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Virus Diseases of Faba Bean (*Vicia faba* L.) in Asia and Africa

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ABSTRACT

Faba bean (*Vicia faba* L.) is the fourth most important pulse crop in the world. Consumed as dry seeds, green vegetable, or as processed food, its products are a cheap source of high-quality protein in the human diet, while its dry seeds, green haulm and dry straw are used as animal feed. This crop is naturally infected by around 50 viruses worldwide, and the number continues to increase. Fortunately only few are of major economic importance in Asian and African countries. This paper will not review the literature on all of these viruses, as there are already a number of comprehensive reviews. Rather will it deal with those of major importance in Asian and African countries and focus on the research progress made over the last two decades. Surveys conducted over the last two decades by ICARDA scientists have shown that the viruses of major economic importance on faba bean in Asia and Africa are: *Faba bean necrotic yellows*, *Bean leafroll*, *Bean yellow mosaic*, *Broad bean mottle* and *Pea seed-borne mosaic viruses*. Other viruses such as *Alfalfa mosaic*, *Beet western yellows*, *Broad bean wilt*, *Broad bean true mosaic*, *Broad bean stain*, *Chickpea chlorotic dwarf*, *Cucumber mosaic*, *Milk vetch dwarf*, *Pea early browning*, *Pea enation mosaic* and *Soybean dwarf viruses* are important in specific locations in specific countries. Significant progress has been made at ICARDA in virus characterization and diagnosis over the last 15 years. The availability of highly sensitive serological methods and specific diagnostic reagents currently permit more accurate detection of viruses. These accomplishments have a positive impact on screening for virus diseases resistance.

Keywords: Algeria, China, control, detection, Egypt, Ethiopia, Iran, Iraq, Japan, Jordan, Lebanon, Libya, Morocco, Pakistan, Sudan, Syria, transmission, Tunisia, Turkey, Yemen

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INTRODUCTION

Faba bean (*Vicia faba* L.) also known as broad bean, horse bean, field bean or tick bean, and is one of the earliest domesticated crops. It is one of the major winter-sown legume crops in the world and has considerable importance as a low-cost food, rich in proteins (20-25% in seeds) and carbohydrates. It is the principal protein source for poor people in some Asian and African countries.

Faba bean's high adaptability is reflected in the diverse ecological regions implying that it is grown from the equator to almost the Arctic Circle, and from sea level to very high altitudes. The different names reflect the variation within the species, with broad bean meaning the large-seeded cultivars grown for human food, while horse bean and field bean refer to cultivars with smaller, harder seeds

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Invited Review

Table 1 Faba bean (dry), area harvested, production and yield in different major production regions in the world during 2002, 2003 and 2004.

Regions	Area harvested (1000 ha)			Yield per hectare (tonnes/ha)			Production (1000 tonnes)		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
WORLD	2659.14	2632.47	2584.29	1.59	1.66	1.65	4226.27	4359.74	4268.10
AFRICA	802.87	860.36	840.63	1.43	1.20	1.30	1150.15	1036.68	1089.40
Algeria	33.61	45.00	45.10	0.68	0.68	0.67	22.93	30.7	30.00
Egypt	127.19	106.07	101.03	3.15	3.18	3.27	400.91	336.84	330.49
Ethiopia	371.67	389.99	380.31	1.22	0.93	1.12	453.13	361.68	426.89
Libya	9.90	9.90	9.96	1.31	1.31	1.30	13.00	13.00	13.00
Morocco	154.10	151.40	150.00	0.58	0.68	0.67	88.78	103.06	100.00
Sudan	58.00	58.00	58.00	2.52	2.41	2.41	146.00	140.00	140.00
Tunisia	43.60	95.00	91.24	0.51	0.51	0.50	22.30	48.00	45.60
ASIA	1298.84	1172.6	1092.02	1.68	1.89	1.88	2179.09	2221.62	2056.53
China	1254.00	1130.00	1050.00	1.67	1.90	1.88	2100.00	2142.00	1976.00
Iraq	*	*	*	*	*	*	*	*	*
Japan	0.10	0.10	0.10	1.00	1.00	1.00	0.10	0.10	0.10
Jordan	*	*	0.34	*	*	2.12	*	*	0.71
Lebanon	*	0.37	0.28		2.16	1.07	*	0.8	0.30
Syria	15.50	15.50	15.49	2.02	2.02	2.02	31.3	31.3	31.30
Turkey	18.00	17.00	17.00	1.78	1.94	1.94	32.00	33	33.00
Yemen	3.28	3.24	2.23	1.35	1.34	1.92	4.44	4.35	4.28
EUROPE	247.35	277.98	282.43	2.60	2.42	2.82	644.21	671.74	796.68
SOUTH AMERICA	112.13	125.93	129.42	0.93	0.90	0.86	104.77	113.05	111.44
N&C AMERICA	40.95	40.60	41.79	0.98	0.98	1.11	40.05	39.65	46.55
AUSTRALIA	157.00	155.00	198.00	0.69	1.78	0.85	108.00	277.00	167.50

Source: FAOSTAT (2007)
* No data available

used for animal feed. Large-seeded cultivars are used as a vegetable, either green or dried, fresh or canned. It is a common breakfast food in the Middle East, Mediterranean region, China and Ethiopia (Bond *et al*. 1985). Roasted seeds are eaten like peanuts in India (Duke 1981). Straw from faba bean harvest fetches a premium in Egypt and Sudan and is considered as a cash crop (Bond *et al*. 1985). The straw is also used for brick making and as a fuel in parts of Sudan and Ethiopia. Faba bean also serves as a break crop in continuous cereal rotations, to improve soil productivity.

Faba bean originated in South Western Asia, probably in the "Fertile Crescent" around the rivers of Tigris and Euphrates. While common beans did not reach Europe before the Spaniards brought them back from America in the early 16^{th} century, the faba bean has been a part of eastern Mediterranean diet for some 8000 years. From this region the faba bean has spread around the world and is now, according to FAO, grown in 50 countries. The major geographical regions that contribute to faba bean production include (a) Far-East, (b) West Asia, (c) North Africa, (d) Nile Valley and Ethiopia, (e) Europe, and (f) Central and South America. The largest producer of faba bean is China (50% of total world production comes from China), followed by Ethiopia and Egypt (FAOSTAT, 2007). The Asian-African countries account for nearly 75% of total global production of faba bean (**Table 1**), and the average yield in this region is nearly the same as the world average.

The world's largest collections of faba bean germplasm are found at the International Centre for Agricultural Research in the Dry Areas (ICARDA) in Syria, and at the Vavilov Institute in Russia. According to the FAO, there are about 26,000 accessions of faba bean held in genebanks around the world.

Abiotic and biotic factors constitute major constraints that limit the realization of the full yield potential of faba bean and cause yield instability. Faba bean is known to be susceptible to over 100 different pathogens (Schmidt *et al*. 1980; Cockbain 1983; Bos *et al*. 1988; Nene *et al*. 1988; van Emden *et al*. 1988). Many of the diseases which affect faba bean, especially those induced by viruses, can also infect other food and forage legumes. Their relative importance, however, varies depending on the geographical location and the agroecological conditions of the crop production system. Worldwide, around 50 viruses have been reported to infect faba bean (Schmidt *et al*. 1980; Cockbain 1983; Bos *et al*. 1988; Makkouk *et al*. 2003c), 16 of which were reported to infect this crop in Asia and Africa. The surveys and inventory of virus diseases affecting faba bean in Asia and Africa are incomplete and every year one or more viruses are added to the list of viruses prevalent in these regions.

In this review, we have attempted to review the work done on the most economically important viruses that attack faba bean in the major production countries in Asia and Africa, their ecology and epidemiology, transmission, sensitive assays available for detection, and appropriate measures for their control.

VIRUSES REPORTED TO INFECT FABA BEAN IN AFRICA AND ASIA

Large-scale surveys carried out during the last two decades in Africa and Asia have identified 16 viruses that are the most economically important: 6 causing yellowing/stunting/necrosis and 10 causing mosaic/mottling symptoms (**Table 2**). These viruses are widespread in specific regions within specific countries.

Viruses causing yellowing, stunting and necrosis

Viruses causing yellowing/stunting are the most important virus diseases in many regions of the world, and were considered for many years (1960-1985) to be caused mainly by infection with *Bean leafroll virus* (BLRV, family *Luteoviridae*). Work conducted between 1985 and 2000 has clearly shown that there are a number of distinct viruses, in addition to BLRV, each of which can produce yellowing/stunting symptoms in faba bean in Asia and Africa. These viruses are *Beet western yellows virus* (BWYV, genus *Polerovirus*, family *Luteoviridae*), *Faba bean necrotic yellows virus* (FBNYV), *Milk vetch dwarf virus* (MDV) (genus *Nanovirus*, family *Nanoviridae*), *Chickpea chlorotic dwarf virus* (CpCDV, genus *Mastrevirus*, family *Geminiviridae*) and *Soybean dwarf virus* (SbDV, family *Luteoviridae*). The distribution of these viruses in Asia and Africa is presented in **Table 2**. FBNYV was found to be the most prevalent virus, followed by BLRV, BWYV and CpCDV. MDV, a virus related to FBNYV, has so far been found only in China and Japan.

The symptoms induced by the above six viruses are mostly leaf-rolling, yellowing and stunting of infected plants (**Fig. 1**). Old leaves of infected plants tend to be leathery. All these viruses are phloem-limited and transmit-

Table 2 Viruses reported to naturally infect faba bean in Africa and Asia.

Continent/ Country	Virus reported on faba bean** (reference number)															
	Viruses causing yellowing/stunting/necrosis symptoms						Viruses causing mosaic/ mottling/ enation symptoms									
	FBNYV	MDV	BLRV	BWYV	SbDV	CpCDV	PEMV	BYMV	PSbMV	BBWV	AlMV	CMV	BBMV	BBSV	BBTMV	PEBV
AFRICA																
Algeria	+^{C,P} (32)		+^{C} (5)	+^{C} (4)				+^{C} (4)	+^{L} (42)				+++ (71)			+++ (38)
Egypt	+++ (32, 43)		+++ (40, 43)			+++ (49)	+++ (40)	+++ (24, 40)	+++ (7, 42)	+++ (24, 43)	+++ (16, 43)	+++ (40, 51)	+++ (40)	+++ (7, 40)	+++ (7, 51)	
Ethiopia	+++ (13, 32)		+++ (13)	+++ (13)	+++ (13)	+++ (2)	+^{L} (63)	+++ (2, 13)	+++ (2, 42)	+^{C} (63)	+^{P} (1)	+^{P} (1)	+^{C} (13)	+++ (2)	+++ (2)	+^{P} (1)
Libya	+++ (19)							+++ (68)	+++ (42)		+++ (28)	+++ (28)				+++ (14)
Morocco	+++ (15)		+++ (22, 40)	+^{C} (23)			+++ (22)	+++ (22, 40)	+++ (22, 42)	+++ (41)	+++ (22)	+^{C} (17)	+++ (22, 40)	+++ (22, 42)	+++ (22)	+++ (22, 37)
Sudan	+++ (48)		+++ (40, 44)			+++ (44)	+++ (40)	+++ (40, 44)	+++ (40, 44)	+++ (41)	+++ (44, 58)	+++ (40, 52)	+++ (40, 54)	+++ (40)	+++ (40)	
Tunisia	+++ (55)		+++ (40, 55)	+++ (55)	+++ (56)		+++ (40)	+++ (40)	+++ (40, 42)	+++ (40, 41)		+++ (40, 55)	+++ (40, 55)	+++ (40, 55)	+++ (40)	
ASIA																
China		+++ (34)	+++ (67)	+++ (62)			+++ (69)	+++ (62, 67)	+++ (62)	+++ (66, 67)		+++ (62, 70)	+++ (21)	+++ (67)	+++ (21)	
Iran	+++ (50)		+++ (29, 50)	+$^{C, L}$ (50)	+$^{C, L}$ (50)	+$^{C, L}$ (50)	+++ (20)	+++ (30, 50)	+++ (29)	+++ (59)	+++ (29)	+++ (29)	+++ (49)	+^{L} (50)		
Iraq	+++ (18)		+++ (18)	+++ (18)	+++ (18)	+++ (18)		+++ (18)	+^{C} (31)	+++ (18)	+++ (18, 60)	+++ (18)	+++ (6)			
Japan		+++ (27, 61)			+^{S} (64)			+++ (26)	+++ (65)	+++ (26)		+++ (65)				
Jordan	+++ (11, 32)		+++ (35)	+++ (35)				+++ (10)	+^{L} (8)	+++ (9)	+++ (57)			+^{L} (8)		
Lebanon	+++ (32)		+++ (40)	+^{C} (25)				+++ (39, 57)	+++ (40)		+++ (57)			+++ (40)	+++ (57)	
Pakistan	+$^{C, L}$ (47)			+$^{C, L}$ (47)		+$^{C, L}$ (47)		+++ (3)	+$^{C, L}$ (47)		+^{C} (47)	+$^{C, L}$ (47)				
Syria	+++ (32)		+++ (40)	+++ (53)	+^{C} (45)	+^{C} (33)	+++ (40)	+++ (40)	+++ (40)	+++ (40, 41)	+++ (53)	+++ (40)	+++ (40)	+++ (40)	+++ (40)	
Turkey	+++ (32)		+^{C} (25)	+^{C} (25)		+^{C} (35)		+++ (36)	+^{L} (42)					+^{L} (12)		
Yemen	+++ (46)		+++ (46)			+++ (46)		+++ (46)	+++ (46)		+++ (46)					
Manner of transmission in faba bean*	Aph-P	Aph-P	Aph-P	Aph-P	Aph-P	Leaf-hoppers	Sa, Aph-P	Sa, Se, Aph-NP	Sa, Se, Aph-NP	Sa, Se, Aph-NP	Sa, Aph-NP	Sa, Se, Aph-NP	Sa, Se, Beetles	Sa, Se, Beetles	Sa, Se, Beetles	Sa, Se, Nematodes

* Sa= Sap, Se= seeds, Aph-NP= Aphids in non-persistent manner; Aph-P= Aphids in persistent manner.
** +++: reported on faba bean, +: reported in this country but not on faba bean, +^{c} reported on chickpea, +^{L}: reported on lentil, +*^{P}: reported on pea, +*^{S}: reported on soybean, FBNYV= *Faba bean necrotic yellows virus*, MDV= *Milk vetch dwarf virus*, BLRV= *Bean leaf roll virus*, BWYV= *Beet western yellows virus*, SbDV= *Soybean dwarf virus*, CpCDV= *Chickpea chlorotic dwarf virus,* PEMV= *Pea enation mosaic virus*, BYMV= *Bean yellow mosaic virus*, PSbMV= *Pea seed-borne mosaic virus,* BBWV= *Broad bean wilt virus,* AlMV= *Alfalfa mosaic virus,* CMV= *Cucumber mosaic virus*, BBMV= *Broad bean mottle virus*, BBSV= *Broad bean stain virus,* BBTMV= *Broad bean true mosaic virus,* PEBV= *Pea early browning virus*, the numbers between brackets are reference numbers as follows: (1) Abraham and Makkouk 2002; (2) Abraham *et al*. 2000; (3) Aftab *et al*. 1989; (4) Ait Yahia *et al*. 1997; (5) Ait Yahia *et al*. 1999; (6) Al-Ani and Al-Azzawi, 1987; (7) Allam *et al*. 1979; (8) Al-Mabrouk and Mansour 2000; (9) Al-Musa *et al*. 1986; (10) Al-Musa *et al*. 1987; (11) Al-Nsour *et al*. 1998; (12) Bayaa *et al*. 1998; (13) Bekele *et al*. 2005; (14) Bos *et al*. 1993; (15) El-Amri 1999a; (16) El-Attar *et al*. 1971; (17) El-Maataoui and El-Hassani 1984; (18) El-Muadhidi *et al*. 2001; (19) Fadel *et al*. 2005; (20) Farzadfar and Izadpanah 2001; (21) Ford *et al*. 1981; (22) Fortass and Bos 1991; (23) Fortass *et al*. 1997; (24) Gamal-Eldin *et al*. 1982; (25) Horn *et al*. 1995; (26) Inouye 1969; (27) Inouye *et al*. 1968; (28) Ismail and Hassan 1995; (29) Kaiser *et al*. 1968; (30) Kaiser 1973; (31) Kassim 1997; (32) Katul *et al*. 1993; (33) Kumari *et al*. 2004; (34) Kumari *et al*. 2007; (35) Kumari 2002; (36) Kurçman 1977; (37) Lockhart and Fischer 1976; (38) Mahir *et al*. 1992; (39) Makkouk *et al*. 1982; (40) Makkouk *et al*. 1988b; (41) Makkouk *et al*. 1990; (42) Makkouk *et al*. 1993b; (43) Makkouk *et al*. 1994; (44) Makkouk *et al*. 1995; (45) Makkouk *et al*. 1997; (46) Makkouk *et al*. 1998a; (47) Makkouk *et al*. 2001; (48) Makkouk *et al*. 2003a; (49) Makkouk *et al*. 2003b; (50) Makkouk *et al*. 2003d; (51) Mazyad *et al*. 1975; (52) Milles and Ahmed 1984; (53) Mouhanna *et al*. 1994; (54) Murant *et al*. 1974; (55) Najar *et al*. 2000; (56) Najar *et al*. 2003; (57) Nienhanus and Saad 1967; (58) Nour and Nour 1962; (59) Parvin and Izadpanah 1978; (60) Salama and El-Behadli 1979; (61) Sano *et al*. 1998; (62) Shiying *et al*. 2007; (63) Tadesse *et al*. 1999; (64) Tamada 1975; (65) Tanaka *et al*. 1973; (66) Xu *et al*. 1988; (67) Xu Zhiang *et al*. 1985; (68) Younis *et al*. 1992; (69) Yu 1979; (70) Yu *et al*. 2005; (70) Zagh and Ferault 1980.

ted by aphids in a persistent manner except CpCDV that is persistently transmitted by a leafhopper. They are neither transmitted mechanically nor by seeds. In some countries (e.g. Egypt, Syria and Tunisia) these viruses have, in some years, caused almost complete failure of the faba bean crop (Makkouk *et al*. 1994, 1998b; Najar *et al*. 2000).

Viruses causing mosaic/mottling

Faba bean viruses causing mosaic/mottling (**Fig. 1**) have been reported in 17 countries in Africa and Asia (**Table 2**). These viruses are: *Alfalfa mosaic virus* (AlMV, genus *Alfamovirus*, family *Bromoviridae*), *Bean yellow mosaic virus* (BYMV), *Pea seed-borne mosaic virus* (PSbMV) (genus *Potyvirus*, family *Potyviridae*), *Broad bean wilt virus* (BBWV, genus *Fabavirus*, family *Comoviridae*), *Broad bean mottle virus* (BBMV, genus *Bromovirus*, family *Bromoviridae*), *Broad bean stain virus* (BBSV), *Broad bean true mosaic virus* (BBTMV) (genus *Comovirus*, family *Comoviridae*), *Cucumber mosaic* virus (CMV, genus *Cucumovirus*, family *Bromoviridae*), *Pea enation mosaic virus-1* (PEMV-1, genus *Enamovirus*, family *Luteoviridae*) and *Pea early browning virus* (PEBV, genus *Tobravirus*).

High incidence of BYMV was detected in most African and Asian countries, followed by PSbMV, CMV and AlMV. PEBV so far has been reported only from North African countries (Lockhart and Fischer 1976; Mahir *et al*. 1992; Bos *et al*. 1993). This virus is transmitted by free-living Trichodorid nematodes, which tend to remain localized in soil but can subsist on many host species including weeds. Disease distribution in crops therefore is usually localized, and such infection spots may only gradually enlarge even in the presence of sensitive crops.

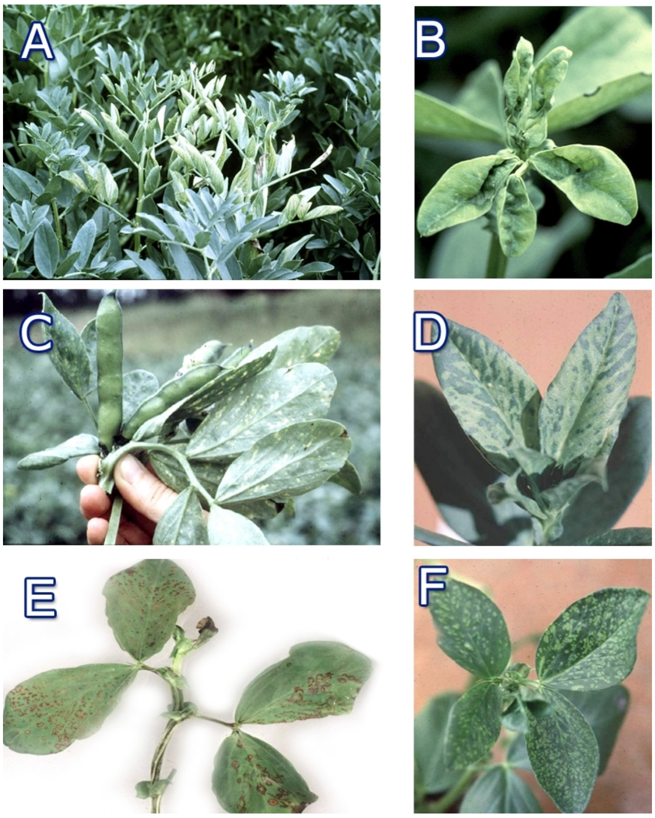

Fig. 1 (**A**) Chlorosis and leaf rolling symptoms in faba bean caused by *Bean leafroll virus*, (**B**) leaf cupping and chlorosis of growing point of faba bean plants caused by *Faba bean necrotic yellows virus*, (**C**) irregular chlorotic spots of pods and leaves of faba bean plant caused by *Pea enation mosaic virus*, (**D**) mosaic symptoms on faba bean leaves caused by *Bean yellow mosaic virus*, (**E**) necrotic symptoms on stem and leaves of faba bean plant caused by *Alfalfa mosaic virus*, (**F**) mottling with chlorotic spots on faba bean leaves caused by *Broad bean mottle virus*.

Other viruses

In addition to the viruses mentioned above, a few other viruses were reported to cause damage to faba bean in specific countries and in limited areas, such as *Tomato spotted wilt virus* (TSWV, genus *Tospovirus*, family *Bunyaviridae*) in China (Yu 1947); *Broad bean necrosis virus* (BBNV, genus *Pomovirus*) in Japan (Inouye and Nakasone 1980); and *Chickpea chlorotic stunt virus* (CCSV, genus *Polerovirus*, family *Luteoviridae*) in Ethiopia (Abraham *et al.* 2006). In addition, broad bean phyllody has been reported in Sudan (Jones *et al.* 1984), caused by a phytoplasma. Phyllody is characterized by the replacement of flower parts by green leaf-like structures.

ECONOMIC IMPORTANCE

Viral disease epidemics and associated crop losses not only depend on the incidence of infection, but also on symptom severity and growth stage at which infection occurs. The growth stage when plants become virus-infected and the proportion of plants infected in the crop are critical factors in determining the extent of yield losses. Losses are generally greatest when plants become infected at vulnerable early growth stages and incidence reaches high levels.

Viruses causing yellowing/stunting can have a marked effect on yield. During the growing season of 1991/1992, a severe FBNYV epidemic affected faba bean in Middle Egypt leading to yield losses of over 90% (Makkouk *et al.* 1994). In Iran, faba bean plants inoculated with BLRV during or after flowering yielded, respectively, 89 and 59% less than uninoculated plants; plants inoculated before flowering failed to produce any seed (Kaiser 1973).

In a field yield experiment in Syria, using 4 x 1.8 m plots and a plant density of 12 seeds/m², artificial infection with BYMV, BBMV and BBSV 11 weeks after sowing (pre-flowering) led to 81, 54 and 84% yield loss, respectively. Inoculation with the same viruses 15 weeks after sowing (flowering) and 20 weeks after sowing (pod setting) led to 56, 84 and 18%, and 39, 37 and 18% yield loss, respectively. The mixed infection of BBMV and BYMV caused almost complete failure of the crop when inoculation was made before or during flowering (Makkouk *et al.* 1988b). In Iran, faba bean plants inoculated with BYMV before, during or after flowering yielded, respectively, 44, 42 and 23% less than uninoculated plants (Kaiser 1973). Inoculation of faba bean variety "Syrian Local" with a Syrian isolate of BBWV 14 weeks (pre-flowering) and 16 weeks after sowing (flowering) led to 25.8 and 1.8% yield loss, respectively (Makkouk *et al.* 1990). Seed yield loss of faba bean inoculated with PSbMV at the flowering stage was 40.5% (Makkouk *et al.* 1993b). In Egypt, the number of pods/plant was 55.5, 11.25 and 20.33% less than that of healthy plants when faba bean plants were inoculated with BYMV, BBTMV and BBSV, respectively (Allam *et al.* 1979).

BYMV is worldwide in distribution, infects many wild and cultivated legumes and is the most common cause of mosaic symptoms in faba bean. Field incidence with BYMV can vary greatly among locations. High incidence, up to 100%, was observed in some regions of Egypt, Sudan and the coastal areas of Syria. These locations are known for their relatively warm winters which favor increased aphid population and movement. Studies conducted in the region suggested that potential yield loss due to BYMV infection could vary from 15 to 45% depending on the time of infection (Kaiser 1973; Makkouk *et al.* 1988b)

Several viruses impair the quality of faba bean seeds thereby rendering them less attractive to consumers. For example, PSbMV induces necrotic rings and line patterns and malformation in faba bean seed coats (Makkouk *et al.* 1993b). Likewise, BBSV infection leads to undesirable staining of faba bean seed coat, which renders the seeds useless for canning (Bos *et al.* 1988) (**Fig. 2**). Kaiser (1973) found that pods of faba beans, infected with BYMV, occasionally developed necrotic ring spotting and discolored seeds.

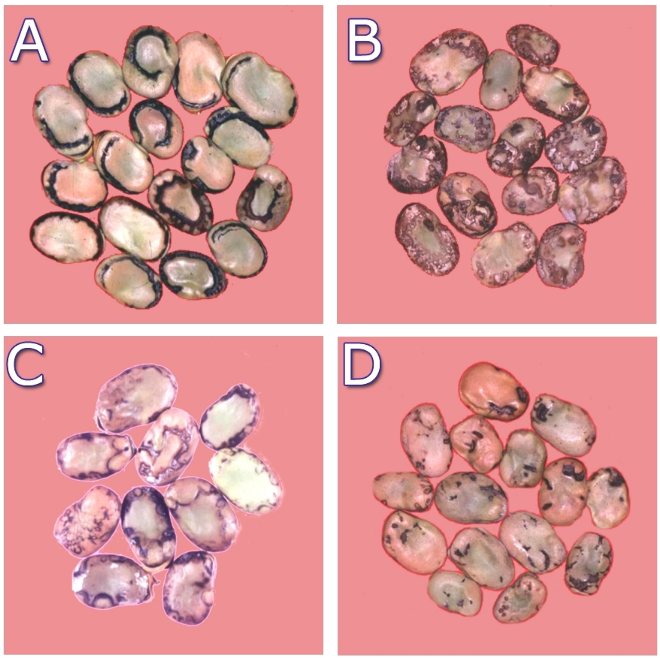

Fig. 2 Seed-coat symptoms of faba bean seeds from plants infected with *Broad bean stain virus* (**A**), *Broad bean mottle virus* (**B**), *Pea seed-borne mosaic virus* (**C**) and *Bean yellow mosaic virus* (**D**).

VIRUS TRANSMISSION

Virus spread by vectors

Insects are particularly important vectors because they are usually highly mobile and may travel long distances. All faba bean viruses reported in Asia and Africa are known to be spread by vectors, with the majority (15 viruses) being transmitted by insects. One of the insect-borne viruses is transmitted by leafhoppers (CpCDV), three by beetles (BBSV, BBMV and BBTMV) and 11 by aphids. Six viruses are transmitted by aphids in a persistent manner and five viruses in the non-persistent manner. Only PEBV is transmitted by nematodes (**Table 2**). Spread of the persistent viruses (e.g. FBNYV, BLRV) can be over a long distance, with the possibility that an individual insect can transmit the virus to many plants. The beetle-transmitted viruses can persist in the vector for days or weeks. **Table 3** summarizes the most important vectors reported to transmit faba bean viruses worldwide.

As is the case of many diseases, the progress curve for virus-infected plants is usually sigmoid. The extent and rate of increase, however, depend on the distance from the inoculum source and the wind direction. A typical distance of spread from the source for non-persistent viruses, such as BYMV, is 100 m upwind and 250 m downwind, and the virus movement from the source to the crop is according to a gradient. On the other hand, persistent transmission by aphids, such as BLRV, is over a long distance. Consequently, the source of infection is difficult to trace, and virus movement to the crop is usually at random and not according to a gradient. In areas where alfalfa is grown, infection with BLRV is usually high because most alfalfa varieties are susceptible to BLRV and often do not show symptoms.

Our observations in faba bean fields in Egypt, Syria and Tunisia indicated that aphid vectors, transmit FBNYV to a few plants in the field early in the season (September-October), often close to the field border. When weather conditions favor aphid population build-up and activity, these single-plant foci increase to patches of 50-100 infected plants within 2-3 weeks. This type of spread suggests that faba bean is a favorable host for both the virus and its vectors and that the spread of FBNYV mainly depends on colonizing aphid species within the crop in a fashion typical of persistently transmitted viruses. In addition, environmental conditions play an important role in the spread of FBNYV. High incidence has been observed in regions characterized by mild winters such as Middle Egypt (Beni Suef and Minia governorates), the Jordan Valley and the coastal areas of Syria and Turkey. In all these regions winter temperatures rarely fall below 5ºC permitting the aphid vector to overwinter parthenogenetically. When temperatures rise the aphids become active, multiply and spread the virus.

Seeds infected with seed-borne viruses are dispersed at random during planting. The spread of virus by insect vectors from these foci can be rapid. Kaiser *et al*. (1968) reported that in Iran, the incidence of BYMV in field trials of faba bean increased from 0.2% seed-borne infections to 85% disease incidence in three months. Seed certification for seed-borne viruses is mainly to limit economic loss rather than to eradicate the pathogen. Tolerance levels, i.e., levels of seed-borne virus that do not lead to economic losses, may be high in regions where viruses have no efficient vector or the vector's population density is low. For example, when faba bean seeds infected with BBSV were multiplied for several years in Scotland, where the beetle vectors *Apion vorax* and *Sitona lineatus* were either absent or rare, virus infection of the seeds declined from year to year (Jones 1980).

Seed transmission

Virus transmission via seed is of dual importance. Virus-infected seeds act both as sources of inoculum and as vehicles of virus dissemination. Out of the 16 viruses reported to infect faba bean in Asia and Africa, eight are seed-transmitted (**Table 4**). Rates of seed transmission greatly depend on the virus, virus strain, host species and host cultivar. Viruses that infect the embryo may also be transmitted in pollen to seeds on virus-free mother plants. Infection of faba bean after flowering rarely leads to infection of the seed. Commonly, infected seeds appear to be normal-looking except in a few cases where visible symptoms are observed, as in the case of BBSV. Thus, visual inspection of seeds cannot be used to eliminate seed-borne viruses. BBSV was thought to have been imported into England with seed from Morocco (Gibbs *et al*. 1968) and, indeed, was later confirmed to be widespread in Morocco (Fischer and Lockhart 1976).

Surveys conducted in the region, have revealed the occurrence of a few viruses with wide distribution and often high incidence in faba bean crops (**Table 2**). Most are potentially of great significance for crop improvement programs because of their transmission in seed. Serious consideration must be given to those viruses in international breeding programs and in systems of commercial seed production. For example, BBMV is known to occur in Syria, Egypt, Sudan, Tunisia, Morocco (Makkouk *et al*. 1988b) and Algeria (Zagh and Ferault 1980). A detailed survey in Morocco revealed its occurrence in 56% of the fields inspected, with a maximum incidence of 33% recorded in one field (Fortass and Bos 1991). The virus is beetle- and seed-transmitted and may cause serious losses.

VIRUS DETECTION

Accurate diagnosis combined with sensitive, rapid and early detection of viral diseases is critical for effective management of faba bean-based cropping systems. Appropriate control procedures can only be applied effectively if the disease is correctly identified and distribution in an area is known. The last three decades have witnessed significant developments in the sensitivity of the methods used to detect faba bean viruses.

Immunological (protein-based) methods

The development of enzyme-linked immunosorbent assay (ELISA) for plant virus detection (Clark and Adams 1977) was a major step forward and replaced earlier serological methods such as gel diffusion, especially for large-scale testing. This was enhanced further with the development of monoclonal antibody technology and its application to a large number of faba bean viruses. Specific reagents (monoclonal and/or polyclonal antibodies) have been developed for most viruses affecting faba bean (**Table 5**), and their utilization in a variety of ELISA tests has made faba bean virus diagnosis simple and fast. Since then a number of ELISA variants were developed which further improved the sensitivity of faba bean virus testing. Sensitivity of detection was increased further by using chemiluminescent substrates (e.g. BYMV in faba bean) (Makkouk *et al*. 1993a). In many laborratories in developing countries, facilities for sophisticated tests are lacking. Accordingly, the simpler the procedure the more widely it can be used. For this reason Tissue-blot immunoassay (TBIA) was developed to identify most faba bean viruses (Makkouk and Kumari 1996). TBIA does not require expensive equipment, is simple to conduct, inexpensive, sensitive and can be completed within 3-4 hours. In addition, it is fairly easy to differentiate infected from healthy plants. TBIA is a useful test to detect all faba bean viruses reported and it is especially recommended for virus surveys (Najar *et al*. 2000; El-Muadhidi *et al*. 2001; Makkouk *et al*. 2001, 2003d) and for evaluating virus-host interactions (Makkouk *et al*. 2002; Kumari and Makkouk 2003) (**Fig. 3**).

Molecular (nucleic acid-based) methods

Nucleic acid hybridization has been used successfully for the detection of many viruses (Hammond and Hammond

Table 3 Major insect and nematode vectors reported to transmit faba bean viruses.

Vector	Virus transmitted	Reference
Aphids		
Acyrthosiphon pisum Harris	AlMV, BWYV, MDV	Cockbain 1983
	BBWV	Makkouk *et al*. 1990
	BLRV	Cockbain 1983; Johnstone *et al*. 1984; Skaf and Makkouk, 1988; Ait Yahia *et al*. 1999
	BYMV	Cockbain 1983; Skaf and Makkouk, 1988
	CMV	Edwardson and Christie 1986
	FBNYV	Katul *et al*. 1993; Franz *et al*. 1998; Al-Nsour *et al*. 1998; Al-Amri 1999b
	PEMV	Cockbain 1983; Cockbain *et al*. 1986; Hagedorn 1996; Kumari *et al*. 2001b
	PSbMV	Makkouk *et al*. 1993b
	SbDV	Makkouk *et al*. 1997; Damsteegt *et al*. 1999; Terauchi *et al*. 2003
Aphis fabae Scopoli	AlMV	Cockbain 1983
	BBWV	Makkouk *et al*. 1990
	BLRV	Kaiser 1973; Johnstone *et al*. 1984; Skaf and Makkouk, 1988; Ait Yahia *et al*. 1999
	BYMV	Cockbain 1983; Skaf and Makkouk, 1988
	CMV	Edwardson and Christie 1986
	FBNYV	Katul *et al*. 1993; Al-Amri 1999b
	PSbMV	Makkouk *et al*. 1993b
Aphis craccivora Koch.	AlMV, PEMV	Cockbain 1983
	BBWV	Makkouk *et al*. 1990
	BLRV	Cockbain 1983; Johnstone *et al*. 1984; Skaf and Makkouk, 1988; Ait Yahia *et al*. 1999
	BWYV	Boswell and Gibbs 1983
	BYMV	Cockbain 1983; Skaf and Makkouk, 1988
	CMV	Edwardson and Christie 1986
	FBNYV	Katul *et al*. 1993; Franz *et al*. 1998; ; Al-Nsour *et al*. 1998; Al-Amri 1999b
	MDV	Cockbain 1983; Sano *et al*. 1998
	PSbMV	Makkouk *et al*. 1993b
Myzus persicae (Sulz.)	AlMV	Edwardson and Christie 1986; Wang *et al*. 2006
	BBWV	Makkouk *et al*. 1990
	BLRV	Cockbain 1983; Johnstone *et al*. 1984
	BYMV, BWYV, MDV	Cockbain 1983
	CMV	Edwardson and Christie 1986
	PEMV	Cockbain *et al*. 1986; Edwardson and Christie 1986; Hagedorn 1996; Kumari *et al*. 2001b
	PSbMV	Makkouk *et al*. 1993b
Macrosiphum euphorbiae (Thomas)	AlMV, BYMV, CMV	Edwardson and Christie 1986
	BBWV	Stubbs 1960
	BLRV	Cockbain 1983; Johnstone *et al*. 1984
	PEMV	Edwardson and Christie 1986; Hagedorn 1996
Rhopalosiphum padi L.	CMV, PEMV	Edwardson and Christie 1986
	PSbMV	Makkouk *et al*. 1993b
Aulacorthum solani (Kaltenbach.)	AlMV, CMV, PEMV	Edwardson and Christie 1986
	BWYV	Cockbain 1983
	SbDV	Tamada 1975; Cockbain 1983; Honda 2001; Terauchi *et al*. 2003
Beetles		
Acalymma trivittata Mannerheim	BBMV	Walters and Surin 1973
Apion aestivum Germ.	BBSV	Cockbain *et al*. 1975
Apion aethiops Hbst.	BBSV, BBTMV	Cockbain *et al*. 1975
Apion arrogans Wencher	BBMV, BBSV	Makkouk and Kumari 1989, 1995a
Apion radiolus Kirby	BBMV	Fortass and Diallo 1993
Apion vorax Hbst.	BBMV	Cockbain 1983
	BBSV, BBTMV	Cockbain *et al*. 1975
Colaspis flavida Say	BBMV	Walters and Surin 1973
Diabrotica undecimpunctata Mannerheim	BBMV	Walters and Surin 1973
Hypera variabilis Herbst	BBMV	Fortass and Diallo 1993
Pachytychius strumarius Gyll	BBMV	Fortass and Diallo 1993
Sitina lineatus var. *viridifrons* Motsch	BBMV	Borges and Louro 1974
Sitona crinita Herbst	BBSV	Makkouk and Kumari 1995a
Sitona limosa Rossi	BBMV, BBSV	Makkouk and Kumari 1995a
Sitona lineatus L.	BBMV, BBSV	Makkouk and Kumari 1995a
	BBMV	Fortass and Diallo 1993
	BBSV, BBTMV	Cockbain *et al*. 1975
Spodoptera exigua Hübner	BBMV	Ahmed and Eisa 1999
Smicronyx cyaneus Gyll	BBMV	Fortass and Diallo 1993
Leafhoppers		
Orosius orientalis (Matsumura)	CpCDV	Horn *et al*. 1993
Orosius albicinctus Distant	CpCDV	Kumari *et al*. 2004
Nematodes		
Trichodorus primitivus, T. viruliferous, Paratrichodorus anemones, P. pachydermus, P. teres	PEBV	Boulton 1996

Table 4 Viruses that can be transmitted via faba bean seeds.

Virus	Reported seed transmission rate (%)	Reference
BYMV	0.1-15	Kaiser 1973; Murant *et al*. 1974; Sasaya *et al*. 1993; Latham and Jones 2001a
BBMV	1-2	Makkouk *et al*. 1988a; Murant *et al*. 1974; Fortass and Bos 1992
BBSV	1-10	Gibbs and Smith 1970; Jones 1978; Makkouk *et al*. 1987a; Allam *et al*. 1979
BBTMV	1-17	Blaszczak 1970; Cockbain *et al*. 1976; Jones 1978; Allam *et al*. 1979
BBWV	0.4-0.6	Putz and Kuszala, 1973; Makkouk *et al*. 1990
CMV	0.1	Latham and Jones 2001a
PEBV	1-10	Fiedorow 1983
PSbMV	0.2-2	Makkouk *et al*. 1993b; Musil 1980; Latham and Jones 2001b

Table 5 Antibodies available for the detection of faba bean viruses

Virus	Antibodies type	Reference
AlMV	Polyclonal	Makkouk *et al*. 1987b
	Monoclonal	Hajimorad *et al*. 1990; Gallo and Matisova 1993
BBMV	Polyclonal	Makkouk *et al*. 1987b, 1988a; Fortass and Bos 1992
BBSV	Polyclonal	Jones and Barker 1976; Makkouk *et al*. 1987a
	Monoclonal	Subr *et al*. 1994
BBTMV	Polyclonal	Jones and Barker 1976; Kumari and Makkouk (ICARDA, unpublished data)
BBWV	Polyclonal	Uyemoto and Provvidenti 1974; Xu *et al*. 1988; Makkouk *et al*. 1990; Qi *et al*. 2002
	Monoclonal	Qing *et al*. 2000
BLRV	Polyclonal	D'Arcy *et al*. 1989; Ashby and Huttinga 1979; Ait Yahia *et al*. 1999; Kumari and Makkouk (ICARDA, unpublished data)
	Monoclonal	Katul 1992
BWYV	Polyclonal	Govier 1985; Kumari and Makkouk (ICARDA, unpublished data)
	Monoclonal	Rabenstein *et al*. 1984; D'Arcy *et al*. 1989; Herrbach *et al*. 1991; Ellis and Wieczorek 1992
BYMV	Polyclonal	Makkouk *et al*. 1988c; Subr and Matisova 1999
	Monoclonal	Scott *et al*. 1989; Jordan and Hammond 1991; Werkmeister and Shukla 1991; Subr and Matisova 1999
CMV	Polyclonal	Kumari and Makkouk (ICARDA, unpublished data)
	Monoclonal	Haase *et al*. 1989; Porta *et al*. 1989; Wahyuni *et al*. 1992; Hayes *et al*. 1994; Hsu *et al*. 2000; Yu *et al*. 2005
CpCDV	Polyclonal	Horn *et al*. 1993; Kumari *et al*. 2006
FBNYV	Polyclonal	Katul *et al*. 1993; Kumari *et al*. 2001a
	Monoclonal	Franz *et al*. 1996
PEBV	Polyclonal	Makkouk and Kumari 1998
PEMV	Polyclonal	Gibbs *et al*. 1966; Izadpanah and Shepherd 1966; Mahmood and Peters 1973; Kumari *et al*. 2001b
PSbMV	Polyclonal	Makkouk *et al*. 1993b
	Monoclonal	Jordan and Hammond 1991
SbDV	Polyclonal	Kojima and Tamada 1976; Makkouk *et al*. 1997; Damsteegt *et al*. 1999
	Monoclonal	D'Arcy *et al*. 1989; Mikoshiba *et al*. 1996; Damsteegt *et al*. 1999

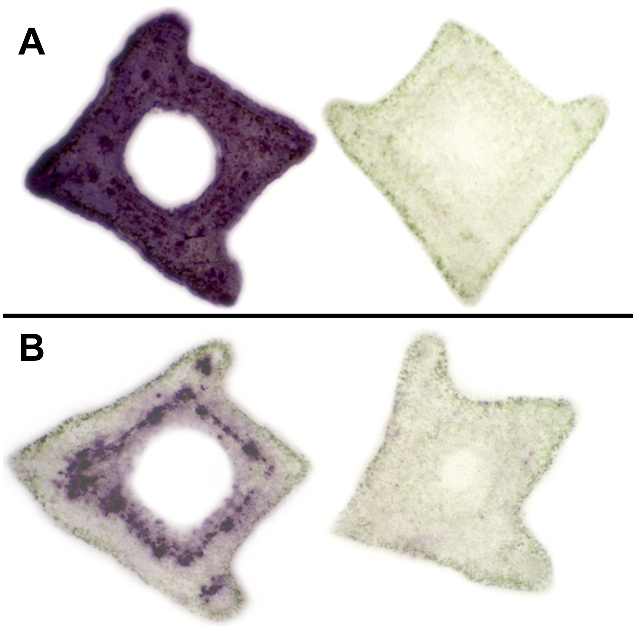

Fig. 3 Detection of *Bean yellow mosaic virus* (**A**) and *Faba bean necrotic yellows virus* (**B**) by tissue blot immunoassay (TBIA) in infected faba bean stem blot (left) as compared to a healthy plant (right).

1985; Pesic and Hiruki 1988; Martin and D'Arcy 1990; Herrbach *et al*. 1991). Cloning of plant viral nucleic acids and the development of nonradioactive detection methods have increased the utility of nucleic acid hybridization for virus detection. The development of polymerase chain reaction (PCR) has greatly improved the sensitivity and utility of hybridization and other nucleic acid based assays. Immunocapture PCR is a very sensitive detection method that combines the advantages of serology and PCR (Phan *et al*. 1997; Shamloul *et al*. 1999; Yu *et al*. 2005). Faba bean viruses for which PCR detection assays have been reported are listed in **Table 6**. The technique has been adapted to the detection of both DNA and RNA viruses (with either single- or double-stranded genomes (**Table 6**). In addition to faba bean virus detection in infected plants, PCR has also been adapted for the detection of viruses in their vectors (van der Wilk *et al*. 1994; Shamloul *et al*. 1999).

VIRUS DISEASE CONTROL

As there is no direct practical way of curing crops from virus infection, all current control strategies emphasize measures that prevent or reduce infection. Control measures can be classified into (i) those that control the virus, (ii) those that are directed towards avoidance of vectors or reducing their incidence, and (iii) integrated approaches, which combine all possible control components in such a way that they complement each other and can be applied at farm level as one control package.

Methods directed to control the virus

Targeting sources of infection

Since around 50% of viruses affecting faba bean (Bos *et al*. 1988) are seed-borne (**Table 4**), it is always recommended to use virus-free seed for planting, especially when the virus is also transmitted by active vectors. The removal of symp-

Table 6 Primers available for detection of faba bean viruses by PCR.

Virus	Genome	Sequence of primer pairs 5′ – 3′	Amplified fragment (bp)	Reference
AlMV	ssRNA	CGTCAGCTTTCGTCGAACA GCCGTCGCGCATGGTAAT	288	Braiana *et al*. 1994
BBWV-II	ssRNA	AACTGAAACTCGCCATCTCC ATAGTTTCCGTGGCTGATTC	444	Uga 2005
BLRV	ssRNA	TCCAGCAATCTTGGCATCTC GAAGATCAAGCCAGGTTCA	391	Ortiz *et al*. 2005
		AAAGAGGTTCTACAGGCCAC GATCAAGTTCCTCGCAGAAC	440	Kumari *et al*. 2006
BWYV	ssRNA	ATGAATACGGTCGTGGGTAC GATAGTTGAGGAAAGGGAGTTG	429	Kumari *et al*. 2006
		GTCTACCTATTTGG ATGGTCGCTAGAGG	950	Fortass *et al*. 1997
		ATGCAATTTCTCGCTCACGCAAACA TCATACAAACATTTCGGTGATGAC	750	Hauser *et al*. 2000
BYMV	ssRNA	GGTTTGGCYAGRTATGCTTTTG GAGAATTTAAAGACGGATA	240	Braiana *et al*. 1994
		CAGTTTATTATGCAGCGG GTTATCATCAATCTTCCTGC	644	Uga 2005
CMV	ssRNA	CGAGTCATGGACAAATCTGAATCAA AGYCCTTCCGAAGAAAYCTAGGAGA	879-881	Uga 2005
		GCCGTAAGCTGGATGGACAA TATGATAAGAAGCTTGTTTCGCG	482-501	Wylie *et al*. 1993
		GGCGAATTCGAGCTCGCCGTAAGCTGGATGGAC CTCGAATTCGGATCCGCTTCTCCGCGAG	920	Abdullahi *et al*. 2001
		TATGATAAGAAGCTTGTTTCGCGCA TTTTAGCCGTAAGCTGGATGGACAACCC	500	Braiana *et al*. 1994
		GTTTATTTACAAGAGCGTACGG GGTTCGAAAGTATAACCGGG	650	Sclavounos *et al*. 2006
		AGTGACTTCAGGCAGT GCTTGTTTCGCGCATTCA	436	Davino *et al*. 2005
FBNYV	ssDNA	TACAGCTGTCTTTGCTTCCT CGCGGAGTAATTAAATCAAAT	666	Kumari *et al*., 2007
		ACATCGAAGAGCAGTATCTGG ACGTTGTCGTTTTCACCTTGG	487	Shamloul *et al*. 1999
		TTTCCCGCTTCGCTAAGTTTAA ACACCCTCCTTGGAACTGGTATAA	931	Shamloul *et al*. 1999
		CATTTCGGATGAACATCTGGG ATGAACTATCAAGCGATGGAG	1002	Shamloul *et al*. 1999
MDV	ssDNA	TCTCTCTATAAAAGCTGTTA AAATGATTGTTGATTTCATT	608	Kumari *et al*. 2007
		TAATGTAATGAAGAACACTA CAGTTCAATATACACTCTAT	997	Sano *et al*. 1998
		CATAGATGGACCTTGGGAG GCGGTTTCTTTCTTCTGGC	1002	Sano *et al*. 1998
PEBV	ssRNA	GGACCCTAATAGGAGGTGCCC CATTACAAACAGTTAAATGAACACCC	886	Vellios *et al*. 2002
PEMV	ssRNA	GAGGGTGCCACCACGACTAC TGAAAATTAGATAAGGAAAACCCAAG	114	Skaf *et al*. 2000
PSbMV	ssRNA	GATTTCTTCGTTGTTTGTT CTTGAGTGCTGGCGTGGTT	494	Phan *et al*. 1997
		GCTCTAGACTCGAGGGGAARTCRAAAGCTAAAAC GTCCTAGAGCTTGCGCAATWGGATTGTA	654	Phan *et al*. 1997
		TACATCTAGATTACATGGCTCTCATTCCGAGAAG CAAACGCGTGACGAAACCAAGGATGATGAAAG	888	Roberts *et al*. 2003
		TACATCTAGATTACATGGCTCTCATTCCGAGAAG GGTTGCTCGAGGGTGATGAGACCAAAGATGAAAG	958	Roberts *et al*. 2003
SbDV	ssRNA	CTGCTTCTGGTGATTACACTGCCG CGCTTTCATTTAACGYCATCAAAGGG	110	Phibbs *et al*. 2004
		AGGCCAAGGCGGCTAAGAG AAGTTGCCTGGCTGCAGGAG	440	Kumari *et al*. 2006
		GGAACTATCACTTTCGGGCCGTCT GGCATGATACCAGTGAAGACC	281	Harrison *et al*. 2005
		GCGGTTAGCAATGTCGCAATAC CATAAGCGATGGAACCTGACGA	372	Wang *et al*. 2006

tomatic plants, known as roguing, is a phytosanitary control measure that is widely used to remove sources of virus infection from affected fields. When practiced 2-3 times early during the growing season, roguing of FBNYV-infected crops was effective in minimizing the incidence of primary infection foci inside small faba bean fields in Egypt (Makkouk *et al*. 1998b). Overwintering or oversummering crops which could play the role of sources of infection should be avoided through spatial isolation. Such methods are more effective with non-persistent viruses than with persistent viruses. With non-persistent viruses, such as BYMV, a few hundred meters may suffice, or better 1000 m. Whereas,

Table 7 Faba bean genotypes reported to be resistant to virus diseases

Genotypes/Cultivars	Resistant to	Reference
2N138	BYMV	Ghad and Bernier 1984
BPL 5247 through to BPL 5255	BYMV	Makkouk and Kumari 1995b
BPL 5271 through to BPL 5285	BLRV	Makkouk *et al*. 2002
G-2/78	BYMV and PEMV	Schmidt *et al*. 1989
B-1/5	BYMV	Schmidt *et al*. 1989
B-1/33	PEMV	Schmidt *et al*. 1989
cvs. Fiord, Barkool, Icarus, Ascot	BYMV	McKirdy *et al*. 2000
cvs. Ascot, Fiord, Icarus	CMV	Latham *et al*. 2001
cvs. Fiord, Barkool, Icarus, Ascot	AlMV	Latham and Jones 2001b
Several genotypes	BBTMV	Mazyad *et al*. 1975

persistently transmitted viruses such as BLRV can be carried from lucerne fields over a long distance, making it difficult to avoid the source of infection.

Selection and breeding for virus resistance

Host resistance, when available is the most acceptable component of virus control because it is environment-friendly, practical and economically feasible for resource-poor farmers. Several workers have identified faba bean lines resistant to viruses (**Table 7**). Resistance to BYMV in faba bean was found to be controlled by two recessive complementary genes, *bym-1* and *bym-2* (Rohloff and Stupnagel 1984; Schmidt *et al*. 1985). Combined resistance to BYMV, *Clover yellow vein virus* (genus *Potyvirus*, family *Potyviridae*) and *Aphis fabae* (Schmidt *et al*. 1986) and to BYMV and PEMV (Schmidt *et al*. 1989) was identified in faba bean. However, host resistance for a number of economically important viral diseases of faba bean persistently transmitted by insects (e.g. FBNYV) has not yet been identified, and control of such diseases is dependent on the availability of other control options. With advances in the development of regeneration systems of faba bean, there is good potential for producing transgenic faba bean through genetic engineering to reduce losses due to luteoviruses, FBNYV or CpCDV. At present, a number of legumes are being transformed with viral genes (coat protein, replicase, etc.) by different groups to produce virus-resistant legumes. There are no cultivars available in the market for immediate use by farmers, but genetic transformation could be a useful alternative, especially where resistance genes are not found in the existing genotypes of legume crops, including faba bean.

Methods directed towards avoidance of vectors or reducing their incidence

Cultural practices

Cultural practices, such as planting date, high seeding rate and narrow row spacing, use of early maturing cultivars, and planting of with borders non hosts have proved to be effective in reducing virus incidence in faba bean crops. Manipulation of planting date to avoid exposing young plants to peak vector populations at the most vulnerable early growth stage is a standard virus control measure that is widely recommended for use with crop legumes (Thresh 2003). For example, in Syria and Egypt, faba bean crops planted early in September are often severely attacked, leading to 100% FBNYV infection (Makkouk *et al*. 1998b). In such circumstances, farmers plough the crop under and replant with another crop. Delaying sowing until October or November often resulted in lower virus infection, and consequently reduced crop losses due to fewer viruliferous aphid vectors arriving from neighboring virus sources. The exact date of sowing in any region, however, should be based on a forecasting system, which is dependent on monitoring the population of viruliferous aphids migrating from sources of infection to the faba bean crop.

Virus vector control (chemical control)

Application of insecticides helps to decrease the spread of some faba bean viruses vectored by insects. However, it is often ineffective because success depends on the mechanism of transmission of the virus and the mode of action of the pesticide selected. In general, success in reducing virus spread by chemical control of vectors is considerably greater with persistently than with non-persistently transmitted viruses. This is mostly because incoming viruliferous vectors carrying non-persistently transmitted viruses tend not to be killed fast enough to prevent probing and subsequent virus inoculation to sprayed plants. In a three-year trial covering large areas of faba bean in East Germany (DDR), insecticide application reduced the average infection by BYMV, PEMV and BLRV by 63, 72 and 71%, respectively (Schmidt *et al*. 1977). Oil sprays can be used instead, but are rarely cost effective because of the repeated applications required. The most effective types of insecticides for control of non-persistently transmitted aphid-borne viruses are the newer generation of synthetic pyrethroids (Loebenstein and Raccah 1980), because of their rapid knockdown and greater anti-feedant activity. Field experiments at ICARDA showed that the use of a systemic seed treatment insecticide Imidacloprid (Gaucho®) at a rate of 0.5-2.8 g a.i./kg seed gave significant protection of faba bean plots (2 x 1.5 m plots and a plant density of 25 seeds/m²), against FBNYV and BLRV infection, which lasted for two months after sowing. Incidence of FBNYV was reduced from 28% in untreated plots to 2% and 1% in plots treated with 1.4 and 2.8 g a.i./kg of seed, respectively, and the yield loss from 37% in untreated plots to 0% in plots treated either with 1.4 or 2.8 g a.i./kg of seed (Makkouk and Kumari 2001).

Breeding for vector resistance

Genetic resistance to the vector was advocated some decades ago, but not much progress has been made in this area. The availability of cheap and effective chemicals in the 1950s and 1960s reduced interest in investigations of vector resistance in plants. However, the development of insect resistance to pesticides and the public awareness of environmental hazards resulting from their heavy use renewed the interest in breeding for insect resistance in plants (Jones 1987; Ajirlo *et al*. 2006). Resistance of faba bean to the aphids *A. craccivora*, *A. fabae* and *Acyrthosiphon pisum* has been reported (Clement *et al*. 1994). In Egypt, over 1000 lines were screened for aphid resistance, and 36 were classified as resistant. The faba bean line BPL 23 was resistant to both *A. craccivora* and *A. fabae* (Bond *et al*. 1994). Whether or not the use of such cultivars could lead to reduced spread of faba bean viruses in the field awaits further evaluation.

Integrated approach

Each of the control measures mentioned provides only partial control, but combining genetic resistance, cultural practices, and chemical sprays is expected to lead to improved disease control. The use of host resistance, whether obtained by classical breeding or genetic engineering, and one or two well-timed sprays coupled with optimal planting date and early roguing of virus-infected plants could offer reasonable and economic control, and stabilize faba bean production. However, selecting the best mix of measures for each virus-crop combination and production system requires knowledge of the epidemiology of the causal virus, and the mode of action and effectiveness of each individual control measure. Each strategy needs to be affordable by farmers and fulfill the requirements of being environmentally and socially responsible. It must also be compatible with control measures already in use against other pests and pathogens. An example of an integrated approach being widely used for practical virus control in a faba bea crop is the one for FBNYV in Egypt. This strategy combines planting late in the growing season, use of high seeding rate, application of one or two systemic insecticide sprays (well timed during the early stages of the crop development), and rouging of infected plants early in the growing season. Its use has led to significant reduction of FBNYV infection and more profitable faba bean production in Egypt (Makkouk *et al.* 2003c).

CONCLUDING REMARKS

The most serious viruses which affect faba bean production are FBNYV and luteoviruses (e.g. BLRV). More work is needed on the epidemiology of these viruses in faba bean to provide information which will assist with the development of improved control strategies. These is also need to determine which aphids species are important in spreading faba bean viruses and understand the conditions which favor colonization of faba bean by aphids. In addition, other aphid species may be important in virus transmission without actually colonizing faba bean, which many occur during probing activity as they migrate over the crop (e.g. cereal aphids such as *Rhopalosiphum padi*). Similarly, aphids colonizing weeds within faba bean crops could also act as vectors.

Many countries in Africa and Asia do not have well-equipped virus research laboratories which permit workers to effectively implement plant quarantine controls. Therefore provision of diagnostic tools and training is essential to expedite progress in many countries.

Controlling FBNYV and luteoviruses which are well adapted to a faba bean crop is not an easy task. These viruses are disseminated by aphids and most currently grown cultivars are susceptible. Application of insecticides helps to reduce spread of theses viruses, but this practice is only effective when applied at regular intervals, a process which increases the cost of production. In addition, environmental concerns impose limitations on pesticide use. Under these circumstances genetic resistance seems to be the most appropriate approach even though complete immunity has not been achieved. In the long term, emphasis should focus on the use of virus-resistant faba bean cultivars. It will be necessary for plant virologists to cooperate closely with faba bean breeders to achieve this goal. In addition, faba bean lines, with useful levels of resistance to virus infection by aphids or with decreased rate of seed transmission (e.g. BBSV, BYMV) can be used in breeding programs. In the future, transgenic faba bean expressing viral genes which can inhibit virus replication may form an integral part of an environmentally safe viral disease management package for faba bean.

Many scientists in developed and developing nations continue to work on the molecular characterization of virus strains, although the outcome of this research has not significantly influenced genetic improvement strategies. The development of molecular markers for virus resistance genes in faba bean, on the other hand, is expected to expedite the selection of virus-resistant faba bean genotypes.

REFERENCES

Abdullahi I, Ikotun T, Winter S, Thottappilly G, Atiri GI (2001) Investigation on seed transmission of cucumber mosaic virus in cowpea. *African Crop Science Society* **9**, 677-684

Abraham A, Makkouk KM (2002) The incidence and distribution of seed-transmitted viruses in pea and lentil seed lots in Ethiopia. *Seed Science and Technology* **30**, 567-574

Abraham A, Makkouk KM, Gorfu D, Lencho AG, Ali K, Tadessi N, Yusuf A, Lencho A (2000) Survey of faba bean (*Vicia faba* L.) virus diseases in Ethiopia. *Phytopathologia Mediterranea* **39**, 277-282

Abraham AD, Menzel W, Lesemann DE, Varrelmann M, Vetten HJ (2006) Chickpea chlorotic stunt virus: a new polerovirus infecting cool-season food legumes in Ethiopia. *Phytopathology* **96**, 437-446

Aftab M, Mughal SM, Ghafoor A (1989) Occurrence and identification of bean yellow mosaic virus from faba bean in Pakistan. *Indian Journal of Virology* **5**, 88-93

Ahmed AH, Eisa EB (1999) Transmission of broad bean mottle virus by the larvae of *Spodoptera exigua*. *FABIS Newsletter* **28**, 30-31

Ait Yahia A, Aitouada M, Illoul H, Taur MI (1997) First occurrence of bean yellow mosaic potyvirus on chickpea in Algeria. *OEPP/EPPO Bulletin* **27**, 261-263

Ait Yahia A, Aitouada M, Hadj Arab K, Belfendes R, Sarni K, Ouadi K (1999) Identification and characterization of bean leaf roll luteoviruses (BLRV), a major component of chickpea stunt disease in Algeria. In: *Proceedings of the 2nd Regional Symposium for Cereal and Legume Diseases*, Nabeul, Tunisia, 10-12 November, 1999, pp 289-293

Ajirlo SA, Jagadish B, Misra RL, Kumar PA (2006) Insect resistant transgenic floricultural crops. In: Teixeira da Silva JA (Ed) *Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues* (1st Edn, Vol III), Global Science Books, London, pp 548-552

Al-Ani RA, El-Azzawi QK (1987) Effect of infection with broad bean mottle and bean yellow mosaic viruses on nitrogen fixation in faba bean. *Journal of Agricultural Sciences* (Iraq) **18**, 199-212

Allam EK, Gamal Eldin AS, Riskallah LR (1979) Some viruses affecting broad bean in Egypt. *Egyptian Journal of Phytopathology* **11**, 67-77

Al-Mabrouk O, Mansour AN (2000) Viruses affecting lentil in Jordan. In: Katbeh Bader A, Shared Hasan H (Eds) *Abstract book of 7th Arab Congress of Plant Protection, 22-26 October 2000, Amman, Jordan*, Arab Society of Plant Protection, Beirut, Lebanon, p 352

Al-Musa A, Al-Haj H, Mansour A, Janakat S (1987) Properties of bean yellow mosaic virus occurring on broad bean in the Jordan valley. *Dirasat* **14**, 135-140

Al-Musa AM, Al-Haj HA, Monayer LO (1986) Light and electron microscopy of the Jordanian isolate of broad bean wilt virus. *Dirasat* **8**, 57-62

Al-Nsour AH, Mansour A, Al-Musa A, Salem, N (1998) Distribution and incidence of faba bean necrotic yellows virus in Jordan. *Plant Pathology* **47**, 510-515

Ashby JW, Huttinga H (1979) Purification and some properties of pea leafroll virus. *Netherlands Journal of Plant Pathology* **85**, 113-123

Bayaa B, Kumari SG, Akkaya A, Erskine W, Makkouk KM, Turk Z, Ozberk I (1998) Survey of major biotic stresses of lentil in South-East Anatolia, Turkey. *Phytopathologia Mediterranea* **37**, 88-95

Bekele B, Kumari SG, Ali K, Yusuf A, Makkouk KM, Aslake M, Ayalew M, Girma G, Hailu D (2005) Survey for viruses affecting legume crops in Amhara and Oromia Regions in Ethiopia. *Phytopathologia Mediterranea* **44**, 235-246

Blaszczak W (1970) Influence of the time of inoculation of horse bean by the broad bean true mosaic virus (*Viciavirus varians* Quantz) on yield and seed transmission of the virus. *Zeszyty Problemowe Postepow Nauk Rolniczych* **11**, 11-20

Bond DA, Lawes DA, Hawtin GC, Saxena MC, Stephens JS (1985) Faba bean (*Vicia faba* L.). In: Summerfield RJ, Roberts EH (Eds) *Grain Legume Crops*, William Collins Sons Co., London, pp 199-265

Bond DA, Jellis GJ, Rowland GG, Le Guen J, Robertson LD, Khalil SA, Li-Juan L (1994) Present status and future strategy in breeding faba bean (*Vicia faba* L.) for resistance to biotic and abiotic stresses. In: Muelbauer FJ, Kaiser WJ (Eds) *Expanding the Production and Use of Cool Season Legumes*, Kluwer Academic Publishers, The Netherlands, pp 592-616

Borges MD, Louro O (1974) A biting insect as a vector of broad bean mottle virus? *Agronomia Lusitiana* **36**, 215-216

Bos L, Hampton RO, Makkouk KM (1988) Viruses and virus diseases of pea, lentil, faba bean and chickpea. In: Summerfield RJ (Ed) *World Crops: Cool Season Food Legumes,* Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 591-615

Bos L, Mahir MAM, Makkouk K (1993) Some properties of an isolate of pea early-browning tobravirus from faba bean (*Vicia faba* L.) in Libya. *Phytopathologia Mediterranea* **32**, 7-13

Boswell KF, Gibbs AJ (1983) *Viruses of Legumes: Descriptions and Keys from Virus Identification and Data Exchange*, Canberra, Australian National University, 139 pp

Boulton RE (1996) Pea early-browning tobravirus. *Plant Pathology* **45**, 13-28

Braiana HS, Shannon AL, Chu PWG, Waterhouse PM (1994) Detection of five seedborne legume viruses in one sensitive multiplex polymerase chain reaction test. *Phytopathology* **84**, 1201-1205

Clark MF, Adams AN (1977) Characteristics of the microplate method of enzyme-linked immunosorbent assay for the detection of plant viruses. *Journal of General Virology* **34**, 475-483

Clement SL, El-Din Sharaf El-Din N, Weigand S, Lateef SS (1994) Research achievements in plant resistance to insect pest of cool season food legumes. In: Muelbauer FJ, Kaiser WJ (Eds) *Expanding the Production and Use of Cool Season Legumes*, Kluwer Academic Publishers, The Netherlands, pp 290-304

Cockbain AJ (1983) Viruses and virus-like disease of *Vicia faba* L. In: Hebblethwaite PD (Ed) *The Faba Bean (Vicia faba L.)*, Butterworths, London, UK, pp 421-461

Cockbain AJ, Cook SM, Bowen R (1975) Transmission of broad bean stain virus and Echtes Ackerbohnenmosaik-Virus to field beans (*Vicia faba*) by weevils. *Annals of Applied Biology* **81**, 331-339

Cockbain AJ, Bowen R, Vorra-Urai S (1976) Seed transmission of broad bean stain virus and echtes ackerbohnenmosaik-virus in field beans (*Vicia faba*).

Annals of Applied Biology **84**, 321-332
Cockbain AJ, Jones P. Woods RD (1986) Transmission characteristics and some other properties of bean yellow vein-banding virus, and its association with pea enation mosaic virus. *Annals of Applied Biology* **108**, 59-69
D'Arcy C, Torrance L, Martin RR (1989) Discrimination among Luteoviruses and their strains by monoclonal antibodies and identification of common epitopes. *Phytopathology* **79**, 869-873
Damsteegt VD, Stone AL, Russo AJ, Luster DG, Gildow FE, Smith OP (1999) Identification, characterization, and relatedness of Luteovirus isolates from forage legumes. *Phytopathology* **89**, 374-379
Davino S, Bellardi MG, Di Bella M, Davino M, Bertaccini A (2005) Characterization of a *Cucumber mosaic virus* isolate infecting *Mandevilla sanderi* (Hemsl.) Woodson. *Phytopathologia Mediterranea* **44**, 220-225
Duke JA (1981) Handbook of Legumes of World Economic Importance, Plenum Press, New York, pp 199-265
Edwardson JR, Christie RG (1986) *Viruses Infecting Forage Legumes*, Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 3 volumes, 742 pp
El-Amri A (1999a) Identification and repartition of faba bean necrotic yellows virus (FBNYV) in Morocco. *Al Awamia* **99**, 19-26
El-Amri A (1999b) Identification of vectors and natural hosts of faba bean necrotic yellows virus in Morocco. *Al Awamia* **99**, 27-31
El-Attar S, Ghabrial SA, Nour Eldin F (1971) A strain of Alfalfa mosaic virus on broad bean in the Arab Republic of Egypt. *Agricultural Research Review* (Egypt) **49**, 277-284
Ellis PJ, Wieczorek A (1992) Production of monoclonal antibodies to beet western yellows virus and potato leafroll virus and their use in luteovirus detection. *Plant Disease* **76**, 75-78
El-Maataoui M, El-Hassani A (1984) Cucumber mosaic virus of chickpea in Morocco. *International Chickpea Newsletter* **10**, 14-15
El-Muadhidi MA, Makkouk KM, Kumari SG, Jerjess M, Murad SS, Mustafa RR, Tarik F (2001) Survey for legume and cereal viruses in Iraq. *Phytopathologia Mediterranea* **40**, 224-233
Fadel S, Khalil J, Shagrun M (2005) First record of *Faba bean necrotic yellows virus* and a Luteovirus in faba bean crop (*Vicia faba* L.) in Libya. *Arab Journal of Plant Protection* **23**, 132
Farzadfar Sh, Izadpanah K (2001) Sources and properties of the Iranian isolate of *Pea enation mosaic virus*. *Iranian Journal of Plant Pathology* **37**, 77
Fiedorow ZG (1983) Pea early-browning virus on horse bean (*Vicia faba* L. ssp. *Minor*). *Zeszyty Problemowe Postepow Nauk Rolniczych* **291**, 97-109
Fischer HU, Lockhart BE (1976) Identification of broad bean stain virus as the cause of a widespread disease of broad beans in Morocco. *Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz* **83**, 332-337
FAOSTAT (2007) Statistical Databases - Food and Agriculture Organization of the United Nations, Rome, Italy, Website: faostat.fao.org
Ford RE, Bissonnette HL, Horsfall JG, Millar RL, Schlegel D, Tweedy BG, Weathers LG (1981) Plant Pathology in China, 1980. *Plant Disease* **65**, 706-714
Fortass M, Bos L (1991) Survey of faba bean (*Vicia faba* L.) for viruses in Morocco. *Netherlands Journal of Plant Pathology* **97**, 369-380
Fortass M, Bos L (1992) Broad bean mottle virus in Morocco; variability, infection with food legume species, and seed transmission in faba bean, and chickpea. *Netherlands Journal of Plant Pathology* **98**, 329-342
Fortass M, Diallo S (1993) Broad bean mottle bromovirus in Morocco; curculionid vectors, and natural occurrence in food legumes other than faba bean (*Vicia faba* L.). *Netherlands Journal of Plant Pathology* **99**, 219-226
Fortass M, van der Wilk F, van den Heuvel JEJ, Goldbach RW (1997) Molecular evidence for the occurrence of beet western yellows virus on chickpea in Morocco. *European Journal of Plant Pathology* **103**, 481-484
Franz A, Makkouk KM, Vetten HJ (1998) Acquisition, retention and transmission of faba bean necrotic yellows virus by two of its aphid vectors, *Aphis craccivora* (Koch) and *Acyrthosiphon pisum* (Harris). *Journal of Phytopathology* **146**, 347-355
Franz A, Makkouk KM, Katul L, Vetten HJ (1996) Monoclonal antibodies for the detection and differentiation of faba bean necrotic yellows virus isolates. *Annals of Applied Biology* **128**, 255-268
Gallo J, Matisova J (1993) Construction and characterization of monoclonal antibodies to alfalfa mosaic virus. *Acta Virologica* **37**, 61-67
Gamal-Eldin AS, El-Amrety AA, Mazyad HM, Rizkallah LR (1982) Effect of bean yellow mosaic and broad bean wilt viruses on broad bean yield. *Agriculture Research Review* (Egypt) **60**, 195-204
Ghad IPS, Bernier CC (1984) Resistance in faba bean (*Vicia faba*) to bean yellow mosaic virus. *Plant Disease* **68**, 109-111
Gibbs A, Giussani-Belli G, Smith HS (1968) Broad bean stain and true broad-bean mosaic viruses. *Annals of Applied Biology* **61**, 99-107
Gibbs AJ, Harrison BD, Woods RD (1966) Purification of pea enation mosaic virus. *Virology* **29**, 348-351
Gibbs AJ, Smith HG (1970) Broad bean stain virus. CMI/AAB Descriptions of Plant Viruses No. 29. Commonwealth Agricultural Bureaus, Slough, 3 pp
Govier DA (1985) Purification and partial characterisation of beet mild yellowing virus and its serological detection in plants and aphids. *Annals of Applied Biology* **107**, 439-447
Haase A, Richter J, Rabenstein F (1989) Monoclonal antibodies for detection and serotyping of cucumber mosaic virus. *Journal of Phytopathology* **127**, 129-136
Hagedorn DJ (1996) Pea enation mosaic virus enamovirus: ecology and control. In: Harrison BD, Murant AF (Eds) The *Plant Viruses, Volume 5: Polyhedral Virions and Bipartite RNA Genomes,* Plenum Press, New Your, pp 345-356
Hajimorad MR, Dietzgen RG, Francki RI (1990) Differentiation and antigenic characterization of closely related alfalfa mosaic virus strains with monoclonal antibodies. *Journal of General Virology* **71**, 2809-2816
Hammond J, Hammond RW (1985) Nucleic acid probe for detection of bean yellow mosaic virus. *Acta Horticulturae* **164**, 373-378
Harrison B, Steinlage TA, Domier LL, D'Arcy CJ (2005) Incidence of *Soybean dwarf virus* and identification potential vectors in Illinois. *Plant Disease* **89**, 28-32
Hauser S, Stevens M, Mougel C, Smith HG, Fritsch C, Herrbach E, Lemaire O (2000) Biological, serological, and molecular variability suggest three distinct Polerovirus species infecting beet or rape. *Phytopathology* **90**, 460-466
Hayes RJ, Pereira VC, McQuillin A, Buck KW (1994) Localization of functional regions of the cucumber mosaic virus RNA replicase using monoclonal and polyclonal antibodies. *Journal of General Virology* **75**, 3177-3184
Herrbach E, Lemaire O, Ziegler-Graff V, Lot H, Rabenstein F, Bouchery Y (1991) Detection of BMYV and BWYV isolates using monoclonal antibodies and radioactive RNA probes, and relationships among luteoviruses. *Annals of Applied Biology* **118**, 127-138
Hond K (2001) Aphids and their transmission of viruses on soybean in Japan. *Agrochemicals Japan* **79**, 2-7
Horn NM, Makkouk KM, Kumari SG, van den Heuvel JFJM, Reddy DVR (1995) Survey of chickpea (*Cicer arietinum* L.) for chickpea stunt disease and associated viruses in Syria, Turkey and Lebanon. *Phytopathologia Mediterranea* **34**, 192-198
Horn NM, Reddy SV, Roberts IM, Reddy DVR (1993) Chickpea chlorotic dwarf virus, a new leafhopper-transmitted geminivirus of chickpea in India. *Annals of Applied Biology* **122**, 467-479
Hsu HT, Barzuna L, Hsu YH, Bliss W, Perry KL (2000) Identification and subgrouping of Cucumber mosaic virus with mouse monoclonal antibodies. *Phytopathology* **90**, 615-620
Inouye T (1969) The legume viruses of Japan. *Review of Plant Protection Research* **2**, 42-51
Inouye T, Inouye N, Mitsuhata K (1968) Yellow dwarf of pea and broad-bean caused by milk vetch dwarf virus. *Annals of the Phytopathological Society of Japan* **34**, 28-35
Inouye T, Nakasone W (1980) Broad bean necrosis virus. CMI/AAB Description of Plant Viruses. No. 223. Commonwealth Mycological Institute, Kew, England, 4 pp
Ismail ID, Hassan MHM (1995) Survey of seed-borne viruses of faba bean in Sebha region south of Libya. *Journal University of Sebha* **2**, 95-109
Izadpanah K, Shepherd J (1966) Purification and properties of pea enation mosaic virus. *Virology* **28**, 463-476
Johnstone GR, Ashby JW, Gibbs AJ, Duffus JE, Thottappilly G, Fletcher JD (1984) The host ranges, classification and identification of eight persistent aphid-transmitted viruses causing disease in legumes. *Netherlands Journal of Plant Pathology* **90**, 225-245
Jones AT (1978) Incidence, field spread, seed transmission and effects of broad bean stain virus and echtes ackerbohnenmosaik-virus in *Vicia faba* in eastern Scotland. *Annals of Applied Biology* **88**, 137-144
Jones AT (1980) Seed-borne viruses of *Vicia faba* and the possibility of producing seed free from broad bean stain virus and echtes ackerbohnenmosaic-virus. In: Bond DA (Ed) *Vicia faba: Feeding Value, Processing and Viruses*, Martinus Nijhoff, The Hague, The Netherlands, pp 319-330
Jones AT (1987) Control of virus infection in crop plants through vector resistance: a review of achievements, prospects and problems. *Annals of Applied Biology* **111**, 745-772
Jones AT, Barker H (1976) Properties and relationships of broad bean stain virus and Echtes Ackerbohnenmosaik-virus. *Annals of Applied Biology* **83**, 231-238
Jones P, Cockbain AJ, Freigoun SO (1984) Association of a mycoplasma-like organism with broad bean phyllody in the Sudan. *Plant Pathology* **33**, 599-602
Jordan R, Hammond J (1991) Comparison and differentiation of potyvirus isolates and identification of strain-, virus-, subgroup-specific and potyvirus group-common epitopes using monoclonal antibodies. *Journal of General Virology* **72**, 25-36
Kaiser WJ (1973) Biology of bean yellow mosaic and pea leaf roll viruses effecting *Vicia faba* in Iran. *Phytopathologische Zeitschrift* **78**, 253-263
Kaiser WJ, Danesh D, Okhovat M, Mossahebi H (1968) Disease of pulse crops (edible legumes) in Iran. *Plant Disease Reporter* **52**, 687-691
Kassim NA (1997) Studies on Certain viruses on chickpea and lentil in Ninevah Governorate. Ph.D. Thesis. University of Mousul, Iraq, 167 pp
Katul L (1992) Characterization by serology and molecular biology of bean leaf roll virus and faba bean necrotic yellows virus. Ph.D. thesis, University of Göttingen, Germany, 115 pp
Katul L, Vetten HJ, Maiss E, Makkouk KM, Lesemann DE, Casper R (1993) Charecteristics and serology of virus-like particles associated with

faba bean necrotic yellows. *Annals of Applied Biology* **123**, 629-647

Kojima M, Tamada T (1976) Purification and serology of soybean dwarf virus. *Phytopathologische Zeitschrift* **85**, 237-250

Kumari SG (2002) A study on Luteoviruses affecting cool-season food legumes. PhD Thesis, Department of Plant Protection, Faculty of Agriculture, Aleppo University, Aleppo, Syria, 230 pp

Kumari SG, Makkouk KM (2003) Differentiation among Bean leafroll virus susceptible and resistant lentil and faba bean genotypes on the basis of virus movement and multiplication. *Journal of Phytopathology* **151**, 19-25

Kumari SG, Makkouk KM, Attar N (2006) An improved antiserum for sensitive serologic detection of Chickpea chlorotic dwarf virus. *Journal of Phytopathology* **154**, 129-133

Kumari SG, Makkouk KM, Attar N, Ghulam W, Lesemann DE (2004) First report of *Chickpea chlorotic dwarf virus* infecting spring chickpea in Syria. *Plant Disease* **88**, 424

Kumari SG, Makkouk KM, Katul L, Vetten HJ (2001a) Polyclonal antibodies to the bacterially expressed coat protein of *Faba bean necrotic yellows virus*. *Journal of Phytopathology* **149**, 543-550

Kumari SG, Makkouk KM, Bayaa B (2001b) *Pea enation mosaic virus-1* infecting lentil in Syria, and further information on its host range, purification, serology and transmission characteristics. *Arab Journal of Plant Protection* **19**, 65-72

Kumari SG, Rodoni B, Hlaing Loh M, Makkouk KM, Freeman A, van Leur J (2006) Distribution, identification and characterization of *Luteoviruses* affecting food legumes in Asia and North Africa. In: *Proceeding of 12th Mediterranean Phytopathological Congress*, 11-15 June 2006, Rhodes Island, Greece, pp 412-416

Kumari SG, Rodoni B, Vetten HJ, Freeman A, van Leur J, Hlaing Loh M, Shiying B, Xiaoming W (2007) Detection and partial characterization of *Milk vetch dwarf virus* in faba bean (*Vicia faba* L.) in Yunnan Province, China. (in preparation)

Kurçman S (1977) Determination of virus diseases on cultural plants in Turkey. *Journal of Turkish Phytopathology* **6**, 27-48

Latham LJ, Jones RAC (2001a) Incidence of virus infection in experimental plots, commercial crops and seed stocks of cool season crop legumes. *Australian Journal of Agricultural Research* **52**, 397-413

Latham LJ, Jones RAC (2001b) Alfalfa mosaic and pea seed-borne mosaic viruses in cool season crop, annual pasture, and forage legumes: susceptibility, sensitivity, and see transmission. *Australian Journal of Agricultural Research* **52**, 771-790

Latham LJ, Jones RAC, McKirdy SJ (2001) Cucumber mosaic cucumovirus infection of cool season crop, annual pasture and forage legumes: susceptibility, sensitivity, and seed transmission. *Australian Journal of Agricultural Research* **52**, 683-697

Lockhart BEL, Fischer HU (1976) Some properties of an isolate of pea early-browning virus occurring in Morocco. *Phytopathology* **66**, 1391-1394

Loebenstein G, Raccah B (1980) Control of non-persistently transmitted aphid-borne viruses. *Phytoparasitica* **8**, 221-235

Mahir MAM, Fortass M, Bos L (1992) Identification and properties of a deviant isolate of the broad bean yellow band serotype of pea early-browning virus from faba bean (*Vicia faba*) in Algeria. *Netherlands Journal of Plant Pathology* **98**, 237-257

Mahmood K, Peters D (1973) Purification of pea enation mosaic virus and the infectivity of it components. *Netherlands Journal of Plant Pathology* **79**, 138-147

Makkouk KM, Kumari SG (1989) *Apion arrogans*, a weevil vector of broad bean mottle virus. *FABIS Newsletter* **25**, 26-27

Makkouk KM, Kumari SG (1995a) Transmission of broad bean stain comovirus and broad bean mottle bromovirus by weevils in Syria. *Journal of Plant Disease and Protection* **102**, 136-139

Makkouk KM, Kumari SG (1995b) Screening and selection of faba bean (*Vicia faba* L.) germplasm for resistance to bean yellow mosaic potyvirus. *Journal of Plant Diseases and Protection* **102**, 461-466

Makkouk KM, Kumari SG (1996) Detection of ten viruses by the tissue-blot immunoassay (TBIA). *Arab Journal of Plant Protection* **14**, 3-9

Makkouk KM, Kumari SG (1998) Further serological characterization of two tobravirus isolates from Algeria and Libya. *Pakistan Journal of Biological Sciences* **1**, 303-306

Makkouk KM, Kumari SG (2001) Reduction of spread of three persistently aphid-transmitted viruses affecting legume crops by seed-treatment with Imidacloprid (Gaucho®). *Crop Protection* **20**, 433-437

Makkouk KM, Lesemann DE, Haddad NA (1982) Bean yellow mosaic virus from broad bean in Lebanon: incidence, host range, purification, and serological properties. *Journal of Plant Diseases and Protection* **89**, 59-66

Makkouk KM, Bos L, Azzam OI, Katul L, Rizkallah A (1987a) Broad bean stain virus: identification, detectability in faba bean leaves and seeds, occurrence in West Asia and North Africa and possible wild hosts. *Netherlands Journal of Plant Pathology* **93**, 97-106

Makkouk KM, Katul L, Rizkallah A (1987b) Electrophoretic separation: an alternative simple procedure for the purification of broad bean mottle and alfalfa mosaic viruses. *FABIS Newsletter* **19**, 12-14

Makkouk KM, Bos L, Rizkallah A, Azzam OI, Katul L (1988a) Broad bean mottle virus: identification, serology, host range and occurrence on faba bean (*Vicia faba*) in West Asia and North Africa. *Netherlands Journal of Plant Pathology* **94**, 195-212

Makkouk KM, Bos L, Azzam OI, Kumari SG, Rizkallah A (1988b) Survey of viruses affecting faba bean in six Arab countries. *Arab Journal of Plant Protection* **6**, 53-61

Makkouk KM, Katul L, Rizkallah A (1988c) A simple procedure for the purification and antiserum production of bean yellow mosaic virus. *Journal of Phytopathology* **122**, 89-93

Makkouk KM, Kumari SG, Bos L (1990) Broad bean wilt virus: host range, purification, serology, transmission characteristics, and occurrence in faba bean in West Asia and North Africa. *Netherlands Journal of Plant Pathology* **96**, 291-300

Makkouk KM, Hsu HT, Kumari SG (1993a) Detection of three plant viruses by dot-blot and tissue-blot immunoassays using chemiluminescent and chromogenic substrates. *Journal of Phytopathology* **139**, 97-102

Makkouk KM, Kumari SG, Bos L (1993b) Pea seed-borne mosaic virus: occurrence in faba bean (*Vicia faba* L.) and lentil (*Lens culinaris* Med.) in West Asia and North Africa, and further information on host range, purification, serology, and transmission characteristics. *Netherlands Journal Plant Pathology* **99**, 115-124

Makkouk KM, Rizkallah L, Madkour M, El-Sherbeeny M, Kumari SG, Amriti AW, Solh MB (1994) Survey of faba bean (*Vicia faba* L.) for viruses in Egypt. *Phytopathologia Mediterranea* **33**, 207-211

Makkouk KM, Dafalla G, Hussein M, Kumari SG (1995) The natural occurrence of chickpea chlorotic dwarf geminivirus in chickpea and faba bean in the Sudan. *Journal of Phytopathology* **143**, 465-466

Makkouk KM, Damsteegt V, Johnstone GR, Katul L, Lesemann DE, Kumari SG (1997) Identification and some properties of soybean dwarf luteovirus affecting lentil in Syria. *Phytopathologia Mediterranea* **36**, 135-144

Makkouk KM, Bahamish HS, Kumari SG, Lotf A (1998a) Major viruses affecting faba bean (*Vicia faba* L.) in Yemen. *Arab Journal of Plant Protection* **16**, 98-101

Makkouk KM, Vetten HJ, Katul L, Franz A, Madkour MA (1998b) Epidemiology and control of faba bean necrotic yellows virus (Chapter 40). In: Hadidi A, Khetarpal RK, Koganezawa H (Eds) *Plant Virus Disease Control*, APS Press, The American Phytopathological Society, St. Paul, Minnesota, USA, pp 534-540

Makkouk KM, Bashir M, Jones RAC, Kumari SG (2001) Survey for viruses in lentil and chickpea crops in Pakistan. *Journal of Plant Diseases and Protection* **108**, 258-268

Makkouk KM, Kumari SG, van Leur JAG (2002) Screening and selection of faba bean (*Vicia faba* L.) germplasm resistant to *Bean leafroll virus*. *Australian Journal of Agricultural Research* **53**, 1077-1082

Makkouk KM, Hamed AA, Hussein M, Kumari SG (2003a) First report of *Faba bean necrotic yellows virus* (FBNYV) infecting chickpea (*Cicer arietinum*) and faba bean (*Vicia faba*) crops in Sudan. *Plant Pathology* **52**, 412

Makkouk KM, Rizkallah L, Kumari SG, Zaki M, Abul Enein R (2003b) First record of *Chickpea chlorotic dwarf virus* (CpCDV) affecting faba bean (*Vicia faba*) crops in Egypt. *Plant Pathology* **52**, 413

Makkouk KM, Kumari SG, Hughes JA, Muniyappa V, Kulkarni NK (2003c) Other legumes: Faba bean, chickpea, lentil, pigeonpea, mungbean, blackgram, lima bean, horegram, bambara groundnut and winged bean. In: Loebenstein G, Thottappilly G (Eds) *Virus and Virus-like Diseases of Major Crops in Developing Countries*, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 447-476

Makkouk KM, Kumari SG, Shahraeen N, Fazlali Y, Farzadfar Sh, Ghotbi T, Reza Mansouri A (2003d) Identification and seasonal variation of viral diseases of chickpea and lentil in Iran. *Journal of Plant Diseases and Protection* **110**, 157-169

Martin RR, D'Arcy CJ (1990) Relationships among luteoviruses based on nucleic acid hybridization and serological studies. *Intervirology* **31**, 23-30

Mazyad H, El-Hammady M, Tolba MA (1975) The broad bean true mosaic disease in Egypt. *Annals of Agricultural Science, Moshtohor* **4**, 87-94

McKirdy SJ, Jones RAC, Latham LJ, Coutts BA (2000) Bean yellow mosaic potyvirus infection of alternative annual pasture, forage and cool season crop legumes: susceptibility, sensitivity and seed transmission. *Australian Journal of Agricultural Research* **51**, 325-345

Mikoshiba Y, Honda K, Kanematsu S, Fujisawa I (1996) Discrimination of soybean dwarf luteovirus strains by using monoclonal antibodies. Xth International Congress of Virology, Jerusalem, Israel, 1996, Abstracts, p 210

Milles PR, Ahmed AH (1984) Host range and properties of cucumber mosaic virus (CMV-Su) infecting *Vicia faba* in Sudan. *FABIS Newsletter* **9**, 31-33

Mouhanna AM, Makkouk KM, Ismail ID (1994) Survey of virus disease of wild and cultivated legumes in the coastal region of Syria. *Arab Journal of Plant Protection* **12**, 12-19

Murant AF, Abu Salih HS, Goold RA (1974) Viruses from broad bean in the Sudan. In: Report Scottish Horticultural Research Institute for 1973, 67 pp

Musil M (1980) Samenubertragbarkeit des Blattrollmosaik-Virus der Erbse. *Tagungsber Akad Landwirtsch Wiss* (DDR, Berlin) **184**, 345-352

Najar A, Makkouk KM, Boudhir H, Kumari SG, Zarouk R, Bessai R, Ben Othman F (2000) Viral diseases of cultivated legume and cereal crops in Tunisia. *Phytopathologia Mediterranea* **39**, 423-432

Najar A, Kumari SG, Makkouk KM, Daaloul A (2003) A survey of viruses affecting faba bean (*Vicia faba*) in Tunisia includes first record of *Soybean dwarf virus*. *Plant Disease* **87**, 1151

Nene YL, Hanounik SB, Qureshi SH, Ben S (1988) Fungal and bacterial diseases of pea, lentil, faba bean and chickpea. In: Summerfield RJ (Ed) *Word Crops: Cool Season Food Legumes*, Kluwer Academic Publishers, England, pp 577-589

Nienhaus F, Saad AT (1967) First report on plant virus diseases in Lebanon, Jordan and Syria. *Zeitschrift fur Pflanzenkrankheiten und Pflzenschutz* **74**, 459-471

Nour MA, Nour JJ (1962) A mosaic disease of *Dolichos lablab* and diseases of other crops caused by alfalfa mosaic virus in the Sudan. *Phytopathology* **52**, 427-432

Ortiz V, Castro S, Romero J (2005) Optimization of RT-PCR for the detection of Bean leaf roll virus in plant host and insect vectors. *Journal of Phytopathology* **153**, 68-72

Parvin S, Izadpanah K (1978) Broad bean wilt virus-identification, host range and distribution in the Fars province of Iran. *Iranian Journal of Agricultural Research* **6**, 81-90

Pesic Z, Hiruki C (1988) Comparison of ELISA and dot-hybridization for detection of alfalfa mosaic virus in alfalfa pollen. *Canadian Journal of Plant Pathology* **10**, 116-122

Phan TTH, Khetarpal RK, Le TAH, Maury Y (1997) Comparison of immuno-capture PCR and ELISA in quality control of pea seed for pea seed-borne mosaic potyvirus. In: Hutchins JD, Reeves JC (Eds) *Seed Health Testing: Progress Towards the 21st Century*, National Institute of Agricultural Botany, Cambridge, UK, pp 193-199

Phibbs A, Barta A, Domier LL (2004) First report of Soybean dwarf virus on Soybean in Wisconsin. *Plant Disease* **88**, 1285

Porta C, Devergne JC, Cardin L, Briand JP, Van Regenmortel MH (1989) Serotype specificity of monoclonal antibodies to cucumber mosaic virus. *Archives of Virology* **104**, 271-285

Putz C, Kuszala M (1973) Two new viruses on broad bean in France. I. Identification and evaluation of their economic importance. *Annales de Phytopathologie* **5**, 447-460

Qi YJ, Zhou XP, Huang XZ, Li GX (2002) *In vivo* accumulation of Broad bean wilt virus 2 VP37 protein and its ability to bind single-stranded nucleic acid. *Archives of Virology* **147**, 917-928

Qing L, Wu J, Qi Y, Zhiu X, Li D (2000) Production of monoclonal antibodies to broad bean wilt virus and application in virus detection. *Wei Sheng Wu Xue Bao* **40**, 166-73

Rabenstein F, Kühne T, Richter J, Kleinhempel H (1984) Production of monoclonal antibodies against beet mild yellowing virus. *Archiv für Phytopathologie und Pflanzenschutz* **20**, 517-519

Rohloff H, Stupnagel R (1984) Resistance to bean yellow mosaic virus in *Vicia faba*. *FABIS Newsletter* **10**, 29

Roberts IM, Wang D, Thomas CL, Maule AJ (2003) Pea seed-borne mosaic virus seed transmission exploits novel symplastic pathways to infect the pea embryo and is, in part, dependent upon chance. *Protoplasma* **222**, 31-43

Salama ES, El-Behadli AH (1979) Strain of alfalfa mosaic virus on broad bean in Iraq. *Bulletin of the Natural History Research Centre* **7**, 101-112

Sano Y, Wada M, Hashimoto Y, Matsumoto Y, Kojima M (1998) Sequences of ten circular ssDNA components associated with the milk vetch dwarf virus genome. *Journal of General Virology* **79**, 3111-3118

Sasaya T, Iwasaki M, Yamamoto T (1993) Seed transmission of bean yellow mosaic virus in broad bean (*Vicia faba*). *Annals of Phytopathological Society of Japan* **59**, 559-562

Schmidt HE, Dubnik H, Karl E, Schmidt HB, Kamann H (1977) Verminderung von virusinfektionen der ackerbohne (*Vicia faba* L.) im rahmen der blattlausbekampfung auf grossflachen. *Nachrichtenblatt für den Pflanzenschutz in der DDR* **31**, 247-250

Schmidt HE, Geissler K, Karl E, Schmidt HB (1986) A line of field bean (*Vicia faba* L.) with combined resistance to BYMV and ClYVV and *Aphis faba* Scop. *Archiv für Phytopathologie und Pflanzenschutz* **22**, 87-99

Schmidt HE, Griesbach E, Zielke E (1980) Viral and bacterial diseases in field bean (*Vicia faba* L.) and lupin (*Lupinus* sp.). *Fortschrittsbericht fur die Landwirtschaft und Nahrugsguterwirtschaft* **18**, 48

Schmidt HE, Meyer U, Haack I, Karl E (1989) Detection, accumulation and characterization of multiple resistance in field bean, *Vicia faba* L. ssp. Miner (Peterm. Em Harz) Rothm. To bean yellow mosaic virus and pea enation mosaic viruses. *Archiv für Zuchtungsforschung* **19**, 193-196

Schmidt HE, Rollowitz W, Schimanski HH, Kegler H (1985) Detection of resistance genes against bean yellow mosaic virus in *Vicia faba* L. *Archiv für Phytopathologie und Pflanzenschutz* **21**, 83-85

Sclavounos AP, Voloudakis AE, Arabatzis Ch, Kyriakopoulou PR (2006) A severe Hellenic CMV tomato isolate: symptom variability in tobacco, characterization and discrimination of variants. *European Journal of Plant Pathology* **15**, 163-172

Scott SW, McLaughlin MR, Ainsworth AJ (1989) Monoclonal antibodies produced to bean yellow mosaic virus, clover yellow vein virus, and pea mosaic virus which cross-react among the three viruses. *Archives of Virology* **108**, 161-167

Shamloul AM, Hadidi A, Madkour MA, Makkouk KM (1999) Sensitive detection of banana bunchy top and faba bean necrotic yellows viruses from infected leaves, *in vitro* tissue cultures, and viruliferous aphids using polymerase chain reaction. *Canadian Journal of Plant Pathology* **21**, 326-337

Shiying B, Xiaoming W, Zhendong Z, Xuxiao Z, Kumari S, Freeman A, van Leur J (2007) Survey for faba bean and field pea viruses in Yunnan Province, China. (submitted)

Skaf JS, Makkouk KM (1988) Aphid transmission of bean yellow mosaic and bean leaf roll viruses in Syria. *Phytopathologia Mediterranea* **27**, 133-137

Skaf JS, Schultz MH, Hirata H, de Zoeten GA (2000) Mutational evidence that the VPg is involved in the replication and not the movement of *Pea enation mosaic virus*-1. *Journal of General Virology* **81**, 1103-1109

Stubbs LL (1960) Aphid transmission of broad bean wilt virus and comparative transmission efficiency of three vector species. *Australian Journal of Agricultural Research* **11**, 723

Subr Z, Gallo J, Matisova J (1994) Characterization of monoclonal antibodies against broad bean stain and red clover mottle viruses. *Acta Virologica* **38**, 317-320

Subr Z, Matisova J (1999) Preparation of diagnostic monoclonal antibodies against two potyviruses. *Acta Virologica* **43**, 255-257

Tadesse N, Ali K, Gorfu D, Abraham A, Lencho A, Ayalew M, Yusuf A, Makkouk KM, Kumari SG (1999) Survey for chickpea and lentil virus diseases in Ethiopia. *Phytopathologia Mediterranea* **38**, 149-158

Tamada T (1975) Studies on the soybean dwarf diseases. *Report of Hokkaido Prefectural Agricultural Experimental Station* **25**, 1-144

Tanaka Y, Kimura Y, Hiraoka K (1973) Studies on the control of broad bean mosaic disease. (2) Identification of the viruses, seasonal changes of population in aphids on broad bean and control of primary infection of the virus. *Bulletin of the Osaka Agricultural Research Centre* **10**, 77-92

Terauchi H, Honda K, Yamagishi N, Kanematsu S, Ishiguro K, Hidaka S (2003) The N-terminal region of the read through domain is closely related to aphid vector specificity of *Soybean dwarf virus*. *Phytopathology* **93**, 1560-1564

Thresh JM (2003) Control of plant virus diseases in Sub-Saharan Africa: the possibility and feasibility of an integrated approach. *African Crops Science Journal* **11**, 199-223

Uga H (2005) Use of crude sap for one-step RT-PCR-based assays of Bean yellow mosaic virus and the utility of this protocol for various plant-virus combinations. *Journal of General Plant Pathology* **71**, 86-89

Uyemoto JK, Provvidenti R (1974) Isolation and identification of two serotypes of broad bean wilt virus. *Phytopathology* **64**, 1547-1548

van der Wilk F, Forsman M, Zoon F (1994) Detection of tobacco rattle virus in nematodes by reverse transcription and polymerase chain reaction. *European Journal of Plant Pathology* **1**, 109-122

van Emden HF, Ball SL, Rao MR (1988) Pest, disease and weed problems in pea, lentil, faba bean and chickpea. In: Summerfield RJ (Ed) *World Crops: Cool Season Food Legumes*, Kluwer Academic Publishers. Dordrecht, The Netherlands, pp 519-534

Vellios E, Brown DJF, MacFarlane A (2002) Substitution of a single amino acid in the 2b protein of Pea early-browning virus affects nematode transmission. *Journal of General Virology* **83**, 1771-1775

Wahyuni WS, Dietzgen RG, Hanada K, Francki RIB (1992) Serological and biological variation between and within subgroup I and II strains of cucumber mosaic virus. *Plant Pathology* **41**, 282-297

Walters HJ, Surin P (1973) Transmission and host range studies of broad bean mottle virus. *Plant Disease Reporter* **57**, 833-836

Wang RY, Kritzman A, Hershman DE, Ghabrial SA (2006) *Aphid glycines* as a vector of persistently and non-persistently transmitted viruses and potential risks for soybean and other crops. *Plant Disease* **90**, 920-926

Werkmeister JA, Shukla DD (1991) Selection of polyclonal antibodies to the N terminus of bean yellow mosaic potyvirus coat protein by induction of tolerance with monoclonal antibody. *Journal of Virological Methods* **34**, 71-79

Wylie S, Wilson CR, Jones RAC, Jones MGK (1993) A polymerase chain reaction assay for cucumber mosaic virus in lupin seeds. *Australian Journal of Agricultural Research* **44**, 41-51

Xu ZG, Cockbain AJ, Woods RD, Govier DA (1988) The serological relationships and some other properties of isolates of broad bean wilt virus from faba bean and pea in China. *Annals of Applied Biology* **113**, 287-296

Xu Zhiang PZ, Qi C, Zhongda F, Cockbain AJ (1985) Virus disease of the faba bean (*Vicia faba* L.) found in Yangtze River valley. *Journal Nanjing Agricultural University* **4**, 42-47

Younis HA, Shagrun M, Khalil J (1992) Isolation of bean yellow mosaic virus from broad bean plants in Libya. *Libyan Journal of Agriculture* **13**, 165-170

Yu C, Wu J, Zhou X (2005) Detection and subgrouping of Cucumber mosaic virus isolates by TAS-ELISA and immunocapture RT-PCR. *Journal of Virological Methods* **123**, 155-161

Yu TF (1947) Spotted wilt of broad bean. *Phytopathology* **37**, 191-192

Yu TF (1979) *Vicia faba Diseases*, Scientific Press, Peking, 168 pp

Zagh S, Ferault AC (1980) A broad bean virus diseases occurring in Algeria. *Annals of Phytopathology* **12**, 153-159