Etiology and Symptomatology, Survey and Host Range Studies of Yellow Mosaic Disease on Horsegram Transmitted by Whitefly (B. tabaci) in North Eastern Karnataka, India

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Abstract

Yellow mosaic disease (YMD) on horsegram caused by begomovirus belongs to family geminiviridae is an emerging threat for crop cultivation in peninsular India and in many parts of Karnataka. The present etiological studies indicated that the symptoms characterized by faint yellow discoloration on the young leaves in the beginning as disease progresses, the leaves show characteristic symptoms of mottling. The mottling are irregular, small, greenish yellow in colour and intermixed with normal green patches, later on the mottling become enlarged and turn bright yellow and eventually become completely bleached. The average incidence of horsegram yellow mosaic disease (HgYMD) varied from 10.68 to 44.91% in major surveyed areas of north eastern Karnataka. The maximum incidence (44.91%) was recorded in Kushtagi taluk of Karnataka. Among the 15 host plants belonging to diversified families tested for host range, blackgram (Vigna mungo), greengram (V. radiata), soybean (Glycine max), pigeon pea (Cajanus cajana), Croton bonplandianum, Parthenium hysterophorus, Malvestrum coromandelium and Alternenthera sessile were shown to be susceptible.

Keywords
Horsegram, Yellow mosaic disease, Geminivirus, Whitefly, Incidence

Introduction

Horsegram (Macrotyloma uniflorum (Lam.) Verde. Syn. Dolichos biflorus), commonly known as kulthi, is one of the hardiest and drought tolerant crops, grown extensively in peninsular India as poor man’s pulse crop. It is an under exploited grain legume with great potential in sustainable agriculture as it enriches soil considerably by fixing
atmospheric nitrogen and increasing the organic matter of soil. It is the only choice crop of the farmers for delayed sowing due to late receipt of rains. It is one of the important minor pulse crops in India and is cultivated in an area of 3.26 lakh hectare with a production of 1.17 lakh tones. Horsegram is one of the important pulse crops being cultivated over a larger area in many dry land regions of Karnataka. Crop is known to suffer from several diseases including fungal, bacterial and viral diseases.

Among the diseases, Yellow mosaic disease (YMD) caused by begomovirus belongs to family geminiviridae is one of the emerging threat for crop cultivation in peninsular India and in many parts of Karnataka. Yellow mosaic disease transmitted by whitefly $B. \text{tabaci}$ (Gennadius) more prevalent in most parts of Indian subcontinent (Varma and Malathi, 2003). Yellow mosaic disease transmitted by whitefly $B. \text{tabaci}$ (Gennadius) more prevalent in most parts of South India (Muniyappa and Reddy, 1976). The disease incidence ranged from 50 to 100 per cent in both summer and early rainy season crops causing substantial loss in grain yield (Muniyappa et al., 1975). The increasing spread of the horsegram yellow mosaic disease due to increase in $B. \text{tabaci}$ population resulted in almost complete loss of the crop during summer (Muniyappa et al., 1976; Rajkumar, 2006 and Prema, 2013). Host range studies with Tomato leaf curl virus (ToLCV) (Muniyappa et al., 2000), Pumpkin yellow vein mosaic in pumpkin (Maruthi et al., 2007), Hibiscus leaf curl virus in Hibiscus (Rajeshwari et al., 2005), Croton leaf curl virus in cotton (Mahesh et al., 2010) and Mungbean yellow mosaic virus in Greengram (Deepa et al., 2017) revealed that begomo viruses have wide host compatibility, however, their infection and further symptoms expression varied between the host plants.

In the recent years, YMD on horsegram has been found severely affected and its incidence reached 80 per cent in different areas of Karnataka. However, work done and literature available on occurrence and distribution of YMD of horsegram from North Eastern parts of Karnataka is very scanty, mode of spread and its relationships with the vector whitefly $B. \text{tabaci}$ have not been studied. Further the sources of reservoir hosts of the virus and the vector in relation to disease severity also not been documented from North Eastern parts of Karnataka. Hence with these backdrops, the present study on occurrence and distribution, symptomatology and host range studies on HgYMD were taken up.

**Materials and Methods**

**Disease incidence**

The roving survey was carried out to assess the status of yellow mosaic disease incidence on horsegram in major horsegram growing areas of north eastern Karnataka such as Koppal, Raichur and Ballari during Rabi 2018. From each selected district, four talukas and from each taluk five villages were monitored. From each village, two horsegram fields are selected and randomly 10 m x 10 m area was observed for disease incidence. Disease incidence was assessed by counting number of symptomatic plants (symptoms viz. chlorosis, mosaic, mottling, reduction in leaf size and stunted growth) over total number of plants (including both symptomatic and non-symptomatic) in randomly selected plots at each location. During the survey, symptomatic leaf samples were collected from each location and designated as separate isolate for further studies. The disease incidence was calculated based on the number of plants infected out of total plant population observed.
To Develop GIS maps for spatial variation of Horsegram yellow mosaic virus (HYMV) incidence in horsegram in North Eastern Karnataka

To develop spatial Geographic positioning system (GPS) maps for the distribution and severity of YMV disease on horsegram in selected districts of North Eastern Karnataka, field survey was carried out in major growing areas of Raichur, Ballari and Koppal districts. The incidence of the disease in each location was calculated as per the formula mentioned in 3.1 based on disease rating scale (0-5) (Bashir, 2005).

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\text{Disease incidence (\%) = } \frac{\text{Number of plants infected in a row}}{\text{Total number of plants in a row}} \times 100
\]

(0: No incidence; 1: 1-10%; 2: 11-20%; 3: 21-30%; 4: 31-50%; 5: >50 %).

The methodology adopted for generation of spatial GIS maps is given below.

**Site selection**

In each of the selected district, four taluks and within each taluk, minimum of five villages and in each village 100 sq. m areas of two locations were identified to record the yellow mosaic distribution based on the disease incidence and severity scale.

**Data collection during Rabi 2018-19**

Initially the collection of data at different places of selected districts during Rabi 2018-19 was planned to assess the spatial variability of horsegram yellow mosaic disease. Further, the survey was carried out by using global positioning system (GPS) (Trimble MAK – Geo XH), where the co-ordinates (latitudes and longitudes) were collected at each sampling point to map the spatial distribution of horsegram yellow mosaic disease. Each site was geo referenced in the Universal Transverse Mercator (UTM) co-ordinate system with a GPS for spatial analysis.

**GPS data import**

The collected sample locations from GPS were imported using path finder software. Since the projection system of collected locations were pre-defined in the GPS, the imported sample points were found within the respective villages administrative boundary (having similar projection and datum i.e., UTM, WGS 84), when imported in the GIS environment.

**Data attachment and mapping**

The field observations on YMV disease distribution and severity were fed in excel sheet with proper labelling for each observation. The unique ID was added and the physical ID was created along with the sample locations imported in the Arc GIS environment. Further the collected field data were attached to the respective GPS location points using unique ID 121 relationships in Arc GIS 2010. The disease incidence of yellow mosaic virus was displayed through unique symbol to understand the spatial distribution of yellow mosaic virus. The maps of spatial distribution of yellow mosaic virus in surveyed districts viz., Raichur, Ballari, and Koppal are given in the fig 3, 4, 5, 6. The DGPS used in this study is the latest version (GeoXH) from Trimble, which is enabled to receive the satellite signals from GNSS which will give more accurate location reading.

**Computer Software**

Arc GIS 10 software from Sujal project laboratory, College of Agriculture, Raichur was used for the processing and analysing the data.
Host range studies

Healthy seedlings of horsegram plants and other pulses of family Leguminaceae and weed hosts belong to Euphorbiaceae, Asteraceae, Amaranthaceae, Phyllanthaceae and Malvaceae were selected and raised in an insect proof glasshouse. Seedlings at the two leaf stage of the respective host were inoculated with viruliferous whiteflies (B. tabaci) after 12h acquisition access period (AAP) feeding on yellow mosaic virus infected horsegram plant. Later the viruliferous whiteflies were allowed to feed on healthy test seedlings for 12 hr (IAP) in insect proof tubes. The inoculated seedlings were kept in insect proof glasshouse for development of symptoms. Observations were recorded on symptoms expression and per cent transmission.

Crop plants selected for host range are Green gram (Vigna radiata), Black gram (Vigna mungo), Piegonpea (Cajanus cajana), Soyabean (Glycin max) and Cowpea (Vigna ungciculata), Pea (Pisum sativum), French bean (Phaseolus vulgaris), Moth bean (Vigna acontifolia), Lima bean (Phaseolus lunatus), Field bean (Vica faba) and Lab lab bean (Lablab purpureus).

Weed hosts selected for the host range are Acalypha indica, Malvastrum coromandelium, Croton bonplandianum, Parthenium hysterophorus and Alterneterra sessile.

Results and Discussion

Disease incidence and symptoms

The roving survey was carried out to know the disease incidence of YMD during Rabi 2018 in major horsegram growing areas of North Eastern Karnataka viz., Koppal, Raichur and Ballari by using disease rating scale 0 to 5. The observation was recorded on surrounding alternate weed hosts and cultivated crops from the respective location.

During the survey, natural symptoms of YMD on horsegram was characterised with irregular faint yellow specks on young trifoliate leaves. In addition, mild to severe mosaic signs with distorted and reduced leaf size were found. The diseased plant was very much stunted with complete chlorosis.

Incidence of YMD in Raichur district

Survey results revealed that, in Raichur taluk, the highest disease incidence of 18 per cent was observed in Galag village followed by Kaydigera and Alkod villages with 13 and 12.3 per cent respectively. The lowest disease incidence of 10.30 per cent was observed in Huched village (Table. 1)

The maximum disease incidence (46 %) was recorded in Mudgal village of Lingasugar taluk followed by 42 and 40 per cent in Mettur and Gudhihal villages respectively. Lowest disease incidence of 12.5 per cent was recorded in Anehosuru.

In Maski taluk, the highest disease incidence was found in Santhekalluru village with 30 per cent and lowest disease incidence of 23.00 per cent in Maski. While in Manvi taluk, 28.00 per cent disease incidence was found in Kotekal village.

Grand mean incidence of YMD in Raichur district varied from 10.68 to 33.50 per cent (Table. 2). Further the disease situation of YMD on horsegram from the selected taluks of Raichur district is represented in GPS maps.

During the survey, different kind of weed host viz., Croton sp., Euphorbia sp, Acalypha sp., Malvastrum sp. and Parthenium sp., were
noticed in the adjacent locations. In addition to this, symptoms similar to YMD were also more prominent in crops like pigeon pea and several weeds such as *Croton* sp., *Euphorbia* sp., and *Malvastrum* sp. Further, in the surrounding surveyed areas, crops like cotton, brinjal and chilli were observed in majority locations of Raichur district.

**Incidence of YMD in Koppal district**

The highest disease incidence of 42 per cent was recorded in Basapur village of Koppal taluk followed by Ginigera with 40 per cent. Lowest disease incidence of 36 per cent was observed in Halagere village.

In Yalburga taluk, the highest disease incidence was noticed in Bandri with 42 per cent and lowest disease incidence of 32 per cent was observed in Adooru.

In Kushtagi taluk, the maximum disease incidence of 55 per cent was recorded in Bewoor, which was followed by Hireraralli and Shakappur villages with 52 and 45 per cent respectively. The minimum incidence of 35 per cent was recorded in Tavaregere.

In Gangavathi taluk, Budagumpa village recorded highest disease incidence of 45 per cent which is followed by Temba (42 %) and Halekunta (40 %). The least disease incidence of 28 per cent was noticed in Waddarahatti.

The mean incidence of YMD in Koppal district range from 37.25 to 44.91 per cent with grand mean disease incidence of 39.81 per cent (Table. 2). Further the disease status of YMD on horsegram from the selected taluks of Koppal district is represented in GPS maps.

In Koppal district, it was found that *Croton* sp., *Euphorbia* sp., *Acalypha* sp., *Malvastrum* sp., *Alternenthera* sp. and *Parthenium* sp with characteristic symptoms of YMD were more prominent in different surveyed locations. Gourd crops, chilli, brinjal and pigeon pea crops were more predominant in surrounding areas of the crop survey.

**Incidence of YMD in Ballari district**

Incidence of YMD in Ballari taluk indicated, the maximum of 52 per cent was recorded in Yelubenchi, followed by Hagari (46 %) and Haraginadoni (44 %). The least disease incidence of 32 per cent was observed in Kuditini.

In Hospet taluk, the maximum disease incidence 40 per cent was observed in Papinayakanahalli, which is followed by Chilakanahalli and Mariyanmanahalli with 36 and 32.00 per cent respectively. The least disease incidence of 28 per cent was seen in Kunikera.

Gudekote village recorded the highest disease incidence of 32 per cent in Kudligi taluk, while least incidence (28 %) found in Hansi.

Chintrapalli village of Hagari bommanahalli taluk registered maximum disease incidence of 29.5 per cent followed by Hampasagara with 27 per cent. Lowest disease incidence of 22.5 per cent was observed in Kodlabalu village.

At Huvina Hadagali taluk, the highest disease incidence of YMD was recorded in Komaranahalli (32 %) followed by Holegundi and Hyarada with 31.5 and 31 per cent respectively. Lowest disease incidence of 28 per cent was recorded in Bennihalli.

The mean incidence of YMD on horsegram in Ballari district varied from 26.75 to 43 per cent with grand mean disease incidence of 32.87 per cent (Table. 2). The disease prominence of YMD on horsegram from the
selected taluks of Ballari district is represented in GPS maps.

During the survey, observations made on surrounding cultivated crops and weed hosts in the respective locations. From the results, different kind of weed hosts such as Croton bonplandianum, Euphorbia geniculata, Phyllanthus madraspatensis, Malvastrum coromandelium, Acalypha indica and Alternenthera sessile with symptoms of vein clearing and light to dark patches of yellow mosaic disease was observed.

Among three districts surveyed the highest grand mean incidence of 39.81 per cent was recorded in Koppal district followed by Ballari and Raichur with 32.87 and 24.67 per cent respectively. Further, the survey also revealed that the incidence was prevailed at all stages of the crop and present in all horsegram growing areas of North Eastern Karnataka. Disease scenario of YMD on horsegram from the selected districts of North Eastern Karnataka is represented in GPS maps (Fig. 1).

The present investigations on YMD survey in major horsegram growing areas of North Eastern Karnataka revealed that the highest incidence of YMD was found in Bewoor (55%) village of Kustagi taluk followed by Bodugumpa village of Gangavati taluk (45 %). While least incidence was noticed in Waddarahatti (28 %) of Gangavati taluk. In Raichur district, mudugal village of Lingasugur taluk has recorded 46 per cent followed by Mettur village (42 %). The lowest incidence was recorded in Huched village of Raichur taluk (10.30%). The highest incidence of YMD in Horsegram was found in Yelubenchi village of Ballari taluk (52 %) followed by Hagari (46 %) and least was noticed in Kodlabalu of HB halli taluk (22.5 %) (Fig. 2).

Highest incidence of yellow mosaic virus disease on horsegram in selected villages of Koppal and Ballari district might be attributed to the presence of abundant cultivated crops viz., Pigeon pea and gourd crops and weed hosts such as Croton bonplandianum, Euphorbia geniculata, Phyllanthus madraspatensis, Malvastrum coromandelium, Acalypha indica and Alternenthera sessile which may served as alternate source of virus inoculums. Further, several surrounding crops such as cotton, chilli, brinjal and gourd crops also found in the major surveyed locations found to be source of whitefly in dissemination of virus inoculum.

Similarly, Deepa et al., (2017a) reported that the highest disease incidence of YMD on Greengram with 76.70 per cent was recorded in Koppal followed by Bidar, Yadgir, Kalburgi with 70.48, 66.70 and 54.51 per cent respectively. Lowest disease incidence of 51.49 per cent was noticed in Raichur district. The high magnitude of YMD on greengram attributed to cultivation of local susceptible greengram variety (Chinamung) and poor awareness of plant protection measures by farmers. The high incidences were influenced by the sources of virus inoculum on leguminous crops such as soybean, pigeon pea and volunteer greengram crops besides potential off season weed hosts such as Alternenthera sessile, Acalypha indica, Croton bonplandianum and Malvastrum coromandelianum are implicated as the reasons for increased occurrence.

Further, higher yellow mosaic incidence on horsegram in North Eastern Karnataka districts could also be accredited to higher temperature and dry climate prevailing in these districts which may had directly influenced the vector population and its migration behavior. In this connection Meghashree et al., (2017) revealed that the
maximum temperature had positive significant correlation with whitefly population and MYMV disease incidence has correlation with maximum relative humidity and maximum temperature and which intern indicates that higher the maximum temperature more is whitefly population and increase in relative humidity increase in disease. In addition to this, YMD incidence differs from location to location based on the cropping pattern and weather patterns. Further, several studies revealed that the population of whitefly and incidence of tomato leaf curl disease was high in August to October wherein rainfall will be very less with dry weather (Board et al., 1993). Similarly in case of cotton, leaf curl virus, whitefly was found positively correlated with maximum temperature and relative humidity and negatively correlated with rainfall (Kadam et al., 2015). There was a similar finding noticed by Abhishek, et al., (2016), who confirmed the higher incidence of tomato leaf curl disease during October due to higher whitefly population.

**Host range studies**

The HYMV is preferably infect horsegram and it produces symptoms like yellow discoloration on the leaves that leads to irregular, small, greenish yellow mosaic. The present investigation to identify the natural hosts of HYMV, different host plants belongs to family leguminaceae and several weeds were tested by artificial inoculation using viruliferous whiteflies.

The results unveiled that the causal virus of the disease was successfully transmitted from infected horsegram to different host plants viz., Blackgram (Vigna mungo), greengram (V. radiata), Soybean (Glycine max), and Pigeon pea (Cajanus cajana) (Table.9). Further, in weeds like Croton bonplandianum, Parthenium hysterophorus, Malvestrunm coromandelium and Alternenthera sessile were also recorded successful transmission of HYMV under artificial inoculation. HYMV was unable to transmit to pea, mothbean and lima bean.

**Symptomatology of Horsegram yellow mosaic virus on inoculated crop plants**

**Blackgram (Vigna mungo)**

The initial symptoms of leaf puckering and mosaic appears on growing trifoliate leaves were observed after 18-22 days of inoculation with 30 per cent transmission. Final symptoms were of severe distorted leaves and stunted growth of plants was observed at 29-32 days after inoculation.

**Soybean (Glycine max)**

The typical symptoms were noticed 20-22 days after inoculation on newly emerging leaves with dark mosaic appears on growing trifoliate leaves, leaf puckering, mosaic and distortion with 40 per cent transmission. Final symptoms of severe reduction in the leaf size and stunting of plants were observed after 30-34 days of inoculation.

**Pigeon pea (Cajanus cajana)**

Forty per cent transmission in 19-24 days after inoculation was noticed with typical symptoms of vein clearing, small yellow patches on trifoliate leaves which later turn to dark yellow mosaic. Finally leaves become sever chlorosis in 35-40 days after inoculation.

**Greengram (Vigna radiata)**

The characteristic symptoms were observed in 18-20 days after inoculation with 50 per cent transmission. The initial symptoms such as vein clearing followed by light mosaic were recorded. In 32-34 days of incubation, final symptoms were obtained with severe yellowing and distorted leaves.
Table 1 Incidence of yellow mosaic disease of horsegram in North Eastern parts of Karnataka during *rabi* 2018-19

| District | Taluk      | Village       | Age of the crop (days) | Disease incidence (%) | Surrounding crop/weeds observed                                      |
|----------|------------|---------------|------------------------|------------------------|-------------------------------------------------------------------|
| Raichur  | Raichur    | Alkod         | 38                     | 12.30                  | Pigeonpea, Cotton and *Croton* sp.                                 |
|          | Raichur    | Galag         | 38                     | 18.00                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
|          | Raichur    | Huched        | 33                     | 10.30                  | Cotton, *Euphorbia* sp., *Acalypha* sp.                           |
|          | Raichur    | Kyadigera     | 31                     | 13.00                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
|          | Raichur    | Yellamanna halla | 38                    | 10.50                  | Pigeonpea, Chilli, Cotton, *Croton* sp.                           |
|          | Raichur    | Chandrabanda  | 35                     | 00.00                  | Cotton and *Croton* sp.                                          |
|          | Lingasuguru| Kadarighal tanda | 45                   | 26.50                  | Pigeonpea, Chilli and *Croton* sp.                                |
|          | Lingasuguru| Eachanahal    | 45                     | 30.00                  | Pigeonpea, Ridge gourd, *Croton* sp.                              |
|          | Lingasuguru| Anehosuru     | 42                     | 12.50                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
|          | Lingasuguru| Mudgal        | 48                     | 46.00                  | *Malvastrum* sp., *Acalypha* sp., Cotton, *croton* sp.            |
|          | Lingasuguru| Mettur        | 50                     | 42.00                  | *Acalypha* sp., Cowpea.                                           |
|          | Lingasuguru| Gudihal       | 46                     | 40.00                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
|          | Lingasuguru| Toralabenchi  | 40                     | 36.00                  | *Euphorbia* sp., *Acalypha* sp.                                   |
|          | Lingasuguru| Basapur       | 42                     | 35.00                  | *Malvastrum* sp., *Acalypha* sp.                                  |
|          | Maski      | Maski local   | 38                     | 23.00                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
|          | Maski      | Santhekalluru | 40                     | 30.00                  | *Euphorbia* sp., *Acalypha* sp.                                   |
|          | Manvi      | Kotekal       | 45                     | 28.00                  | Cotton, Pigeonpea, *Euphorbia* sp.                                |
| Koppal   | Koppal     | Ginigera      | 45                     | 40.00                  | *Croton* sp., *Malvastrum* sp., Gourd crops                       |
|          | Koppal     | Basapur       | 42                     | 42.00                  | *Malvastrum* sp., *Acalypha* sp., Sunflower.                      |
|          | Koppal     | Kunikera      | 40                     | 40.00                  | *Euphorbia* sp., *Acalypha* sp., Brinjal and Vegetables           |
|          | Koppal     | Hyati         | 41                     | 39.00                  | *Croton* sp., *Malvastrum* sp., Gourd crops                       |
|          | Koppal     | Halagere      | 40                     | 36.00                  | *Acalypha* sp., *Malvastrum* sp., black gram                      |
|          | Koppal     | Bhanapura     | 42                     | 37.50                  | *Malvastrum* sp., *Acalypha* sp.                                  |
| Yelburga | Yelburra   | Adooru        | 40                     | 32.00                  | *Croton* sp., *Malvastrum* sp., Gourd crops                       |
|          | Yelburga   | Kukanoooru    | 45                     | 40.00                  | *Malvastrum* sp., *Acalypha* sp.                                  |
|          | Yelburga   | Bandri        | 42                     | 42.00                  | *Euphorbia* sp., *Croton* sp., Pigeonpea                         |
| Kushtagi | Kushtagi   | Hirareralli   | 45                     | 52.00                  | *Croton* sp., *Malvastrum* sp., Gourd crops                       |
|          | Kushtagi   | Bewooru       | 48                     | 55.00                  | *Croton* sp., *Malvastrum* sp., Gourd crops                       |
| District       | Taluk         | Village         | Age of the crop (days) | Disease incidence (%) | Surrounding crop/weeds observed                      |
|----------------|---------------|-----------------|------------------------|-----------------------|-----------------------------------------------------|
| Ballari        | Ballari       | Hagari          | 38                     | 46.00                 | Cotton, Pigeonpea, Euphorbia sp.                    |
|                |               | Kudutini        | 40                     | 32.00                 | Malvastrum sp., Acalypha sp.                       |
|                |               | Haraginadoni    | 41                     | 44.00                 | Euphorbia sp., Croton sp., Pigeonpea               |
|                |               | Yelubenchchi    | 42                     | 52.00                 | Malvastrum sp., Acalypha sp.                       |
|                | Hospet        | Mariyammanahalli| 40                     | 32.00                 | Euphorbia sp., Croton sp., Cowpea                  |
|                |               | Chilakanahalli  | 40                     | 36.00                 | Alternenthera, Croton sp., Chilli                  |
|                |               | Papinayakanahalli| 41                    | 40.00                 | Alternenthera, Croton sp., Pigeonpea              |
|                |               | Kunikera        | 42                     | 28.00                 | Euphorbia sp., Croton sp., Cowpea                  |
|                | Kudligi       | Kudligi         | 42                     | 28.50                 | Malvastrum sp., Croton sp., Chilli                |
|                |               | Gudekote        | 41                     | 32.00                 | Alternenthera, Croton sp., Pigeonpea              |
|                |               | Ichanala bommanahalli | 41              | 30.00                 | Euphorbia sp., Croton sp., Alternenthera          |
|                |               | Hansi           | 41                     | 28.00                 | Euphorbia sp., Croton sp., Cowpea                  |
|                | Hagari bommanahalli | Chintrapalli  | 42                     | 29.50                 | Malvastrum sp., Pigeon pea                        |
|                |               | Kodlabalu       | 43                     | 22.50                 | Euphorbia sp., Croton sp.                         |
|                |               | Hampasagara     | 42                     | 27.00                 | Alternenthera, Pigeon pea                         |
|                | Huvina Hadagal | Bennihalli      | 40                     | 28.00                 | Malvastrum sp., Alternenthera                     |
|                |               | Holalalu        | 39                     | 29.50                 | Euphorbia sp., Croton sp., Alternenthera          |
|                |               | Hyarada         | 40                     | 31.00                 | Malvastrum sp., Sunflower, Gourd crops            |
|                |               | Holegundi       | 43                     | 31.50                 | Malvastrum sp., Alternenthera, Gourd crops        |
|                |               | Komaranahalli   | 40                     | 32.00                 | Euphorbia sp., Croton sp., Gourd crops            |
Table 2 Average incidence of yellow mosaic disease on horsegram in different districts of North Eastern Karnataka during *rabi* 2018-19

| District | Taluk               | Average disease incidence (%) | Grand mean incidence (%) |
|----------|---------------------|-------------------------------|--------------------------|
| Raichur  | Raichur             | 10.68                         | 24.67                    |
|          | Manvi               | 28.00                         |                          |
|          | Maski               | 26.50                         |                          |
|          | Lingsugur           | 33.50                         |                          |
| Koppal   | Koppal              | 39.08                         | 39.81                    |
|          | Yelburga            | 38.00                         |                          |
|          | Kushtagi            | 44.91                         |                          |
|          | Gangavathi          | 37.25                         |                          |
| Ballari  | Ballari             | 43.00                         | 32.87                    |
|          | Kudligi             | 29.62                         |                          |
|          | Hadagali            | 31.00                         |                          |
|          | Hagari bommanahalli | 26.75                         |                          |
|          | Hospet              | 34.00                         |                          |
Table 3 Host range of *Horsegram yellow mosaic virus* on different crops

| Sl. No | Crop                        | Family      | Total No. of plants tested | Total No. of plants infected | Per cent transmission | Days to first symptom appearance | Days to final symptom appearance | Early symptom appearance | Final symptom appearance                                      |
|--------|-----------------------------|-------------|-----------------------------|------------------------------|------------------------|----------------------------------|---------------------------------|---------------------------|---------------------------------------------------------------|
| 1      | Blackgram (Vigna mungo)     | Leguminaceae| 10                          | 3                            | 30.00                  | 18-22                            | 29-32                           | Leaf puckering, mosaic and distorted leaves | Severe distorted leaves and plants become stunted             |
| 2      | Soybean (Glycine max)       |             | 10                          | 4                            | 40.00                  | 20-22                            | 30-34                           | Light green mosaic appears on growing trifoliate leaves | Leaves become dark green mosaic with deformation and leathery appearance |
| 3      | Pigeon pea (Cajanus cajana) |             | 10                          | 4                            | 40.00                  | 19-24                            | 35-40                           | Vein clearing followed by light mosaic | Leaves become sever yellowing and distorted                 |
| 4      | Green gram (Vigna radiata)  |             | 10                          | 5                            | 50.00                  | 18-20                            | 32-34                           | Vein clearing followed by light mosaic | Leaves become yellowing and distorted                       |
| 5      | Pea (Pisum sativum)         |             | 10                          | 0                            | 0.00                   | -                                | -                               | Nil                                      | Nil                                                          |
| 6      | Moth bean (Vigna aconitifolia) |           | 10                          | 0                            | 0.00                   | -                                | -                               | Nil                                      | Nil                                                          |
| 7      | Lima bean (Phaseolus lunatus) |           | 10                          | 0                            | 0.00                   | -                                | -                               | Nil                                      | Nil                                                          |

Note: No. of whiteflies/seedlings: 10, Culture: MYMV, AAP: 12 h, IAP: 12h, Nil: No symptom expression
**Table 10** Host range of *Horsegram yellow mosaic virus* on different weed hosts

| Sl. No. | Weeds                      | Family        | Total No. of plants tested | Total No. of plants infected | Per cent transmission | Days to first symptom | Days to final symptom | Early symptom appearance                                      | Final symptom appearance                                      |
|---------|----------------------------|---------------|----------------------------|-----------------------------|------------------------|-----------------------|-----------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1       | *Croton bonplandianum*     | Euphorbiaceae | 5                          | 3                           | 60.0                   | 20-22                 | 35-40                 | Vein clearing and light to dark patches of yellow mosaic      | Complete yellowing, puckering and raised green areas.         |
| 2       | *Euphorbia geniculata*     |               | 5                          | 0                           | 0.00                   | -                     | -                     | Nil                                                           | Nil                                                           |
| 3       | *Acalypha indica*          |               | 5                          | 0                           | 0.00                   | 0                     | 0                     | -                                                             | -                                                             |
| 4       | *Parthenium hysterophorus* | Asteraceae    | 5                          | 2                           | 40.00                  | 20-24                 | 38-41                 | Mild leaf curl, partial yellow mosaic                         | Complete yellowing                                           |
| 5       | *Ageratum conyzoides*      |               | 5                          | 0                           | 0.00                   | -                     | -                     | Nil                                                           | Nil                                                           |
| 6       | *Phylanthus niruri*        | Phyllanthaceae| 5                          | 0                           | 0.00                   | -                     | -                     | Nil                                                           | Nil                                                           |
| 7       | *Alternenthera sessile*    | Amaranthaceae | 5                          | 4                           | 80.00                  | 21-22                 | 39-41                 | Vein clearing on trifoliate leaves with light mosaic          | Complete dark yellowing of leaves                            |
| 8       | *Malvastrum coromandelianum* | Malvaceae   | 5                          | 3                           | 60.00                  | 18-20                 | 35-40                 | Vein clearing and small yellow patches                        | Complete yellowing of leaves                                 |

Note: No. of whiteflies/seedlings: 10, Culture: HYMV, AAP: 12 h, IAP: 12 h, Nil: No symptom expression.
Fig. 1 GIS map showing spatial variation of YMD on horsegram in selected districts of North Eastern Karnataka during *rabi* 2018-19
Severe outbreak of yellow mosaic disease on horsegram in north eastern Karnataka during rabi 2019
Croton sp. Showing systemic infection upon inoculated with Horsegram yellow mosaic virus
Greengram expressing mosaic like symptoms
Symptomatology of HYMV on inoculated weed hosts

**Croton bonplandianum**

Sixty per cent transmission was obtained with initial symptoms of vein clearing and light to dark patches of yellow mosaic symptoms at 20-22 days after inoculation.

Final symptoms of complete yellowing and leaf puckering signs were observed at 35-40 days after inoculation.

**Parthenium hysterophorus**

The initial symptoms were observed on plants at 20-24 days after inoculation with 40 per cent transmission. The infected plants exhibited mild leaf curling and partial yellow mosaic. The final symptoms of complete yellowing was noticed at 38-41 days after inoculation.

**Alternenthera sessile**

The symptoms of vein clearing on trifoliate leaves with light mosaic were observed after 21-22 days of inoculation with 80 per cent transmission. The infected plants exhibited final symptoms of sever leaf yellowing and distortion at 39-41 days after inoculation.

**Malvastrum coromandelianum**

Sixty per cent transmission with typical symptoms was noticed at 18-20 days after inoculation. On newly emerging leaves, vein clearing and small yellow patches appeared on trifoliate leaves. Finally yellowing with distorted and malformed leaves was noticed at 35-40 days after inoculation.

The present findings are in confirmatory with the host range studies of most of the yellow mosaic viruses of legume is restricted to

Leguminaceae or Fabaceae species (Nene et al., 1971 and Rathi and Nene, 1974). Further, Muniyappa et al., (1987) who successfully transmitted HYMV to 11 leguminous species viz., Cajanus cajan, Centrosema sp., Phaseolus acontifolius, P. atropurpureus, P. lathyroides, P. lunatus, P. vulgaris, Vigna radiata, G. max, Vigna mungo and Teramnus uncinatus which shown yellow mosaic symptoms. Further, MYMIV infect several leguminous species like blackgram, cowpea (V. unguiculata), French bean (P. vulgaris), mungbean and soybean (G. max) (Varma et al., 1992).

The above results are found similar with the investigations on host range of *Mung bean yellow vein mosaic virus* (Deepa et al., 2017). The virus was limited to only few plant and weed species viz., Tobacco (*Nicotiana benthamiana*), Blackgram (*Vigna mungo*), Cowpea (*V unguiculata*), Horsegram (*Macrotyloma uniflorum*), Pigeon pea (*Cajanus cajana*), Soybean (*Glycine max*), Acalypa indica, Alternenthera sessile, Croton bonplandianum, Euphorbia geniculata and Malvestrunm coromandelium, with varied transmission rates.

The comprehensive research towards the identification of source and perpetuation of HYMV, seven plant species and eight dicotyledonary weed hosts were inoculated with HYMV isolate from horsegram. Among the seven crop plants examined, HYMV was able to cause mosaic symptoms on Blackgram (*Vigna mungo*), greengram (*V. radiata*), Soybean (*Glycine max*) and Pigeon pea (*Cajanus cajana*). Among eight weed species tested, HYMV was able to cause infection on Croton bonplandianum, Parthenium hysterophorus, Malvestrunn coromandelium and Alternenthera sessile with characteristic symptoms like vein clearing, leaf curling, irregular small yellow patches and complete yellowing were observed. Further there was a
difference in transmission rates and expression of virus symptoms between crops and weeds. This could be due to B. tabaci preference and also host biochemical compositions which may interfere with virus multiplications (Pramesh et al., 2013). Further the transmission efficacy on different hosts depends on the age of the seedlings. When the age of the seedlings increases the per cent transmission going to decrease and also severity will be more at early stages of the host (Jayappa et al., 2017). In addition, virus-induced biochemical and physiological changes in the host-plant have been shown to influence vector insect host preference (Mauck et al., 2014).

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