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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

A broad range of viruses can infect lettuce. These may be latent or cause difficult-to-spot symptoms but they could lead to unattributable yield loss. This literature review identifies the viruses that pose the greatest risk.

Background

Lettuce crops are susceptible to a number of well-known viruses and virus complexes such as *Lettuce mosaic virus* and big-vein disease, respectively. Previous work on other crops such as brassicas and asparagus showed that asymptomatic viruses could negatively affect crop yields. However, it is not known whether UK lettuce crops may also be infected with asymptomatic or latent viruses that are causing problems which are then attributed to other factors.

The purpose of this literature review was to determine the prevalence of viruses that can infect lettuce grown in the UK and elsewhere, and to compile a list of the more common viruses for testing in symptomatic and asymptomatic lettuce samples. ELISA will be used for virus testing in further work.

Summary

Sixty-one viruses are reported to have the potential to infect lettuce [1-5]. Thirty-four occur naturally on lettuce. Of these, eleven different viruses have been reported as occurring on UK lettuce, and two additional viruses are also likely to be present. The remaining twenty-one viruses occur naturally on lettuce but have not yet been reported on UK lettuce; but some of the viruses have been found on lettuce in EU member states.

While several of the viruses are well-known e.g. *Lettuce mosaic virus* and cause recognisable symptoms, a number of viruses cause minimal or highly variable symptoms that could easily be attributed to other causes. It is therefore possible that more viruses are present in UK lettuce than have been formerly reported. For example, *Broad bean wilt virus* (BBWV) is present in the UK on species other than lettuce, and is widespread on European lettuce. Symptoms of BBWV are highly variable, and include slow growth. It is therefore of interest to conduct a screen of virus presence in UK lettuce to determine whether hitherto unrecognised viruses are impacting crop quality and yield, and whether susceptibility and symptoms vary with cultivar. Twelve viruses have been selected for testing based on their presence and severity on lettuce in the UK and elsewhere, and after consultation with the lettuce industry. More detail is available in the full review.

SCIENCE SECTION - LITERATURE REVIEW

Introduction

Field-grown lettuce crops in the UK are prone to a wide range of viruses arising from a variety of sources. Viruses can be introduced to field crops via infected seed and young plants, weed hosts, or via insect and fungal vectors. Dispersal from initial infection sites can occur through mechanical field operations or via insect vectors. A range of visible symptoms may be observed in infected plants, including stunting, twisting, chlorosis, discolouration, and necrosis. However, it is unclear whether UK lettuce crops may also be harbouring asymptomatic viruses that nevertheless lead to reductions in quality or yield. This review of current literature aims to identify viruses of greatest risk that a) occur in the UK, b) are known to cause problems in UK field lettuce crops, c) are present in the EU and have the potential to be transported to the UK, and d) occur in lettuce outside Europe but that still present a potential threat to UK production.

The need for a review

Studies in other field vegetable crops identified viruses in asymptomatic plants and putatively linked the incidence of virus to crop problems. HDC Project FV 365 identified decreases in crop yield associated with asymptomatic *Turnip yellows virus* (TuYV) in Brassica crops, and project FV 384/384a observed a range of viruses in asymptomatic asparagus crops thought to contribute towards the phenomenon known as ‘asparagus decline’.

Growers in the UK experience a wide range of symptoms in field lettuce crops, the causes of which cannot always be diagnosed with certainty. Symptoms such as tip-burn (seen in Brassica plants infected with TuYV), leaf discolouration, and stunting are often attributed to physiological causes and are not investigated further. No broad screening of UK lettuce crops for virus has been undertaken, at least for a considerable length of time. The causes of such non-specific symptoms are therefore unclear, particularly with regard to potential viral causes.

The aim of this investigation is to gather baseline data for virus incidence in geographically diverse UK outdoor lettuce crops and to conduct a preliminary virus screen with the aim of determining possible correlations between virus presence and yield reduction or increased variability in crops. The primary purpose of the review was to identify the viruses that present the greatest risk. These will be included in the first screening programme, subject to availability of appropriate antisera.

Viruses

Viruses are sub-microscopic infectious particles comprised of nucleic acids encased in a coat of protein or other biochemical substance [1]. Most viruses are unable to survive in nature outside a host (such as a plant), and, in field situations, are transmitted primarily by vectors such as aphids, leafhoppers, thrips, beetles, soil-borne nematodes, and fungi. Human-mediated transmission is also of great importance, as virus-contaminated plant sap can be disseminated by machinery or on the hands of field workers. Notably, at least two viruses affecting lettuce (*Tomato bushy stunt virus* and *Lettuce necrotic stunt virus*) have no known vector and likely exist freely in soil and water. Some viruses including TBSV and LMV, for example, are also seed-borne. LNSV, which is very similar to TBSV, may also be transmitted in this manner.

The primary sources of a virus in a field crop may be the crop itself (on young transplants), previous crops in the same field, weed hosts, infected seed, pollen, or vectors (including some that are soil-borne) that have obtained the virus elsewhere.

Viruses that can infect *Lactuca sativa*

Lactuca sativa is susceptible to a number of plant viruses (Table 1). In Table 1, susceptibility is defined as the ability of lettuce to be infected by a given virus through natural or artificial means. Details of virus natural incidence on lettuce in the UK and elsewhere, and potential alternative hosts, are shown. The Plant Viruses Online database [2], EPPO PQR software [3], DPV database [4], plant pathology handbooks [1, 5] and other literature sources were used to compile distribution and host data. Viruses that are described as having a worldwide distribution are assumed to also be found in the UK.

Table 1: Distribution of viruses that can infect lettuce (*Lactuca sativa*)

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Alfalfa mosaic virus	AMV	Alfamovirus	-	France	Broad host range incl. tomato, pepper, potato, poss. weeds	+
Arabis mosaic virus	ArMV	Nepovirus	+	Europe	Several hosts incl. hop, asparagus, cucumber	+
Beet pseudo-yellows virus	BPYV	Crinivirus	+	Europe	Wide host range, incl. cucumber, endive, spinach and weeds incl. sowthistle, dandelion	+
Beet western yellows virus (aka *Beet mild yellowing virus)*	BWYV	Polerovirus	+	Europe	Broad host range incl. cabbage, rape, spinach, beet and weeds incl. sowthistle and shepherd's purse	+
Beet yellows virus	BYV	Closterovirus	-	-	Several hosts including beet and spinach	+
Beet yellow stunt virus	BYSV	Closterovirus	+	USA	Broad host range incl. beet and weeds incl. sowthistle	+
Bidens mosaic virus	BiMV	Potyvirus	-	Brazil	Several hosts, incl. sunflower	-
Bidens mottle virus	BiMoV	Potyvirus	-	USA, Taiwan	Wide range, incl. ornamentals and weeds	-
Broad bean wilt virus	BBWV	Fabavirus	-	Europe	Broad host range incl. broad bean, pea, spinach, Solanacae, and weeds incl. sowthistle	+
Carnation ringspot virus	CRSV	Dianthovirus	-	-	Several hosts, incl. carnation, orchard trees, and weeds incl. common chickweed	+

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Cassava green mottle virus	CGMV	Nepovirus	-	-	None known	-
Cassia mild mosaic virus	CasMMV	Carlavirus	-	-	*Cassia* spp.	-
Chicory yellow mottle virus	ChYMV	Nepovirus	-	-	Chicory and parsley	-
Clover yellow mosaic virus	ClYMV	Potexvirus	-	-	Several hosts incl. pea, clover, common chickweed	-
Cucumber mosaic virus	CMV	Cucumo-virus	+	Europe	Very wide host range incl. cucurbits, tomato, pepper, spinach and weeds incl. sowthistle.	+
Cucurbit yellow stunting disorder virus	CYSDV	Crinivirus	-	-	Cucurbits, possibly some weeds	-
Cymbidium ringspot virus	CyRSV	Tombus-virus	-	-	Cymbidium, white clover	+
*Dandelion yellow mosaic virus (*possibly = *Lettuce mottle virus)*	DYMV /DaYMV	Sequivirus	+ DYMV	+ LMoV- (Brazil)	Dandelion (DYMV), not known (LMoV)	+
Dogwood mosaic virus	DMV	Nepovirus	-	-	Flowering dogwood	-
Endive necrotic mosaic virus	ENMV	Potyvirus	-	France/ Germany	Not known	?
Epirus cherry virus	EpCV	Ourmiavirus	-	-	Cherry	-

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Galinsoga mosaic virus	GaMV	Carmo-virus? Gallanti-virus?	-	-	*Galinsoga parviflora*	-
Impatiens necrotic spot virus	INSV	Tospovirus	-	Europe	Ornamentals	+
Lettuce big-vein associated virus (formerly *Lettuce big-vein virus)*	LBVaV	Varicosa-virus	+[1]	Europe	Several hosts incl. endive and *Sonchus* spp.	+[1]
Lettuce chlorosis virus	LCV	Crinivirus	-	USA	Several hosts, incl. beet and some weeds. Does not affect cucurbits	-
Lettuce infectious yellows virus	LIYV	Crinivirus	-	USA	Wide host range incl. cucurbits, beet, and weeds	-
Lettuce mosaic virus	LMV	Potyvirus	+	Europe	Several hosts incl. peas, weeds incl. sowthistle and dandelion, and some ornamentals	+
Lettuce necrotic spot virus	LNSV†	Nepovirus	-	Portugal	Not known	-
Lettuce necrotic stunt virus (v. similar to TBSV)	LNSV†	Tombus-virus	-	USA[2]	Not known, but possibly similar host range to TBSV	+[3]
Lettuce necrotic yellows virus	LNYV	Cyto-rhabdovirus	+	Europe	Weeds incl. *Sonchus* spp.	+
Lettuce ring necrosis virus	LRNV	Ophiovirus	+[1]	Europe	Several hosts incl. endive and *Sonchus* spp.	+[1]
Lettuce speckles mottle virus	LSMV	Umbravirus	-	USA	Beet, spinach	-

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Lettuce yellow mottle virus	LYMoV	Cyto-rhabdovirus	-	France	Not known	?
Mirafiori lettuce big-vein virus	MiLBVV /MILBVV	Ophiovirus	+	Europe	Several hosts incl. endive and *Sonchus* spp.	+
Narcissus mosaic virus	NMV	Potexvirus	-	-	Daffodil, iris	+
Pepper veinal mottle virus	PVMoV	Potyvirus	-	-	Pepper, petunia	-
Plum American line pattern virus	APLPV	Ilarvirus	-	-	*Prunus* spp.	-
Potato black ringspot virus	PBRSV	Nepovirus	-	-	Potato	-
Prune dwarf virus	PDV	Ilarvirus	-	-	*Prunus* spp.	+
Prunus necrotic ringspot virus	PNRSV	Ilarvirus	-	-	*Prunus* spp., hops, cucumber, rose	+
Red clover necrotic mosaic virus	RCNMV	Diantho-virus	-	-	Clovers, alfalfa	+
Ribgrass mosaic virus	RMV	Tobam-ovirus	-	-	Weeds incl. lamb's tongue, white campion	+
Rubus Chinese seed-borne virus	RCSV	Nepovirus	-	-	*Rubus* spp.	+
Sonchus virus	SonV	Cyto-rhabdovirus	-	-	Sowthistle	-
Sonchus yellow net virus	SYNV	Nucleo-rhabdovirus	-	USA	Weeds incl. *Sonchus* spp.	-
Sowthistle yellow vein virus	SYVV	Nucleo-rhabdovirus	-	Netherlands, Italy, France	Sowthistle	+

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Soybean dwarf virus	SbDV	Luteovirus	-	-	Several hosts incl. pea, bean, clovers, beet	-
Strawberry latent ringspot virus	SLRSV	Unassigned	-	-	Several hosts incl. strawberry, *Rubus* spp., asparagus, clover, and weeds incl. dandelion	+
Tobacco mosaic virus	TMV	Tobamo-virus	-	-	Wide host range including tomato, pepper, cucumber, and weeds.	+
Tobacco necrosis virus	TNV	Necrovirus	-	Europe	Several hosts incl. bean, cucumber.	+
Tobacco rattle virus	TRV	Tobravirus	-	Denmark, Italy	Several hosts, incl. pepper, celery, spinach, weeds incl. shepherd's purse.	+
Tobacco ringspot virus	TRSV	Nepovirus	-	Slovenia	Several hosts incl. tomato, cucumber.	+
Tobacco streak virus	TSV	Ilarvirus	-	Iran	Several hosts, incl. asparagus, endive, tomato, strawberry.	+
Tomato black ring virus	TBRV	Nepovirus	-	France	Wide host range incl. leek, beet, bean, tomato.	+
Tomato bushy stunt virus (v. similar to LNSV)	TBSV	Tombus-virus	-	USA[2]	Several hosts incl. tomato, pepper, tulip, cherry	+
Tomato infectious chlorosis virus	TiCV	Crinivirus	-	USA	Several hosts, incl. tomato, potato, and weeds incl. shepherd's purse and sowthistle	?
Tomato pseudo curly top virus	TPCTV	Topocuvirus	-	-	Several hosts incl. tomato, bean, and weeds incl. nightshade and common chickweed	-

Virus	Abbrev.	Virus type	Virus reported on cultivated lettuce		Reported natural hosts other than lettuce	Potential presence in UK on hosts other than lettuce
			UK*	Elsewhere (nearest location)		
Tomato spotted wilt virus	TSWV/ TCSV	Tospovirus	+	Europe	Very wide host range, incl. tomato, potato, spinach, cucumber, ornamentals, and weeds incl. common chickweed, *Sonchus* spp., dandelion	+
Turnip crinkle virus	TCV	Carmovirus	-	-	*Brassica* spp.	+
Turnip mosaic virus	TuMV	Potyvirus	+	Europe	Cruciferae and others incl. common chickweed.	+
Viola mottle virus	VMV	Potexvirus	-	-	Sweet violet	-

* Reported on lettuce in the UK at least once.

[1] LBVaV and LRNV are likely to be present in the UK on lettuce and other hosts as they are often transmitted alongside MiLBVV.

[2] Lettuce dieback disease has been attributed to both LNSV and TBSV.

[3] Lettuce necrotic stunt virus is thought to have a similar host range to TBSV, and so possibly present in the UK on similar hosts.

† LNSV is the acronym for both lettuce necrotic stunt virus and lettuce necrotic spot virus.

Lettuce viruses in the United Kingdom

Eleven viruses have been reported as occurring in lettuce crops within the United Kingdom. *Lettuce big-vein associated virus* (LBVaV) and *Lettuce ring necrosis virus* (LRNV) are also likely to be present as they are commonly found associated with *Mirafiori lettuce big-vein virus* (MiLBVV), the causative agent of lettuce big-vein disease, and are transmitted by the same fungal agent (*Olpidium brassicae*). Further details of these viruses are provided in Table 2. Many of the viruses listed have very wide host ranges, and all are found in at least one weed species; *Sonchus* and *Taraxacum* spp. are particularly important in this regard. Data are collated from the Plant Viruses Online database [2], EPPO PQR software [3], DPV database [4], and plant pathology handbooks [1, 5] unless otherwise stated.

Table 2: Viruses reported on lettuce in the United Kingdom.

Virus	Trans-mission	Symptoms on lettuce	Notes
Arabis mosaic virus	Nematode (e.g. *Xiphinema diversicaud-atum*), seed	Variable, including mosaics, chlorotic ring spots and occasionally necrosis. Symptoms may disappear after infection.	Found on lettuce in the UK in 1967 [6]. Very similar to *Dogwood mosaic virus*.
Beet pseudo-yellows virus	Whitefly (*Trialeurodes vaporariorum)*	Yellowing and thickening of older leaves. Symptoms can be attributed to nutrient deficiencies.	Mainly problematic indoors. Found in UK lettuce in 1990 [7].
Beet western yellows virus	Aphids (e.g. *Myzus persicae*)	Chlorotic patches that become yellow, followed by generalized interveinal yellowing. Leaves become brittle and thick.	Serious ongoing problem on outdoor lettuce in Europe.
Beet yellow stunt virus	Aphids (e.g. *Hyperomyzus lactucae*)	Yellowing of old leaves and sudden plant death	Found in UK lettuce in 1989 [8].
Cucumber mosaic virus	Aphids (e.g. *Myzus persicae*)	Variable according to location. In the UK, may be stunted with yellow mottling and necrosis.	More serious in northern Europe than southern Europe.
Dandelion yellow mosaic virus	Aphids (e.g. *Myzus persicae*)	Leaf mottling, vein chlorosis and necrosis, severe stunting.	Very similar or identical to *Lettuce mottle virus* [9].
Lettuce big-vein associated virus	*Olpidium brassicae*	Necrotic spots and rings.	Previously thought to be latent. Symptoms are similar to LRNV and may be masked by big-vein disease [10]. Assumed to be present in the UK due to association with MiLBVV.

Virus	Trans-mission	Symptoms on lettuce	Notes
Lettuce mosaic virus	Aphids (e.g. *Myzus persicae*), seed	Variable, including severe stunting, deformation and mosaic patterning, mottling, leaf deformation and rolling of outer leaves.	Serious lettuce disease worldwide.
Lettuce necrotic yellows virus	Aphids (e.g. *Hyperomyzus lactucae*)	Pale green, then chlorotic, leaves that may be flaccid. Plants are stunted.	–
Lettuce ring necrosis virus	*Olpidium brassicae*	Responsible for orange spot disease. Chlorotic spots appear orange and oily under the leaves. Leaf yellowing in advanced infection.	Assumed to be present in the UK due to association with MiLBVV.
Mirafiori lettuce big-vein virus	*Olpidium brassicae*	Chlorosis along veins, which appear larger than normal. Ruffling and blistering of leaves, stunting.	Causative agent of Lettuce big-vein disease. LBVaV, LRNV, and MiLBVV are all transmitted by *O. brassicae* and can co-occur [11].
Tomato spotted wilt virus	Thrips (e.g. *Franklinella occidentalis*)	Leaf yellowing with chlorotic/necrotic spots. Leaf deformation and wilting.	Very similar to impatiens necrotic spot virus.
Turnip mosaic virus	Aphids (e.g. *Myzus persicae*)	Yellow mottled or mosaic spots, with leaves eventually becoming completely yellow.	Found worldwide, causes occasional problems on lettuce crops. Susceptibility varies with lettuce variety.

Other viruses

Thirteen of the sixty-one viruses identified in this review as having the potential to infect lettuce (Table 1) have been found on lettuce in the UK or are likely to be present due to their strong associations with other viruses.

The list of 61 viruses includes those that have not been observed naturally on lettuce, but for which artificial inoculation is possible. Fifteen of the sixty-one viruses have not been reported on lettuce, at least commercially, and have not been observed in the UK on other species. A further twelve viruses have been reported in the UK, albeit not on lettuce, and have not reported naturally on lettuce elsewhere (Table 3). These viruses will not be discussed further.

Details of the remaining twenty-one viruses, which naturally infect lettuce but are not found on lettuce in the UK, are provided in Table 4.

Table 3: Viruses not thought to occur naturally on lettuce

Category	Viruses
Not found in the UK, and not reported elsewhere on lettuce	*Cassava green mottle virus, Cassia mild mosaic virus, Chicory yellow mottle virus, Clover yellow mosaic virus, Cucurbit yellow stunting disorder virus, Dogwood mosaic virus, Epirus cherry virus, Galinsoga mosaic virus, Pepper veinal mottle virus, Plum American line pattern virus, Potato black ringspot virus, Sonchus virus, Soybean dwarf virus, Tomato pseud-curly top virus, Viola mottle virus.*
Potentially found in the UK on other species, but not reported as occurring naturally on lettuce.	*Beet yellows virus, Carnation ringspot virus, Cymbidum ringspot virus, Narcissus mosaic virus, Prune dwarf virus, Prunus necrotic ringspot virus, Red clover necrotic mosaic virus, Ribgrass mosaic virus, Rubus Chinese seed-borne virus, Strawberry latent ringspot virus, Tobacco mosaic virus, Turnip crinkle virus.*

Table 4: Viruses occurring naturally on lettuce outside the UK

Virus	Trans-mission	Symptoms on lettuce	Notes
Alfalfa mosaic virus	Aphids (e.g. *Myzus persicae*)	Bright yellow/white spots. Damage reported as minimal.	Ubiquitous and widespread. Causes severe losses on other crop types. Regularly found on lettuce in France.
Bidens mosaic virus	Aphids (e.g. *Aphis coreopsidis*)	Mosaics, necrotic and chlorotic spots.	Only found in Brazil to date.
Bidens mottle virus	Aphids (e.g. *Myzus persicae*)	Mottling, distorted leaves, vein clearing.	Only found in USA, Taiwan, to date.
Broad bean wilt virus	Aphids (e.g. *Myzus persicae*)	Sporadic on lettuce. Variable symptoms, including slow growth.	Widespread on lettuce in Europe. Two serotypes are found: BBWV I and BBWV II.
Endive necrotic mosaic virus	Aphids (e.g. *Myzus persicae*)	Necrotic mosaic, stunting, deformation.	Many lettuce varieties are resistant, but can cause severe losses on susceptible plants. Found in Europe.
Impatiens necrotic spot virus	Thrips (e.g. *Franklinella occidentalis*)	Variable symptoms	Main host is Impatiens, but has been found on lettuce in Europe and on other species in the UK. Similar to *Tomato spotted wilt virus.*
Lettuce chlorosis virus	Whitefly (e.g *Bemisia tabaci*)	Vein lightening and leaf yellowing. Stunting.	Only found in the USA to date. *B. tabaci* is under quarantine status in the UK but is occasionally intercepted on imported crops e.g. Poinsettia.
Lettuce infectious yellows virus	Whitefly (e.g *Bemisia tabaci*)	Vein lightening and leaf yellowing. Stunting.	Only found in the USA to date. *B. tabaci* is under quarantine status in the UK but is occasionally intercepted on imported crops e.g. Poinsettia.
Lettuce necrotic spot virus	Nematodes (likely *Xiphinema* spp.)	Mosaic, mottling, concentric rings, and necrosis.	Found only in Portugal to date.
Lettuce necrotic stunt virus	Mechanical / soilborne. Possibly seed.	Severe stunting and chlorosis.	Causative agent of lettuce dieback disease. Iceberg unaffected. Primarily found in the USA. Very similar to TBSV.

Virus	Trans-mission	Symptoms on lettuce	Notes
Lettuce speckles mottle virus	Aphids (e.g. *Myzus persicae*)	Chlorosis and angular spots.	Only found in the USA to date.
Lettuce yellow mottle virus	Aphids (likely *Hyperomyzus lactucae*)	Yellow mottling, angular yellow smudges.	Found in France and characterized in 2007 [12]. No information regarding prevalence elsewhere.
Sonchus yellow net virus	Aphids (e.g. *Aphis coreopsidis*)	Vein lightening and leaf yellowing.	Only found on lettuce in the USA to date.
Sowthistle yellow vein virus	Aphids (e.g *Hyperomyzus lactucae*)	Vein lightening and poor growth.	Found on lettuce in the USA and on other hosts in the UK and Europe.
Tobacco necrosis virus	*Olpidium Brassicae*	Brown necrotic spots close to veins.	Widespread on wide host range, but infects lettuce infrequently.
Tobacco rattle virus	Nematodes (e.g. *Trichodorus minor*)	Yellow mottling, spots, and rings. Slow growth.	Very widespread on wide host range. Found on lettuce in Europe and USA.
Tobacco ringspot virus	Nematodes (e.g. *Xiphinema americanum*)	Yellow mottling and rings. Stunting.	Widespread on wide host range, but reported only rarely on lettuce.
Tobacco streak virus	Thrips (e.g. *Franklinella occidentalis*)	Necrotic/chlorotic spots and rings, slow growth.	Widespread on wide host range, but thought to be insignificant on lettuce.
Tomato black ring virus	Nematodes (e.g *Longidorus elongates*)	Ring-shaped spots.	Widespread on wide host range, but reported only rarely on lettuce.
Tomato bushy stunt virus	Mechanical / soilborne, Seed.	Stunting, leaf necrosis.	Very similar to lettuce necrotic stunt virus. Incidence on lettuce unclear.
Tomato infectious chlorosis virus	Whitefly (e.g. *Trialeurodes vaporariorum*)	Symptoms unclear on lettuce.	Found in Europe, but only identified in lettuce in the USA to date. Symptoms on tomato include leaf yellowing, rolling, and stunting.

Viruses highlighted in bold text are of primary interest due to their virulence on lettuce and/or widespread presence in the UK or Europe.

Availability of high-throughput ELISA reagents for viruses of interest

As part of HDC project FV 427, lettuce samples will be tested for virus presence using high-throughput ELISA reagents, the availability of which is shown for viruses of primary interest (Table 5). Viruses of primary interest are defined as those found on lettuce in the UK (Table 2) and highlighted in bold in Table 4. Tobacco mosaic virus is also included, as consultation with lettuce growers indicated that there was an interest in testing for the presence of this virus.

Table 5: Availability of high-throughput ELISA reagents for viruses of interest

Virus	**Supplier**
Alfalfa mosaic virus	Agdia, Neogen, Loewe Biochimica
Arabis mosaic virus	Agdia, Neogen, Loewe Biochimica
Beet pseudo-yellows virus	None found
Beet western yellows virus	Agdia, Neogen, Loewe Biochimica
Beet yellow stunt virus	None found
Broad bean wilt virus	Agdia, Neogen, Loewe Biochimica
Cucumber mosaic virus	Agdia, Neogen, Loewe Biochimica
Dandelion yellow mosaic virus	None found
Endive necrotic mosaic virus	None found
Lettuce big-vein associated virus	None found
Lettuce mosaic virus	Agdia, Neogen, Loewe Biochimica
Lettuce necrotic yellows virus	None found
Lettuce necrotic stunt virus	Loewe Biochimica
Lettuce ring necrosis virus	None found
Mirafiori lettuce big-vein virus	Neogen, Loewe Biochimica
Tobacco mosaic virus	Agdia, Neogen, Loewe Biochimica
Tobacco rattle virus	Agdia, Neogen, Loewe Biochimica
Tomato spotted wilt virus	Agdia, Neogen, Loewe Biochimica
Turnip mosaic virus	Agdia, Neogen, Loewe Biochimica

Catalogues from Agdia-Biofords (France), Loewe Biochimica (Germany), and Neogen Europe (UK) were searched for all viruses. Remaining viruses were searched for available reagents from any supplier, but no high-throughput reagents for those viruses were found.

Discussion

The purpose of this literature review was to determine the primary plant viruses that can infect lettuce (Table 1), and, of those, which have been reported on lettuce in the UK (Table 2), or elsewhere (Table 4).

Eleven viruses have been reported on UK lettuce, with an additional two viruses also likely to be present. Some of these viruses, such as *Arabis mosaic virus* and *Beet yellow stunt virus*, have been formally reported in the UK only once or twice, but it is possible that they persist, undetected, and that symptoms are attributed to other causes such as nutritional deficiency. A number of viruses are found on UK species other than lettuce that have nevertheless been found on lettuce elsewhere. It is similarly possible that some of these viruses are present in the UK but have not yet been recognised. This is particularly possible for viruses that have broad host ranges and are already found widely on lettuce in Europe.

Virus presence will be assessed in this study using ELISA assays, and twelve viruses will be tested on two separate occasions during the season. High-throughput reagents are available for a number of viruses of interest in a 96-well format (Table 5). An initial list of eight viruses for testing was compiled based on ELISA availability and presence in the UK (Table 6) and lettuce growers were consulted on the choice of the remaining four viruses.

Growers expressed interest in testing for *Beet yellow stunt virus* (BYSV), *Lettuce necrotic stunt virus* (LNSV), *Tobacco mosaic virus* (TMV) and *Impatiens necrotic spot virus* (INSV). It is unclear whether TMV causes problems on lettuce, but its widespread distribution and broad host range make this a good additional choice. Whilst LNSV is primarily found in the USA, it causes severe lettuce dieback, making this is another good choice for additional testing. INSV is very similar to *Tomato spotted wilt virus* (TSWV), and these can be tested in combination. As the aim of the first year of this study is a broad screen, INSV and TSWV will be co-tested. Unfortunately, no high-throughput reagents are available for testing BYSV. Finally, *Broad bean wilt virus* (BBWV) will also be assessed due to its presence on lettuce in Europe and elsewhere. Virus testing choices will be reassessed as the study progresses.

Table 6: Viruses that will be assessed in the first year of this study

Number	Virus
1	*Alfalfa mosaic virus*
2	*Arabis mosaic virus*
3	*Beet western yellows virus*
4	*Broad bean wilt virus*
5	*Cucumber mosaic virus*
6	*Lettuce mosaic virus*
7	*Lettuce necrotic stunt virus*
8	*Mirafiori lettuce big-vein virus*
9	*Tobacco mosaic virus*
10	*Tobacco rattle virus*
11	*Tomato spotted wilt virus / Impatiens necrotic spot virus*
12	*Turnip mosaic virus*

References

1. Koike, S.T., Gladders, P. and Paulus, A.O. (2007). Vegetable diseases: a colour handbook. CRC Press.

2. Brunt, A.A., et al. (1996 onwards). Plant Viruses Online: Descriptions and Lists from the VIDE Database., http://biology.anu.edu.au/Groups/MES/vide/.

3. EPPO (2014). PQR - EPPO database on quarantine pests. http://www.eppo.int.

4. Adams, M.J. and Antoniw, J.F. (2006). DPVweb: a comprehensive database of plant and fungal virus genes and genomes. Nucleic Acids Res 34:D382-5.

5. Blancard, D., et al. (2006). A colour atlas of diseases of lettuce and related salad crops: observation, biology and control. Academic Press.

6. Walkey, D.G.A. (1967). Chlorotic stunt of lettuce caused by arabis mosaic virus. Plant Pathology 16(1): 20-22.

7. Coffin, R.S. and Coutts, R.H.A. (1990). The occurrence of beet pseudo-yellows virus in England. Plant Pathology 39:632-635.

8. Wright, D.M., Fletcher, J.T. and McPherson, G. M. (1989). Detection of beet yellow stunt virus in England. Plant Pathology 38:297-299.

9. Pavan, M.A., et al. (2008). Virus Diseases of Lettuce in Brazil, in Plant Viruses. Global Science Books.

10. Verbeek, M., et al. (2013). Evidence for Lettuce big-vein associated virus as the causal agent of a syndrome of necrotic rings and spots in lettuce. Plant Pathology 62:444-451.

11. Moreno, A. and Fereres, A. (2012). Virus diseases in lettuce in the Mediterranean Basin, in Viruses and Virus Diseases of the Vegetables in the Mediterranean Basin, G. Loebenstein and H. Lecoq, Eds. Academic Press.

12. Heim, F., et al. (2008). Complete nucleotide sequence of a putative new cytorhabdovirus infecting lettuce. Arch Virol 153(1):81-92.

