Differentiation of Sugarcane, Maize Dwarf, Johnsongrass, and Sorghum Mosaic Viruses Based on Reactions of Oat and Some Sorghum Cultivars

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ABSTRACT

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Different virus strains, formerly called sugarcane mosaic virus (SCMV) and maize dwarf mosaic virus (MDMV), were studied under the same experimental conditions. The objective was to determine if a differential set of oat and 11 sorghum cultivars would distinguish among the four viruses in the new taxonomic system now classified as SCMV, MDMV, johnsongrass mosaic virus (JGMV), and sorghum mosaic virus (SrMV). Fifteen well-characterized strains of these four were used in this study. These viruses are separable based on symptom expression in sorghum and oat. JGMV alone infects oat. Strains within MDMV and JGMV react uniformly in sorghum. SCMV strains differ in reactions on some sorghum cultivars. SrMV strains differ on two sorghum cultivars. These infectivity results clearly support the new taxonomy suggesting that, although helpful, it is not essential to have biochemical and serological laboratory capabilities to classify these 15 virus strains.

Gramineous-limited potyviruses have morphology, particle structure, physical and biophysical properties, host range, and modes of transmission (3) in common and are generally considered strains of SCMV (7). Mosaic on sugarcane, maize, sorghum, and other Gramineae has been known since 1919; since 1965, it has been attributed worldwide to the sugarcane mosaic virus (SCMV) (7). United States strains of SCMV have been designated A, B, C, D, E, F, G, H, I, J (or Jg), K, L, and M (7,10). Sorghum red stripe virus (SRSV) is a European strain that causes both red stripe on sorghum and mosaic on maize (1,2,11). Maize mosaic virus-European type (MMV-Et) (12) and Indian type (three strains are SCMV-C, E [12], and H [5, 13]) were shown related to SCMV (1,2,12). Australian strains are designated SCMV-JG, infecting johnsongrass; SCMV-SC, infecting sugarcane; SCMV-BC, infecting blue couch grass; and SCMV-Sabi, infecting Sabi grass (7,10).

Maize dwarf mosaic virus (MDMV), described as new on corn in the United States in 1962 in Ohio and soon thereafter in other cornbelt states (2,8) has strains designated A, B, D, E, F, KS-1, and O (4,10,13).

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MDMV and SCMV strains have similar host ranges (2,8,13). Some researchers (2,7) showed that MDMV can infect sugarcane by causing a mild mosaic on some cultivars while remaining symptomless on others. MDMV-A and B are distinctly different based on host range (2,13). Some sorghum cultivars can differentiate among MDMV and SCMV strains (13). MDMV-A, SCMV-J and MMV-Et are considered identical. Also considered identical are MDMV-B and SCMV-E, with MDMV-B more closely related to SCMV strains than to MDMV-A (12,13). SCMV-H and I are unique and can cause severe symptoms on some differentials while SCMV-A, B, and D differ enough to consider them as separate strains (7).

Serological analyses have shown similarities between SRSV and SCMV (7), between MDMV and SCMV strains (7,13,14), and among MMV-Et and MDMV and SCMV strains (12). The use of cross-absorption in serological analyses showed differences in antigenicity among SCMV and MDMV strains (13,14). MDMV-B is closely related serologically to SCMV strains but not to MDMV-A, and SCMV-I differs in antigenicity from the other SCMV strains (13), differences also shown by immunoelectron microscopy (10). SCMV and MDMV strains have now been regrouped based on clear evidence shown by the electroblot serological method (9) as follows: MDMV (A, D, E, F, and the former SCMV-J infective to johnsongrass in the U.S. and MMV-Et in Yugoslavia); SCMV (A, B, D, E, and MB, the former MDMV-B in the U.S., and SC, BC, and Sabi from Australia); JGMV (formerly SCMV-JG from Australia and MDMV-O from the U.S.); and SrMV (formerly SCMV-H, I, and M from the U.S.).

Based on research and a review of the host range literature of SCMV and MDMV, Ford and Tosic (2) suggested that a host list coupled with serological, physical, and chemical properties would help to identify and differentiate viruses infecting maize. Our objective was to determine if a differential set of plants reacting to infection by MDMV, SCMV, JGMV, and SrMV would aid in the new classification or corroborate and provide the means for the same identification and classification in the absence of serological, physical, or chemical measurements.

MATERIALS AND METHODS

Sorghum cultivars used as test and indicator plants in these studies were Atlas, Rio (Exotic), OKY8, New Mexico 31, BTX398 (Martin), TX2786 (= SC0097-14E), SA8735, Trudex, Aunis, R430, and Tamaran. Sorghum seeds were supplied by Dr. Jerry Johnson, Northrup King Co., New Deal, Texas, and oat cultivar Clintland was supplied by the Department of Agronomy, University of Wisconsin-Madison. Seeds were sown in steam-sterilized soil in 12-cm-diameter pots under greenhouse conditions. At the 2–3 leaf stage, at least 20 seedlings were inoculated mechanically with the virus under study in each of the three tests.

The following virus strains and isolates were studied: MDMV-A, isolates Illinois and Iowa 65-74 (supplied by R. E. Ford), Ohio (supplied by D. T. Gordon), J (SCMV-J supplied by R. J. Shepherd) from the United States, and Y (MMV-Et supplied by M. Tosic) from Yugoslavia; SCMV-A, B (originally from sugarcane), and D (supplied by A. G. Gillaspie, Jr.), E (supplied by J. L. Saladini), SC, BC, Sabi (supplied by D. D. Shukla), MB (MDMV-B originally from maize, isolates Illinois and Iowa 66-188 supplied by R. E. Ford), and Ohio (supplied by D. T. Gordon); JGMV (SCMV-JG supplied by D. D. Shukla from Australia) and O (MDMV-O supplied by D. T. Gordon from the U.S.);

and SrMV-H and I (supplied by A. G. Gillaspie, Jr., from the U.S.). All viruses were propagated in sweet corn cultivar Gold Cup in a greenhouse. Inocula were prepared by homogenization of 14-day infected sweet corn leaves showing mosaic symptoms.

Symptoms on inoculated sorghum seedlings were observed at four intervals of 1 wk each after inoculation. Lack of, questionable, or mild symptoms were all reconfirmed by reinoculations on Gold Cup seedlings in a greenhouse. Symptoms on sorghum seedlings or positive back-inoculations to Gold Cup were considered proof of susceptibility for each cultivar tested.

The terminology used in the text and in Table 1 referring to necrotic symptoms is as follows: streaks are necrotic areas of tissue about 1 mm wide and up to 10 mm long, lines are necrotic areas of tissue about 1 mm wide and longer than 10 mm, and stripes are 2 mm or more wide, sometimes the entire length of the leaf blade.

Experiments were repeated three times, once at the University of Illinois, Department of Plant Pathology, Urbana, in the summer of 1987 and twice at the University of Belgrade, Faculty of Agriculture, Beograd-Zemun, Yugoslavia, in the fall of 1987 and in the spring of 1988.

RESULTS

Our investigations on the susceptibility of sorghum cultivars and oat to infection by MDMV, SCMV, JGMV, and SrMV show that these viruses can be differentiated from each other by symptoms. The symptom reactions of infected sorghum cultivars did not differ significantly among the three experiments. All reactions of sorghum cultivars to infections by the virus strains are summarized (Table 1).

All tested isolates of MDMV reacted identically in all sorghum cultivars. The eight SCMV strains differ in reactions on some sorghum cultivars. Only JGMV infected oat. The two JGMV isolates

Table 1. Reaction of sorghum cultivars and oat to representative isolates of maize dwarf mosaic (MDMV), sugarcane mosaic (SCMV), johnsongrass mosaic (JGMV) and sorghum mosaic (SrMV) viruses

Virus strains	Sorghum cultivars											Oat
	Atlas	Rio	BTX 398	NM31	SA 8735	R430	OKY8	Tamaran	Aunis	Trudex	TX 2786	Clintland
MDMV[a]												
A	M[b] rNn	M rNn	M	M rNn	M	M rNn	M	M	M rNn	M	M	...
SCMV												
A	M NSkSt n	M	M	NSkSt in	M	M NSkSt n	M	M NSkSt in	M	M rNn	...	...
B	M NSkSt in	M rNn	M	M NSkSt in	M	M NSkSt n	M NSkSt in	M	M rNn	M rNn	M	...
D	M NSkSt in	M	M	M NSkSt in	M	M NSkSt in	M	M NSkSt in	M	M rNn	...	...
SC	M NSkSt in	M	M	M NSkSt in	M	M NSkSt n	M	M NSkSt in	M	M rNn	...	...
Sabi	M NSkSt in	M	M	M NSkSt in	M	M NSkSt in	M	M NSkSt in	M	M rNn	...	...
BC	NSkSt in	M	...	M NSkSt in	M	M NSkSt n	...	M NSkSt in	M	M rNn	...	...
E	NSkSt i	...	...	NSkSt i	Mr	Mr NSkSt n	Mr	Mr NSkSt i	Mr	M rNn	...	...
MB *Iowa*[c]	NSk i	Mr	...	NSkSt i	Mr	...	...	NSkSt in	...	Mr	...	...
Illinois	NSk i	...	...	NSkSt i	...	...	...	...	...	...	...	...
Ohio	NSk i	...	...	NSkSt i	...	Mr Nn	...	M NSk n	M	M NSk n	...	...
JGMV[d]	Mm rNn	Mm	Mm	Mm rNn	M	Mm	M Nn	Mm	Mm	M rNn	Mm	Mm
SrMV[e]												
H	M Ns	M rNn	M	M Nn	M rNn	M NSkSt	M	M NSkSt	M	M rNn	...	...
I	M N	M	M	M Nn	M rNn	NSkSt in	M	M NSkSt in	M	M rNn	...	...

[a]The five sources of strain MDMV-A tested were Iowa 65-74, Illinois, Ohio, and SCMV-J and Y (Yugoslavia), all of which infected and caused identical symptoms in each sorghum cultivar.

[b]Abbreviations for symptom reactions are as follows: M = mosaic, N = necrosis or necrotic, Sk = streaks, St = stripes, r = rare, i = inoculated leaves, n = new leaves, m = mild, and s = slow. Streaks and stripes are described in the Materials and Methods section.

[c]Iowa isolate Ia66-188.

[d]The two strains of JGMV tested were SCMV-JG (Australia) and MDMV-O, both of which infected and caused identical symptoms in each sorghum cultivar.

[e]For SrMV we retained the same strain identification of H and I as they were described in all literature for SCMV prior to publication (9).

caused rather uniform reaction on sorghums. SrMV infected neither oat nor TX 2786 whereas MDMV infected TX 2786. The two SrMV isolates differ in their reactions on sorghums.

MDMV, which infected all sorghum cultivars but not oat, caused either mosaic on BTX398, SA8735, OKY8, Tamaran, Trudex, and TX2786 or mosaic followed by rare necrosis on new leaves of Atlas, Rio, and New Mexico 31.

DISCUSSION

Most of the sorghum cultivars studied here were also tested for susceptibility to the previous MDMV and SCMV strains by other researchers. Atlas and Rio have been used frequently as differential hosts (7,10,12,13). In addition, OKY8, SA8735, NM 31, BTX3197, SC0097-14E, BTX398, and R430 have been used as test and differential host plants (6,10,13). In one of those studies (6), seed of seven sorghum varieties was distributed to various laboratories to differentiate among nine isolates of MDMV-A and SCMV-Jg. The authors appropriately indicated that the experiment would be most valid by comparing all well-characterized virus isolates on all hosts at one location. We did this and, in addition to their seven sorghum cultivars, we added four more that in our hands (Tosic) also had useful characteristics for distinguishing among strains. Symptoms in all sorghum cultivars in our experiments corroborated those in the literature.

Tamaran, Aunis, and Trudex sorghums developed mosaic symptoms when infected by MDMV (Table 1). Only Aunis developed some necrosis on new leaves. JGMV caused mild mosaic on all three, and Trudex developed necrosis but rarely on new leaves. SrMV-H and I did not differ on these three cultivars. Tamaran, Aunis, and Trudex reacted similarly to SCMV and SrMV strains, with mosaic symptoms most common, although necrotic streaks and stripes occurred on both inoculated and new leaves of Tamaran. Necrosis was rare on new leaves of Trudex.

Because oat alone was infected by JGMV, it differentiates JGMV from the other three viruses (10). Upon careful review of the Australian data and the results from back-inoculations (which were done for the first time) on maize and sorghum following inoculation of oat, one of us (Shukla) finds that our report of infection of oat by SCMV-Jg, BC, and Sabi was in error (10). We believe the ability to infect oat is restricted to JGMV. Like MDMV and SCMV-B, JGMV was infectious to all sorghum cultivars tested on which it caused mosaic (SA8735), mild mosaic (Rio, BTX398, R430, Tamaran, Aunis, and TX2786), mosaic followed by necrosis on new leaves (OKY8), and mild mosaic followed by rare necrosis on new leaves (Atlas, NM 31, and Trudex).

All strains of JGMV and MDMV and strain B of SCMV infected TX2786. The mosaic symptoms caused by MDMV are generally more pronounced, and MDMV did not cause necrosis on OKY8 and Trudex but JGMV did.

SrMV is easily separated by an inability to infect oat and TX2786. The strains H and I of SrMV were differentiated by necrosis that developed in Atlas (most pronounced for I). Usually, all seedlings of Atlas infected with SrMV-I died within 14 days, but necrosis was less pronounced and slower to develop with H. With SrMV-I, only mosaic developed on Rio seedlings whereas H causes both mosaic and occasional necrosis on new leaves. SrMV-I caused only necrotic streaks and stripes on inoculated and new leaves of R430, while H caused only mosaic. These results suggest that SrMV-H and I are distinct strains. SrMV-H previously had been shown to be distinct from SCMV (7).

We have designated as SCMV-MB the strain which prior to 1989 in the literature has been designated as MDMV-B. We believe this will avoid confusion with SCMV-M. The SCMV group of strains exhibit the most variability in symptoms on sorghum. Therefore, the sorghum cultivars we used may not be as appropriate to differentiate SCMV strains as the sugarcane varieties currently used (7,10). SCMV-E and MB cause necrotic streaks and stripes on inoculated leaves whereas the other strains caused these symptoms only systemically on Atlas. Some differences noted were that SCMV-E causes necrotic streaks and stripes while MB caused only necrotic streaks. SCMV-E, BC, and MB did not infect BTX398; all other strains caused mosaic on BTX398 and Rio, and MB caused some necrosis. SCMV-E did not infect Rio and MB caused only rare mosaic. SCMV-MB did not infect OKY8 or Aunis. SCMV-E and MB also reacted with some differences on R430. These data did not allow us to determine whether SCMV-E and MB are the same or separate strains.

All other SCMV strains (A, B, D, BC, SC, and Sabi) differed distinctly from MDMV, JGMV, and SrMV as well as from SCMV-E and MB. SCMV-B differed from all other SCMV strains. Among all SCMV strains, only SCMV-B infected TX2786. SCMV-B caused only mosaic on Tamaran while the other strains caused both mosaic and necrotic streaks and stripes on inoculated and new leaves. On Aunis and Rio, SCMV-B caused mosaic followed by rare necrosis, while the other strains caused only mosaic. SCMV-BC differed from A, B, D, SC, and Sabi on Atlas by causing only necrotic streaks and necrotic stripes on new leaves whereas the others caused mosaic followed by necrotic streaks and necrotic stripes on inoculated leaves only (SCMV-A) or on inoculated and new leaves (SCMV-B, D, SC, and Sabi). SCMV-A differed from other SCMV strains on Atlas and NM 31. It caused mosaic followed by necrotic streaks and stripes on new leaves of Atlas. All other strains except SCMV-BC caused mosaic, followed by necrotic streaks and necrotic stripes on both inoculated and new leaves. SCMV-BC caused necrotic streaks and necrotic stripes on inoculated and new leaves of Atlas but no mosaic. SCMV-BC did not infect BTX398 while strains A, B, D, SC, and Sabi caused mosaic. SCMV-SC differed from D and Sabi on R430 because SC caused mosaic followed by necrotic streaks and necrotic stripes on new leaves, while D and Sabi caused mosaic and necrotic streaks and necrotic stripes on both inoculated and new leaves. Our data suggest that SCMV-D and Sabi are identical. A more complete understanding of the relationships among SCMV strains may be needed. Sugarcane cultivars were not available for this study, but SCMV strains have been described based on sugarcane cultivar differentials (7,10).

We concluded that the sorghum cultivars tested here, as well as physical, chemical, and serological properties, can aid in identification viruses infecting corn, sorghum, and sugarcane. Based on symptom reactions on sorghums and oat, the four newly established viruses, MDMV, SCMV, JGMV, and SrMV, can be differentiated, which supports the serological and chemical data (9,10).

The matching of host reaction and serological properties may have some general implications in virus evolution, although this study was not designed to test such an hypothesis.

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