Eptam inhibited PVX in capsicum[343]. Some other chemoprophylactic treatments for reducing the severity of the disease have also been reported. Lal and Singh[344] and Mukherjee and Raychaudhuri[345] suggested application of GA or GA with 2, 4-D (daily application at 50 ppm dose each) for reducing the severity of tomato leaf curl disease. Raychaudhuri and Chatterjee[346] and Raychaudhuri and Ganguly[173] suggested, similarly, rhizome treatment with 0.075% hydroquinone and soil drenching with 0.1% thiouracil for reducing the chirke infection in cardamom. Hariharasubramaniam[347] reported inhibition of Dolichos enation mosaic virus by daily treatment with 2, 4-D and 2 base analogues, 24 hours after inoculation with the virus. Khurana[348] reported root dip treatment of homepathic drug (Thuja 30 and Sulphur 30) to reduce CMV infection in vegetable marrow. Antiviral compounds were reported to be produced from local lesions incited by PVX and PVY in potato and chilli[349]. The author has also isolated and identified some phenols and amino acids from local lesions incited by TMV infection on plants like *Chenopodium amaranticolor*. These isolated chemicals inhibited the virus (TMV) when further assayed (unpublished).

Control of Plant Virus Diseases

For controlling the plant virus diseases, individual crops have to have their own individual strategy depending on the type of viral pathogen which is to be combated. In potatoes, the conventional method of raising disease free seed stocks has been followed from last three decades[350] raising seed crops in high temperate hilly areas where low temperature, high wind velocity and continuous precipitation persists as at Kufri (Simla Hills) in the West, Darjeeling and Shillong in the East and Nilgiri Hills in the South. On the basis of the epidemiological data collected from various localities on the incidence of aphid population in the plains, a technique for producing healthy seed potatoes during September to November in North India was suggested as the crop would be free from aphid attack and, hence, viral infection. This technique is given the name of 'Seed plot technique[350,351]'.

Nirula[352] reported that potato crop sprayed at weekly intervals with 0.2% DDT and 0.1% endrin, malathion, parathion or methyl dementon were effective reducing aphid population. Soil application of systemic insecticides such as phorate, disulphoton, temik, menazonfi aphidan and thiometon checked aphid population and incidence of viroses such as PLRV and PVY at Simla and Poona[353,354].

For controlling vector population in paddy, John[355] found sevin as a good insecticide having residual effect for 15–20 days. Mitra *et al*[356] reported Carbofuran to be the most effective systemic insecticide having residual effect for as long as 30 days and suggested its use for seed dressing and pre-transplanting seedling dip for checking the vector population during the most vulnerable stage of the paddy plants. Mishra *et al*[357] suggested three such treatments with Furadan to check the incidence of vectors and the virus, namely as seed treatment, pre-transplanting soil application and post-transplanted application (40 days after transplanting). Bhargava and Khurana[358] reported control of papaya mosaic by oil sprays.

Breeding Resistant Varieties

The breeding programmes for resistance have been taken up in respect of many economically important crop plants. In this context sources of resistance have been determined in case of papaya mosaic, banana mosaic viruses in *Carica cauliflora*[359], *M. cilicarpa, M. coccinia* and *M. accuminata,* respectively[360]. The large cardamom variety 'Sawaney' and 'Kapringe' [346] and chilli varieties 'Puri Red' and 'Puri Orange' have been found to be resistant to Chirke and mosaic and leaf curl viruses of chilli, respectively[361,325]. The inheritance to chilli mosaic virus was found to be controlled by one gene factor. It seems to have linkage with characters like pigmentation (unpublished). Resistance to mulberry mosaic virus has also been demonstrated in four varieties of *Morus alba* and *M. latifolia*[176]. Krishnamurthy *et al*[362] reported Vamon-50 as resistant donor in the case of tobacco mosaic virus in tobacco.

Some wild species, namely, *Abelmoschus manihot* cv. pungen, *A. crinitus, Hibiscus vitifolius* and *H. panduraeformis* have been found to be immune to yellow vein mosaic virus of bhindi[363]. The cultivar 'Pusa Sawani' developed at IARI is reported to be tolerant[364]. Bean variety 'Kentucky Wonder', cowpea varety 'Early Sugar Crowder' and 'Taylor' were found to be resistant to mosaic viruses affecting these crops[6,2]. High degree of resistance to leaf curl of tomato has been shown in *Lycopersicon peruviana*[365] and in some selections by Som[366] and Joshi[367].

Paliwal and Raychaudhuri[368] located source of resistance in ten exotic inbred lines of indigenous open pollinated varieties of maize and the resistance was found to be due to double recessive condition of 'bb' gene at one location. Similarly in rice Shastry *et al*[369] reported that the resistance in Pankhari 203 against RTV is governed by two comple-

mentary dominant genes.

Studies on Vectors

Details of virus vector relationship which include minimum and optimum period of acquisition and inoculation feeding, effect of pre and post acquisition fasting, retention of infectivity, incubation period etc. have been extensively worked out for aphid transmitted viruses such as mosaics of chilli, broadbean, large cardamom, sarson, phlox, pea, cowpea, ragi, mulbery etc.[370,371,172,372,373,374,67] and grassy shoot of sugarcane[257]. Strainal or clonal variations in the efficiency of *Aphis gossypii* and *Myzus persicae* were reported in connection with transmission of eleusine mosaic[67] and potato virus Y and leaf roll[231]. Most of these aphid borne viruses were considered to be stylet borne. 'Katte' of cardamom in *Pentalonia nigronervosa* was considered to be semi persistent. The relationship of foorkey disease of large cardamom in *P. nigronervosa* and groundnut chlorosis in *A. craccivora* was considered to be persistent[158,170].

Rao[73] reported transmission of cucumber green mottle mosaic virus through regurgitated excreta of beetle.

The mycoplasma and viruses, transmitted by leaf hoppers were persistent in their relationship with their vectors except for the rice tungro virus transmitted by *Nephotettix* spp. Basu *et al*[269] reported simultaneous transmission of yellow dwarf and rice tungro virus by *N. virescens* after acquisition from plants infected by both. Sahambi[276] and Prasad[277] studied the virus vector relationship in detail in the case of sesamum phyllody. Mite transmission was studied by Seth[24] and Vashisth and Nagaich[375] in the case of sterility disease of pigeon pea and fig mosaic, respectively. Varma[376,377] has worked in detail on the various aspects of transmission of viruses by white flies (*Bemisia* spp.). According to him the yellow mosaic viruses are of circulative nature in the vector, when it is retained for as long as 20 days. Capoor and Ahmed[100] transmitted pumpkin yellow vein virus in semi-persistent manner. Rathi and Nene[378] reported better efficacy of female white flies in transmitting mungbean yellow mosaic virus to urid. Sang and Varma[379] transmitted marigold mosaic by feeding aphids on infectious sap through parafilm membrane.

Conclusion

It is evident from this account that for over last two decades, a number of virus diseases have been reported. Some of these are new records and are economically important. The identification of the causal viruses of these diseases have been primarily based on the symptoms, transmission, host range and stability of the virus. Vector pathogen relationship aspects, including breeding resistant varieties, have also received attention of researchers and some very important contributions have been made in these fields. This has led to the development of well founded field of 'descriptive virology' and a modest beginning towards 'experimental virology'. More intimate studies on the virions with the help of electronmicroscopy, purification procedures and serology have been only recently emphasized and increasingly used in diagnostic studies.

The studies on epidemiology are still in infancy. We are trying to develop experimental epidemiology for understanding the model epidemics as in the case of rice, to obtain useful information on the screening of insecticides and in breeding programmes. Results obtained on inhibition of viruses has been of value in the therapy of viroses. Heat therapy and tissue culture techniques are most useful for crops like potato, sugarcane and ornamentals. However, biochemical and biophysical aspects are still not used in the study of virus diseases.

(The exchange of information on a global basis as arranged here would be beneficial to all of us.)

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Discussion

I. N. Oka, Indonesia: How many rice viruses are being identified throughout India so far and which, among them, is considered the most important ones?

Answer: The most important rice virus is tungro virus. Grassy stunt which has been observed earlier as unimportant virus has recently been assuming importance as reported for many new other areas. Orange leaf disease, though suspected, has not been finally proved to be existing.

K. C. Ling, IRRI: Is "albino" or "grassy shoot" of sugarcane still a serious disease problem in India? Is it transmitted by aphid?

Answer: Albinism in sugarcane is reported to be caused as a result of magnesium deficiency whereas grassy shoot has been shown to be caused by mycoplasma like bodies. It is transmitted by aphid. This work is now being done at the Sugarcane Research Institute, Lucknow.

T. Soelaeman, Indonesia: South African greening is considered to be different from Asian greening, i.e., from the standpoints of temperature reactions and vector.

For detection of S. A. greening, Dr. Schwara uses the gentisoyl glucose test. Is it still used in India for detection of the Asian greening of do you use any other test?

Answer: Yes, greening of citrus has a different vector as compared to South African greening disease. In India the detection of greening is not done by the g–g test. However, Kumar et al used fluorescein isothiocynate labelled antiserum for this purpose. The only other method for detecting the infection is by indexing as presently practiced in India.

D. A. Benigno, Philippines: Do you have any studies in India on the strains of sugarcane mosaic virus?

Answer: Yes, a number of strains have been reported. This work is being conducted at the Sugarcane Research Institute, Luckhow.

D. A. Benigno, Philippines: May I know if sugarcane ratoon stunt disease is still considered virus disease or caused by *Corynebacterium sp.*?

Answer: In India we are getting indication of a bacterium being associated with this disease (sugarcane ratoon stunting). This work is in confirmative stage at Sugarcane Research Institute, Lucknow.

N. Yamada, Japan: You present a comprehensive listing of virus diseases citing as many as nearly 400 literatures, but I fail to find out virus diseases for chick pea. I understand that chick pea is grown in your country utilizing residual moisture after rice cultivation, and when the climate is wet, the crop suffers from many diseases, I wonder is there any virus disease for chick pea?

Secondry, I would like to know which virus is related to the Dr. Swaminathan's research result shown in page 9 of your paper?

Answer: Chick pea is reported to be a natural host of sesamum phyllody. In addition, evidence of some virus diseases occurring on chick pea has also available. This work is presently being done at the Indian Agricultural Research Institute. However, no authentic publication is yet avilable.

Dr. Swaminathan's research reports one on Chilli mosaic virus (No. 1, in the text).