CHAPTER ONE –REVIEW OF LITERATURE

Introduction

Hot peppers, *Capsicum* c*hinense* Jacquin, are grown in Jamaica and other Caribbean countries, and in Jamaica the most preferred cultivar is 'Scotch Bonnet' because of its unique flavor. Commercial production of hot peppers started in Jamaica about 1970, and fruits were mainly processed into sauces (Ministry of Agriculture, Jamaica, unpublished report[1]). Only recently have hot peppers been included among Jamaica's non-traditional export crops. In 1996 about 71 metric tons of hot peppers were exported to the United States, Canada and the United Kingdom, (The Data Bank and Evaluation Division of the Ministry of Agriculture, Jamaica) but the export market constitutes only a small fraction of the total pepper production in Jamaica. The greater portion goes to meet the high demand on the local market. For example, 9,069 metric tons of hot peppers were produced in 1996 (The Data Bank and Evaluation Division of the Ministry of Agriculture, Jamaica). The annual production of peppers, which is comprised mostly of *C.* c*hinense*, has increased steadily from 1989 through 1997 (The Statistical Institute of Jamaica 1998). However, several pests threaten the production of Jamaican hot peppers (Martin *et al.* 1998, Lawrence *et al.* 2000). Chief among them are viruses to which Scotch Bonnet is especially vulnerable. Other important pests are the broad mite, *Polyphagotarsonemus latus* (Banks), (Acari: Tarsonemidae) (Martin *et al.* 1998, Lawrence *et al.* 2000) and the gall midges, *Contarinia lycopersci* (det. Gagné) and *Prodiplosis longifila* Gagné (Diptera: Cecidomyiidae) (Lawrence *et al.* 2000).

The widespread infection and severity of plant viruses in Jamaican Scotch Bonnet pepper fields has reduced the production and profitability of this crop by reducing the period that the crop can be harvested (Myers 1996). Under normal conditions, Scotch Bonnet pepper is grown as a perennial crop, but since the occurrence of the mosaic viruses it has been grown as an annual crop (Ministry of Agriculture, Jamaica, unpublished report). Viruses most commonly affecting Scotch Bonnet pepper in Jamaica are *tobacco etch virus* (TEV), *potato virus Y* (PVY)

(McGlashan *et al.* 1993, Myers 1996, Lawrence *et al.* 2000) and *tobacco mosaic virus* (TMV) (McGlashan *et al.* 1993, Martin *et al.* 1998).

TEV and PVY are aphid-borne, whereas TMV is mechanically transmitted. TEV may cause mottling, mosaic discolorations and deformation of pepper leaves, accompanied by malformation of fruit and stunting of plants (Bawden and Kassanis 1941, Brunt *et al.* 1996). PVY is known to cause mild mottling in pepper leaves and more severe symptoms when occurring in mixed infections with other viruses (Brunt *et al.* 1996). In Jamaica, PVY and TEV often occur in mixed infections in the field (McGlashan *et al.* 1993, Myers 1996) but the symptoms of PVY are suppressed by TEV (Myers 1996). Plants infected with these viruses produce leaves that are chlorotic and reduced in size.

Scotch Bonnet pepper

Scotch Bonnet pepper is a variety of *Capsicum chinense* Jacquin and belongs to the family Solanaceae. *C. chinense* is one of five domesticated species of *Capsicum* (Andrews 1984) and is most closely related to the domesticated species, *C. annuum* and *C. frutescens* (Pickersgill *et al.* 1979). *C. chinense* can hybridize with *C. annuum* and *C. frutescens* (Schweid 1989, DeWitt and Bosland 1996). *C. chinense* is grown mostly in the Caribbean and South America (Purseglove *et al.* 1981, Andrews 1984) and is thought to have originated in either the Andes mountains (Purseglove *et al.* 1981) or Amazon Basin (DeWitt and Bosland 1996). The species is comprised of about 40 varieties, varying in shape, color and heat levels. Heat levels range from 0 to 577,000 Scoville units within *C. chinense* (Dewitt and Bosland 1996). Scotch Bonnet derived its name from the shape of the fruit. It is also known for its distinct flavor and its pungency, which places it in the upper range of known heat levels of hot peppers (Andrews 1984, DeWitt and Bosland 1996).

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[1] Marjorie McCarthy, Agricultural officer, Ministry of Agriculture, Jamaica. Growing hot peppers in South Manchester. Unpublished report (1973?).

Aphid transmitted viruses of Scotch Bonnet pepper

Many solanaceous plants, including *Capsicum* spp., are hosts to PVY and TEV. TEV and PVY belong to the genus, *Potyvirus,* in the family Potyviridae. Potyviridae are single-stranded, positive-sense, RNA viruses (Matthews 1997). The RNA of potyviruses has a single open reading frame that codes for a poly-protein, which is later cleaved into independent proteins by viral-encoded proteases.

McGlashan (1993) and Myers (1996) found the symptoms of TEV in Scotch Bonnet peppers to be more severe than those of PVY. Symptoms of TEV in Scotch Bonnet peppers include chlorotic mosaic, leaf deformation, reduction in leaf size (McGlashan 1993, Myers 1996), puckering of leaves (McGlashan 1993), retention of chlorophyll in the area of the midrib, and fruit deformation (Myers 1996). In contrast, symptoms of PVY in Scotch Bonnet peppers include “inconspicuous mosaic” discolorations and vein banding on leaves, knobs on the fruit surface and uneven ripening of fruits (Myers 1996). Mixed infection with TEV and PVY results in stunting of growth, deformation of leaves and fruits, chlorotic mosaic (McGlashan 1993, Myers 1996), severe rugosity and curling of leaves (McGlashan 1993) and reduced fruit size (Myers personal communication).

Transmission of aphid-borne viruses

Aphids transmit nearly two-thirds of all insect-transmitted plant viruses and about 39% all known plant viruses (Nault 1997). To date, there are about 145 species of aphids known to transmit viruses in the genus *Potyvirus* (Nault 1997). PVY alone has over 24 recorded aphid vectors (de Bokx and Huttinga 1981), while TEV is reported to have over 10 known aphid vectors (Eckel and Lanpert 1993, Brunt *et al.* 1996). Aphids are ideal vectors of viruses because effective transmission of viruses requires penetration without excessive injury to or death of plant cells and aphids probe plant cells without causing much trauma (Shepherd 1977, Powell 1991).

Viruses transmitted by arthropod vectors have been classified into four groups (Nault 1997) based on how long they are retained by the vector and the mechanism by which they are transmitted. These categories are as follows: 1) nonpersistently transmitted, 2) semipersistently transmitted, 3) persistently transmitted, circulative, and 4) persistently transmitted, propagative viruses. The persistence is expressed as the half-life of retention of the virus by its vector and may be minutes (non-persistent), hours (semipersistent), days, weeks, or months (persistent) (Sylvester 1969, Nault 1997). The retention period by the vector is closely related to the mechanism of transmission. Hence, nonpersistently transmitted viruses are acquired within one minute, transmissible immediately after acquisition and are lost after the aphid probes a new host (Sylvester 1969, Harris 1977). The acquisition period for semipersistently transmitted viruses requires minutes, although they can be transmitted shortly after they are acquired. Persistently transmitted viruses are only acquired after minutes to hours of feeding, require a latent period before they are transmissible and are retained in their vectors where they remain transmissible for weeks. Propagative viruses reproduce inside of, and are retained throughout the life of their vectors (Sylvester 1980).

Both nonpersistent and semipersistent viruses are carried on the linings of the food canal formed by the stylets and foregut (Pirone and Blanc 1996, Bos 1999) and lost when the vector molts (Nault 1997). Nonpersistently transmitted viruses are likely to be removed from the stylets and foregut during long acquisition periods and during long probes or feeding (Sylvester 1969). Starving aphids such as those landing on plants after a long flight tend to make brief probes and are more likely to transmit non-persistent viruses. Nonpersistently transmitted viruses exhibit limited vector specificity within insect families (Sylvester 1969). However, members from more than one insect family will not normally transmit the same virus (Shepherd 1977).

Although the transmission of nonpersistent viruses by aphids has very little specificity with respect to individual aphid species, some aphid species are more efficient in transmitting certain virus species or strains than are other aphid species (Eastop 1977). For example, PVY and TEV are nonpersistently transmitted by several aphid species. *Myzus persicae* (Sulzer) is most efficient in transmitting PVY in peppers (Laird and Dickson 1963, Simons 1982). *M. persicae and Aphis gossypii* Glover seem equally efficient in transmitting TEV from pepper to pepper (Laird and Dickson 1963). Sometimes a less efficient vector may be more important in spreading a virus if it occurs in greater abundance than more efficient vectors (Raccah 1983). For example, Halbert *et al.* (1981), Shultz *et al*. (1985) and DiFonzo *et al.* (1997) correlated virus incidences in soybean and potato with high numbers of inefficient vectors when numbers of efficient vectors were low. Alate and apterous aphids of the same species are equally able to transmit any one virus but alates have the advantage of carrying the virus greater distances (Eastop 1977, Simons 1982).

The efficiency of transmission by the vector is sometimes affected by the plant from which the virus is acquired (Simons 1954). Sylvester and Simons (1951) found that *M. persicae* could efficiently transmit *Brassica nigra* virus from pak choi (38%) or from mustard (45%) to mustard but could not transmit the virus from pak choi to pak choi (0%) and was a poor vector from mustard to pak choi (2%). The efficiency of *Lipaphis erysimi* Hille Ris Lambers (syn. = *Rhopalosiphum pseudobrassicae* Wolcott) was not affected by the source or the target host plant in equivalent tests (Sylvester and Simons 1951). The authors hypothesized that some component in the saliva of *M. persicae* together with the cellular contents of the inoculated pak choi might have inhibited infection of the virus. Nishi (1969) extracted a chemical from the saliva of *M. persicae* that reversibly inhibited TMV, TuMV and Potato virus X.

The ability of an aphid to transmit a virus might also depend on the presence of other viruses and the type of helper component (HC) protein acquired by its potential vector. For example, the ability of *L. erysimi* to transmit TEV is dependent on the type of HC protein available (Wang *et al.* 1998). *L. erysimi* reared on virus-free mustard was unable to transmit TEV from tobacco to tobacco. Tests showed that *L. erysimi* could acquire purified TEV via artificial membrane feeding in the presence of PVY HC but could not retain the virus long enough to transmit it to tobacco. However, in the presence of *turnip mosaic potyvirus* (TuMV) HC, it was able to transmit TEV almost as efficiently as *Myzus persicae.* Similarly, *L. erysimi* was only able to transmit TuMV to mustard in the presence of the TuMV HC. Conversely, *M. persicae* was able to transmit both TEV and TuMV in the presence of PVY HC or TuMV HC (Wang *et al.* 1998).

Helper components are virus-encoded amorphous accumulating within the cytoplasm of virus-infected plant cells (Pirone 1977). HC aids transmission of a vector-borne virus by forming a bridge between the attachment site on the vector and the coat protein of the virus (Pirone and Blanc 1996). Some viruses produce HCs that will work with other viruses and transmission of some viruses can only be assisted by a limited variety of HCs (Pirone 1977). The results of Wang *et al.* (1998) illustrate how some aphid vectors can only use a few specific HCs and how the presence of certain HCs will determine the ability of a vector to transmit particular viruses.

Aphid species in Jamaica

Twenty-six species of aphids are recorded from Jamaica (Frank and Bennet 1970), Smith and Cermali 1979, Murray 1985, Jayasingh 1996, Nafría *et al.* 1994) (Table 1.1). Local sources of information on aphid species found in Jamaica are sparse and incomplete. Frank and Bennett (1970) found 3 aphid species associated with sugar cane. Murray (1985) reported only two species of aphids, one on groundnuts and the other on *Caeladuim* sp. Jayasingh's was the most comprehensive local report, mentioning 14 of the 26 species, including 2 of the three species found on sugar cane. Fifteen species are reported by Smith and Cermali (1979), 9 of which were not otherwise reported by local authors (Table 1.1). The information presented by Jayasingh (1996), Nafría *et al.* (1994) and Smith and Cermali (1979) all appear to be compilations from several sources. There is need for a comprehensive survey of aphid species and their host plants in Jamaica.

According to Dr. David Voegtlin[2] (personal communication), the aphid name, *Rhopalosiphum sativum* is dubious. While none of the *Rhopalosiphum* species are likely to feed on legumes, the most recent list of the world's aphids does not contain any with the name *sativum*. The only

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[2] Center for Biodiversity, Illinois Natural History Survey, Champaign, Illinois.

Table 1.1. List of aphid species found in Jamaica

Aphid	Plant(s) collected from	Author
Acyrthosiphon pisum (Harris) ◊	Arac*his hypogea* L.	Murray 1985
Aphis craccivora Koch ◊	No plant given	Smith and Cermali 1979
(syn = *A. medicaginis* Wolcott)	*Solanum tuberosum* L.	Jayasingh 1996
Aphis fabae Scopoli ◊	*Cajanus cajan* (L.) Millsp.	Jayasingh 1996
Aphis gossypii Glover◊	No plant given	Smith and Cermali 1979
	Hibiscus esculentus L. (syn. *Abelmoschus esculentus* L. (Moench.))*, Capsicum* spp., *Cucurbita pepo* L., *Cucumis melo* L., *Lycopersicon esculentum* Mill.*, Solanum molongena* L.*, Solanum tuberosum* L.*, Vigna unguiculata* (L.) Walp.	Jayasingh 1996
Aphis illinoisensis Shimer	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
	Geranium sp.	Jayasingh 1996
Aphis nerii Boyer de Fonscolombe	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
Aphis spiraecola Patch ◊	No plant given	Smith and Cermali 1979

◊Known vector of TEV (Eckel and Lampert 1993)

Table 1.1 Cont'd

Aphid	Plant(s) collected from	Author
Aphis pomi de Geer	*Citrus* spp.	Jayasingh 1996
Cerataphis orchidearum (Westwood)	No plant given	Smith and Cermali 1979
Cerataphis brasiliensis (Hempel)	No plant given	Smith and Cermali 1979
Ceratophis sp.	*Alpinia purpurata* (Vieill.) K. Schum.	Jayasingh 1996
Eriosoma lanigerum Haustnann	*Citrus* spp.	Jayasingh 1996
Macrosiphoniella sanborni (Gillette)	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
Macrosiphum euphorbiae (Thomas)	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
(Syn. = *M. solanifolii* (Ashmead))	*Solanum tuberosum* L.	Jayasingh 1996
Macrosiphum martorelli Smith	*Theobroma cocoa* L.	Jayasingh 1996
Melanaphis (syn. = *Longiunguis) sacchari* (Zehntner)	*Saccharum officinarum* L.	Frank and Bennet 1970
Myzus persicae (Sulzer) ◊	No plant given	Smith and Cermali 1979
	Brassica oleracea L., *Lycopersicon esculentum* Mill., *Vigna unguiculata* (L.) Walp.	Jayasingh 1996

◊Known vector of TEV (Eckel and Lampert 1993)

Table 1.1 Cont'd

Aphid	Plant(s) collected from	Author
Pentalonia nigronervosa Coquerel	No plant given	Nafria *et al.* 1994
Pentalonia nigronervosa form *caladii* van der Goot	*Caeladuim* sp.	Murray 1985
Rhodobium porosum (Sanderson)	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
Rhopalosiphum maidis (Fitch*)*	*Saccharum officinarum* L.	Frank and Bennet 1970
(Syn. = *Aphis maidis* (Fitch))	*Saccharum officinarum* L., *Zea mays* L.	Jayasingh 1996
Rhopalosiphum rufiabdominalis (Sasaki)	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
Rhopalosiphum sativum	*Vigna unguiculata* (L.) Walp.	Jayasingh 1996
Sipha flava (Forbes)	*Saccharum officinarum* L.	Frank and Bennet 1970
	Saccharum officinarum L.	Jayasingh 1996
Tetraneura nigriabdominalis (Sasaki)	No plant given	Smith and Cermali 1979
	No plant given	Nafría *et al.* 1994
Toxoptera aurantiae (Boyer de Fonscolombe)	No plant given	Smith and Cermali 1979
	Theobroma cocoa L.	Jayasingh 1996
Toxoptera citricida (Kirkaldy)	No plant given	Smith and Cermali 1979

$^{\Diamond}$Known vector of TEV (Eckel and Lampert 1993) close specific name in the literature is *Aphis sativae* Williams, which is very unlikely to be the species found in Jamaica (D. Voegtlin, personal communication). Another possible explanation could be that "*Rhopalosiphum sativum*" is a synonym that is no longer being used for this aphid.

Management of aphid-borne viruses

Understanding the epidemiology of aphid-borne viruses such as PVY and TEV is important for developing appropriate management strategies for these viruses. The epidemiology of each virus will vary with locality and time, and is a factor of the local sources of inoculum, the vector complex involved and how the presence of vectors synchronizes with the phenology of the crop (DiFonzo *et al.* 1997). DiFonzo *et al.* (1997) found greater associations between the incidence of PVY in potatoes grown in the Red River Valley of Minnesota and North Dakota and eight species of relatively inefficient aphid vectors. These aphids built up large populations on common weeds found in and around potato farms. The more efficient *M. persicae* was not significant in the epidemiology of the disease due to its low abundance (DiFonzo *et al.* 1997). Thus, the severity and incidence of a vector-borne disease is determined by the interaction of the pathogen, susceptible host and the environmental conditions and the behavior of its vector (Carter 1961, Irwin and Ruesink 1986).

One of the first steps in the management of plant viruses is to start with a good seed source. Healthy, pathogen-free seeds will produce healthy seedlings. Plants that are healthy will be more tolerant to viruses (Broadbent 1969). Periods of rapid growth of plants will foster rapid multiplication of viruses because all the needed resources are readily available during this time (Matthews 1997). Seedlings are therefore more susceptible to virus infection than mature plants and should be protected. Seedbeds should be established away from sources of inoculum, such as, old virus infected pepper fields and weed hosts of the virus.

In Florida the weed, *Solanum viarum* Dunal, was found to harbor PVY, TEV, cucumber mosaic cucumovirus (CMV), tomato mosaic tobamovirus (ToMV), potato leaf roll luteovirus (PLRV) and tomato mottle bigeminivirus (TMoV) (McGovern *et al.* 1994). PVY and ToMV were mechanically transmissible from *S. viarum* to pepper and tobacco, and from tomato to *S. viarum,* while TEV was mechanically sap transmissible from pepper to *S. viarum* (McGovern *et al.* 1994). PVY is thought to have spread from black nightshade, *S. nigrum* L., to peppers and tomatoes in Florida (Simons *et al.* 1956). *S. nigrum* may remain symptomless with PVY infection (Ferres *et al.* 1996). Many virus-infected weeds are asymptomatic (Bos 1981).

Most of the measures used to control vector-borne viruses are aimed at the vectors. Hence, methods aimed at avoiding or excluding the vector, or reducing the ability of the vector to transmit viruses are most important in the management of nonpersistently transmitted plant viruses. Planting and harvest dates can be shifted so that susceptible crop stages can escape infection during peak aphid flights (Broadbent 1969). In Sweden, during years of low aphid flights, potato haulms are allowed to remain in the field to produce both seed and “ware” potato but when vector flights are high, potatoes are harvested early to prevent infection to valuable seed potatoes by PVY (Sigvald 1986).

Aphid-borne viruses can be transmitted by apterous and alate aphids (Eastop 1977, Simons 1982). Spread of viruses between fields is caused by alates. Alates are therefore responsible for the primary spread of the virus into a crop (Simons 1982). Research has shown that immigrant aphids tend to alight on crops at the edges of fields, and that virus-infected plants tend to be concentrated near the periphery of fields (Broadbent 1969). Therefore, as field size increases and the proportion of field perimeter to field area decreases, the likelihood of the entire field becoming infected decreases (van der Plank 1948). Increasing plot size and planting virus resistant barrier crops on the edges of fields could aid in delaying and/or reducing the spread of nonpersistently transmitted viruses in the field, especially where the aphid vector (e.g. *Aphis fabae* Scopoli) tends to stay in the area where it first landed (Broadbent 1969). The incoming viruliferous aphids would lose their virus inoculum to the barrier plants, which they are most likely to probe first.

Barrier crops have an added advantage if they are taller than the field crop because aphids also tend to land on taller plants (Broadbent 1969). Simons (1957, 1960) found that barriers consisting of a single row of sunflower plus a 15 m band of beans around pepper plots established 45 m from PVY infected *S. nigrum* plants delayed infection by about 10 days compared with plots without barriers. Eighty days after the peppers were transplanted, PVY incidence was 50, 70 and 80% less than the control in plots with barriers comprised of one row of sunflower, one row of sunflower plus a 15-m wide band of bean, and one row of sunflower plus a 15-m wide band of bean sprayed with parathion, respectively. All barriers were placed around the three sides of the pepper plots nearest to the virus source. Pepper plots with barriers comprised of sunflower and bean had 50% less infection than the control at 115 days after transplanting, while pepper plots with a sunflower barrier had only 10% less (Simons 1957, 1960).

Immigrant aphids tend to land where the plant canopy is broken (A'Brook 1968, Broadbent 1969, Smith 1969) and aphids generally move horizontally through the crop (Müller 1953). Increased planting densities (A'Brook 1968, Broadbent 1969, Smith 1969), virus resistant cover crops or weeds that are non-hosts for the virus and vectors may be used to provide a closed canopy (Broadbent 1969, Smith 1969, A'Brook 1973) and reduce the landing rates of aphids within crops. Smith (1969) found that greater numbers of *Brevicoryne brassicae* Linnaeus were caught with water traps in clean-weeded brussels sprout plots than in brussels sprout plots with complete ground cover provided by a controlled carpet of weeds. *A. craccivora* Koch*, A. gossypii* and *Melanaphis* (syn. = *Longiunguis) sacchari* (Zehntner) were caught more frequently over widely spaced than over close-spaced groundnuts (A'Brook 1968). A similar response was elicited by eight aphid species captured over kale (A'Brook 1973). The experiments of A'Brook (1968, 1973) also demonstrated that the response of particular species of aphid might be affected by the type of crop studied. *R. maidis* (Fitch) did not respond to spacing trials with groundnut (A'Brook 1968) but tended to land more frequently in widely-spaced than in closely-spaced kale and cocksfoot (A'Brook 1973).

During take off, migrant aphids are attracted to the short wavelength radiation such as ultraviolet light (Halgren 1970, Klingauf 1987). In contrast, during landing, they are attracted to long wavelengths such as yellow and green and are repelled by short-wave light (Smith and Webb 1969, Kennedy and Frosbrooke 1973). Surfaces that reflect short-wave light will also repel immigrant aphids. For example, reflective mulches reduced the landing rate of aphids and delayed the incidence and severity of infection of nonpersistently transmitted, aphid-borne viruses (Johnson *et al.* 1967, Smith and Webb 1969, Nawrocka *et al.* 1975, Chiang *et al.* 1983, Basky 1984). Johnson *et al.* (1967) reported $\geq$ 87 to 97% reduction in the number of winged aphids caught in water traps over gladiolus planted with mulches made from aluminum foil laminated onto paper, asphalt coated with aluminum powder, and white polyethylene. Loebenstein *et al.* (1975) reported 95-97% reduction in aphid landing rates in pepper plots covered with aluminum foil and 88-94% reduction with gray plastic mulch. During years of high natural virus infection, incidence of PVY and CMV infection in mulched plots was 10-13% of the incidence obtained in the control at the time of harvest, and yields were 40-50% higher in mulched plots than in the control (Loebenstein *et al.* 1975). Although repellence of aphids decreased as the plant canopy increased and closed over the reflective mulches (Smith and Webb 1969, Nawrocka *et al.* 1975), crop yields were greater in mulched plots than in unmulched plots (Smith and Webb 1969, Nawrocka *et al.* 1975, Chiang *et al.* 1983). The reason for this is that mature plants are more tolerant to virus infection than younger plants (Loebenstein *et al.* 1975). Reflective mulches are most effective when 57-83% of the ground is covered at planting (Loebenstein *et al*. 1975).

Use of row covers during the early vegetative growth stages of crops delays and reduces virus incidence. Aphids and the viruses they transmit were entirely excluded from muskmelon (Perring *et al.* 1989, Espinoza and McLeod 1994, Orozco *et al.* 1994, Farias *et al.* 1999), yellow squash (Conway *et al.* 1989), and fall-grown squash (Webb and Linda 1992) with various types of synthetic row covers until these covers were removed. At the end of the growing season, Espinoza and McLeod (1994) found that virus incidence in uncovered muskmelon plots was 8 to 12 times greater than in plots that were previously covered. Muskmelon plants that were covered produced 274 more boxes of fruit per hectare than plants that were not covered. Webb and Linda (1992) also reported that yield of squash from covered plants was 3 to > 10 times greater than yield of squash from plants that were not covered.

Mineral oils prevent the transmission of stylet-borne viruses without killing the vector or destroying the virus (Vanderveken 1977, Simons *et al.* 1995). Oils prevent aphids from retaining virus particles during acquisition and inoculation (Loebenstein *et al.* 1964, Wang and Pirone 1996). DeWijs *et al.* (1979) found that the greater the viscosity of the oil the greater its ability to inhibit transmission of stylet-borne viruses. Oil coats plant surfaces but tends to accumulate in depressions between epidermal cells where aphids probe (Simons and Beasley 1977). Complete coverage of leaves with oils is necessary for full protection (Simons *et al.* 1977). Loebenstein *et al.* (1964) tested the ability of various concentrations of oil sprays to prevent infection of cucumber by CMV, using *A. gossypii* as a vector. While $\geq$ 5% concentrations of oil tended to completely inhibit transmission of CMV, they were very phytotoxic. CMV transmissions were reduced by 67-89% with 1% oil emulsions and its effect lasted for up to 7 days after application. With 0.5% oil emulsions, CMV transmission was reduced by 30-80% for 1 to 3 days after being applied. Phytotoxicity was minimal with 1% oil and absent with 0.5% oil (Loebenstein *et al.* 1964).

Marco (1993) tested the efficacy of conventional insecticides, whitewash, mineral oil, and combinations of mineral oil with insecticides and whitewash in reducing aphid transmitted virus infections in *C. annuum*. Virus incidence was reduced by 40% when mineral oil or whitewash was used alone and by 60% with combinations of mineral oil and whitewash or whitewash and the insecticide bifenthrin compared with untreated plots. However, the mineral oil and whitewash caused phytotoxicity. Nawrocka *et al.* (1975) found no significant reductions of CMV infections or increased yields in lettuce with the use of mineral oil. Nitzany (1966) found that a light mineral oil could delay the spread of PVY in pepper by 15 to 20 days but the delay was insufficient to reduce yield loss, as pepper is a slow growing crop.

Most commercial mineral oils adopted for use in experiments to reduce the transmission of vector-borne viruses were phytotoxic because they were not developed specifically for use on crops (Simons and Zitter 1980). Mineral oil developed to prevent transmission of plant viruses should be used in low concentrations of about 0.75% preferably with a nonionic emulsifier to reduce phytotoxicity (Simons and Zitter 1980, Simons 1982). Viscosities between 50 and 180 SUS (Saybolt Universal Seconds) and oil droplets with a diameter of about 2 µm contained within emulsion droplets of about 40 µm in diameter allows for adequate distribution of oil droplets on the leaf surface, particularly into the grooves between epidermal cells where aphids probe. An appropriate combination of spray pressure and nozzle tips is necessary to produce the ideal droplet size. Control is best when pressure is ca. 2800 kPa, although moderate control can be obtained with a pressure of ca. 1400 kPa (Simons and Zitter 1980, Simons 1982). JMS Stylet-Oil® was developed specifically for use on plants against viruses. When JMS Stylet-Oil® is applied at the correct concentration and pressure, weekly applications control viruses in crops such as pepper, tomato and squash without causing phytotoxicity (Simons and Zitter 1980, Simons 1982). JMS Stylet-Oil® and any other mineral oil are best used with other management strategies. Mansour (1997) reported that control of aphid-borne viruses in squash using stylet oil and reflective mulch together was greater than using stylet oil alone, or stylet oil and an insecticide.

The most effective component of virus management is the use of virus resistant plants. While traditional breeding techniques still continue (Villalon 1981), genetic engineering has allowed for the rapid introduction of resistant plant genes as well as virus genes that protect crops against virus infection (Tomlinson 1987). Villalon (1979) was successful in breeding high yielding varieties of *Capsicum* spp., including *C. chinense,* which were resistant to TEV, PVY, TMV and pepper mottle virus (PepMoV). Ariyaratne (1996) reported that the *C. chinense* line, PI 152225, and 5 other *Capsicum* genotypes were resistant to several TEV isolates. Resistance of PI 152225 (and PI 159236) to TEV-HAT and PepMoV is conferred by an unlinked recessive locus named, pvr1 (Murphy *et al.* 1998). If this gene is also responsible for resistance to other TEV isolates, then it could be introduced into susceptible varieties, such as Scotch Bonnet, using molecular techniques. Swaney *et al.* (1995) used non-structural genes from TEV to obtain highly resistant tobacco lines as well as lines that would recover from TEV infections. RNA mediated resistance to TEV was also achieved when one or two transgene copies for the coat protein of the virus were inserted into tobacco (Goodwin *et al.* 1996). Tobacco plants exhibited a recovery response (Goodwin *et al.* 1996). Maiti *et al.* (1999) found that no resistance to TEV was achieved when more than one type of potyvirus gene was inserted into tobacco. Tobacco plants with the multiple potyvirus genes, N1a+N1b+coat protein, were more susceptible to TEV and tobacco vein mottling virus than plants with just a coat protein gene (Maiti *et al.* 1999).

While transgenic or traditionally improved virus resistant varieties are promising, no single resistant line is a panacea for all localities. The performance of a resistant line is dependent on the strain of the virus to which it is exposed, the weather and soil conditions of the locality in which it is grown and the type of farming practice employed (Villalon 1981). An integrated approach to virus and vector management is still the best and most sustainable solution.

The goal of this research was to identify possible components that could be used to develop a sustainable approach for the management of TEV and other aphid-borne viruses of hot peppers in Jamaica. To address this goal, the following research objectives were formulated: 1) identify seasonal patterns in aphid flight activity and the species diversity in a hot pepper agroecosystem in St. Catherine parish, Jamaica, 2) describe the spatio-temporal distribution of TEV in a typical *C. chinense* field in Jamaica, 3) determine if incidence of TEV is correlated with flight activity of aphids, 4) examine the effect of timing of TEV infection on growth and yield in Scotch Bonnet and West Indian Red peppers to identify the length of period required for protecting plants from TEV to minimize economic loss, and 5) determine how spread of TEV in a Scotch Bonnet pepper field is affected by protecting seedlings and/or applying JMS Stylet-Oil® with the Solo® 423 knapsack mist blower.

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