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| **Project number:** | FV 365 |
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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**



**SCIENCE SECTION**

# GROWER SUMMARY

## Headlines

- Despite low aphid numbers, TuYV incidences of 55-60% were found in cauliflower and sprout crops in the 2010/11 season.

- Growers could double their yields / profits by growing the least affected Brussels sprout variety, rather than the most susceptible ones, in years where aphid numbers are at average or high levels.

## Background

Turnip yellows virus (TuYV, previously known as Beet western yellows virus) is widespread in the UK and we have found very high incidences in some years (100% of plants infected in some crops we have sampled). TuYV is transmitted by aphids and infects a number of weeds and most Brassica crops, including oilseed rape, which acts as a very large overwintering reservoir / host for the virus and its aphid vectors. We have found oilseed rape crops with 100% TuYV infection in recent years.

Our previous research has shown that this virus can reduce the yields of cabbage by 16-36% depending on the variety. But little is known about the effect of the virus on other vegetable Brassicas.

In order to investigate how widespread the virus is in winter cauliflower and Brussels sprout crops in the UK, sampling and testing was carried out.

Commercial cauliflower crops were sampled in Lincolnshire, Kent, Cornwall and the Isle of Wight in the winter of 2010/11 and tested for the presence of Turnip yellows virus. Commercial Brussels sprout crops were sampled in Lincolnshire, Lancashire, Yorkshire and Scotland in the winter of 2010/11 and tested for the presence of Turnip yellows virus.

In order to determine the effect of Turnip yellows virus on different cauliflower and Brussels sprout varieties, fully replicated controlled experiments were carried out.

## Summary of the project and main conclusions

- Despite low aphid numbers in 2010, Turnip yellows virus incidences of up to 60% were found in cauliflower crops and 55% in Brussels sprout crops.
- These results clearly indicate that in years when there are average, or high aphid numbers, vegetable Brassica crops in many regions (particularly the main Brassica growing regions) are likely to suffer 100% infection by Turnip yellow virus.
- Controlled experiments in gauzehouses, showed that Turnip yellows virus induced very little in terms of leaf symptoms in Brussels sprout or cauliflower plants. Only by growing infected Brussels sprout plants side by side with uninfected plants, was it clear to the eye that Turnip yellows virus infection stunted plant growth in all seven varieties tested (by 7-16%) .
- These results confirm that growers would not be aware that their crops were infected by the virus, unless they had them tested for the presence of the virus.
- Turnip yellows virus reduced the marketable yield of seven Brussels sprout varieties by up to 65%. The variety that showed the lowest marketable yield reduction had its yield reduced by 22%.
- The highest marketable yield achieved for virus-infected plants was from the variety Speedia which produced double the yield of virus-infected plants of two other varieties and almost three times the yield of another variety.
- These results clearly indicate that in years when there is high aphid activity and a lot of Turnip yellows virus infection, growers could double their profits by growing the least affected Brussels sprout variety rather than the most susceptible ones.
- Even the highest yielding Brussels sprout variety had its marketable yield reduced 30% by Turnip yellows virus.
- This result and the higher marketable yield reductions in other varieties (up to 65%) clearly demonstrate the need for further research on the control of Turnip yellows virus in vegetable Brassicas.
- Turnip yellows virus significantly reduced the shelf life of two of the seven sprout varieties tested.

### *Incidence of Turnip yellows virus in cauliflower and Brussels sprouts*

High levels of Turnip yellows virus (TuYV) infection were found in cauliflower crops in England (up to 60% of plants infected in particular crops) in 2010/11 despite low levels of aphids in 2010. The infection levels detected varied between 0% and 60% and are indicated in Table 1.

**Table 1:** The incidence of Turnip yellows virus in cauliflower crops

| Region | Field / grid reference | Turnip yellows virus incidence (= % infection) in cauliflower crops |
|---|---|---|
| Lincolnshire | Butterwick | 20% |
| Lincolnshire | Fosdyke | 5% |
| Lincolnshire | Frieston Shore | 0% |
| Lincolnshire | Frieston | 25% |
| Lincolnshire | Holbeach St Marks | 20% |
| Lincolnshire | TF096453 | 10% |
| Lincolnshire | TF096453 | 60% |
| Lincolnshire | TF093457 | 5% |
| | | |
| Kent | Crumps | 15% |
| Kent | Front field | 25% |
| Kent | Cottington | 55% |
| | | |
| Cornwall | Perranuthnoe Marazion | 40% |
| Cornwall | Rose Goonhaven | 50% |
| Cornwall | Strawberry Lane Hayle | 30% |
| | | |
| Isle of Wight | Field 1 | 0% |
| Isle of Wight | Field 2 | 10% |
| Isle of Wight | Field 3 | 10% |

High levels of Turnip yellows virus infection were also found in Brussels sprouts crops in the UK (up to 55% of plants infected in particular crops) in 2010/11. The infection levels detected varied between 0% and 55% and are indicated below.

**Table 2:** The incidence of Turnip yellows virus in Brussels sprout crops.

| Region | Field / grid reference | Turnip yellows virus incidence (= % infection) in Brussels sprout crops |
|---|---|---|
| Lincolnshire | Butterwick | 10% |
| Lincolnshire | Swinesherd | 40% |
| Lincolnshire | Friskney | 55% |
| | | |
| Lancashire | Cropper’s Lane | 20% |
| Lancashire | Poppy Lane | 5% |
| Lancashire | Scarith Hill | 10% |
| Lancashire | Edge Hill | 15% |
| | | |
| Yorkshire | Colnabs Field | 25% |
| Yorkshire | Mansions Field | 25% |
| Yorkshire | Chris’ field | 10% |
| | | |
| Scotland | Rankeiar | 0% |
| Scotland | Kenly Green | 5% |
| Scotland | Ravensby | 0% |

 

***The effect of Turnip yellows virus on the yield and storage***

Cauliflower varieties Alpen, CAU820, Cendis, Jerome, Medallion, Trewint and Triomphant were grown in two gauzehouses at Wellesbourne in a fully replicated experiment where half of the plants of each cultivar were infected with Turnip yellows virus and the other half were left uninfected.

**Figure 1.** Gauzehouse with cauliflower growing.

Very cold temperatures of < -14$^{o}$C were experienced on site and the experiment was affected. Although there were small, but significant differences in the amount of virus detected in the different cultivars and differences in the yields of the cultivars, the adverse effects of the cold temperatures on the cauliflowers does not give us confidence in this data.

The experiment on the effect of Turnip yellows virus on Brussels sprout varieties Dominator, Doric, Genius, Maximus, NZ16-4391, Petrus and Speedia went well. The virus caused large (30 - 65%) and statistically significant reductions in marketable yield of six of the seven varieties and the virus caused a 22% reduction in the marketable yield of the cultivar where there wasn't a 'statistically significant' effect (Table 3).

 

**Table 3:** The effect of Turnip yellows virus on the marketable yield of Brussels sprout plants.

| Variety | Mean marketable weight (g) of sprouts from uninfected plants | Mean marketable weight (g) of sprouts from infected plants | % reduction in yield caused by TuYV |
|---|---|---|---|
| Doric | 969 | 761 | 22 |
| Speedia | 1482 | 1039* | 30 |
| Petrus | 1045 | 717* | 31 |
| Maximus | 879 | 580* | 34 |
| Genius | 1282 | 730* | 43 |
| Dominator | 1287 | 499* | 61 |
| NZ16-4391 | 1008 | 354* | 65 |

*Weight of sprouts from infected plants significantly less than weight from uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 281.

Turnip yellows virus reduced the height of plants for all seven varieties significantly, by 7-16%. Turnip yellows virus significantly reduced the shelf life of two of seven sprout varieties.

**Figure 2:** The effect of Turnip yellows virus on Brussels sprouts. An uninfected sprout plant of cultivar Genius is shown (top) and a virus-infected Genius plant (bottom).

There were significant differences in the amount of Turnip yellows virus detected in the seven different sprout varieties, however, the amount of virus detected did not appear to be clearly related to the yield reductions of all varieties, or effect on shelf life caused by the virus.

## Financial Benefits

An estimate of the mean incidence of Turnip yellows virus in sprouts in the U.K. in 2010/11 based on the fields we sampled was 16.9%.

The provisional area of Brussels sprouts grown in the UK in 2010/11 was 3,041 hectares (http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/bhs/) so this equates to 513.9 hectares infected by Turnip yellows virus.

The provisional value of the Brussels sprout crop in the UK in 2010/11 was £38.756 million (http://www.defra.gov.uk/statistics/foodfarm/landuselivestock/bhs/), based on the provisional area of 3,041 hectares, this gives a value of £12,744.5 / hectare.

So the area affected by Turnip yellows virus (513.9 hectares) had a value £6.55 million. If we take the minimum marketable yield reduction for infected plants of 22% from our trials, this would equate to losses in 2010/11 of £1.44 million.

If we take the maximum marketable yield reduction of a current cultivar of 61% from our trials, this would equate to yield losses of £4 million, giving a range of £1.44 - £4 million for losses due to Turnip yellows virus in 2010/11.

Without details of the area of each cultivar grown, it is difficult to predict the financial benefit that could have been achieved by growing the most tolerant variety. The calculations suggest that significant benefits could be achieved (even in years where there are few aphids and relatively low virus incidences) by growing the more virus-tolerant variety.

In years like 2011 when much higher Turnip yellow virus incidences are being detected in crops, benefits from growing a tolerant variety could be in the £10s of millions.

## Action points for growers

- The results from this first phase of the project emphasise the importance of developing control measures for Turnip yellows virus in vegetable Brassica crops, particularly those that are in the field during aphid peak flight periods.

- The time of infection of Brussels sprouts and winter cauliflower by Turnip yellows virus and the efficacy of a range of insecticidal treatments in controlling the virus are being investigated in the second phase of this project (FV 365a).

- Until the results of Phase 2 of the project are available, during the growing season, growers should go to the Rothamsted Insect Survey Aphid bulletin (http://www.rothamsted.bbsrc.ac.uk/insect-survey/STAphidBulletin.php), locate their closest trap site, and monitor bulletins weekly.

- When the presence of the major vectors of Turnip yellows virus, *Myzus persicae* gp start to be caught in their local trap, they should consider treating their crops with an approved aphicide.

# SCIENCE SECTION

## Introduction

### The problem

- The virus *Turnip yellows virus* (TuYV, formerly known as *Beet western yellows virus*), is very common in oilseed rape (OSR) in the UK and isolates that infect oilseed rape readily infect horticultural Brassicas. We have recorded incidences of 100% in OSR in our surveys over the past 4 years, representing a massive reservoir of infection affecting horticultural Brassicas. Higher incidences have been found in a major vegetable Brassica growing area (Lincs) than in arable areas (North Yorks and Warks).
- TuYV is also very common in horticultural Brassicas and all the crops we have tested were infected; we recorded incidences of 100% in cauliflower, cabbage and calabrese crops in Lincolnshire, 53% in Brussels sprouts in Lincolnshire and 68% in Brussels sprouts in Lancashire in recent years and 81% in cabbage in Lincolnshire this year.
- Our previous research has shown that this virus can reduce the yields of cabbage by 16-36% depending on the cabbage variety (Hunter et al. (2002).

### The need for the project

- Little is known about the effect of the virus on vegetable Brassicas other than our data on cabbage.
- In most crops, TuYV infection is symptomless, consequently growers are not aware of its presence and the damage it is causing. It has been shown to reduce the yield of cabbage by over 30% at harvest. It also dramatically affects the quality of cabbage causing internal tipburn. Tipburn has caused losses of over 40% in stores in some years. As the virus is so common in the different Brassica vegetable types and there are such large reservoirs in oilseed rape, research is needed to determine the effect of the virus, particularly on the Brassica crop types with a long growing season (overwintered cauliflower and Brussels sprout) where they are exposed to infection for a longer period of time and there is much greater opportunity for the virus to affect tonnage and quality because of the long growing period.

**Opportunities**

- Preliminary knowledge of the effect of the virus on the most vulnerable Brassicas (overwintered cauliflower and Brussels sprouts) will allow avoidance and control strategies to be developed.
- Preliminary knowledge of the incidence of TuYV in different regions of the UK will reveal where the biggest problems are and hence where avoidance and control strategies are most needed and will be most beneficial.
- Preliminary knowledge of the relative susceptibilities of different overwintered cauliflower and Brussels sprout varieties will eventually allow growers to make informed choices in high risk areas and thereby reduce losses in yield and also post-harvest quality once Phase 2 of the project has been completed.

**Outline of phase 1 of the project**

- In order to investigate how widespread the virus is in winter cauliflower and Brussels sprout crops in the U.K. sampling and testing was carried out.
- Commercial cauliflower crops were sampled in Lincolnshire, Kent, Cornwall and the Isle of Wight in the winter of 2010/11 and tested for the presence of Turnip yellows virus.
- Commercial Brussels sprout crops were sampled in Lincolnshire, Lancashire, Yorkshire and Scotland in the winter of 2010/11 and tested for the presence of Turnip yellows virus.
- In order to determine the effect of Turnip yellows virus on different cauliflower and Brussels sprout varieties, fully replicated controlled experiments were carried out where a range of cauliflower and Brussels sprout varieties were infected with Turnip yellows virus and grown alongside uninfected control plants of each variety.

## Materials and methods

*Virus isolate used in experiments at University of Warwick, Wellesbourne.*

The U.K. isolate of Turnip yellows virus (TuYV) found to cause tipburn by Hunter *et al*. (2002) was used in the experiments carried out in gauzehouses to determine the effect of TuYV on cauliflower and Brussels sprouts. TuYV is not mechanically transmissible, so aphids have to be used to infect plants with this virus. The University of Warwick MP1S colony of the peach potato aphid (*Myzus persicae*) was used to transmit TuYV in these experiments.

*Cauliflower and Brussels sprout cultivars used in experiments at University of Warwick, Wellesbourne.*

The 7 varieties of cauliflower that were tested for susceptibility to TuYV in gauzehouses at the University of Warwick, Wellesbourne were as follows:

Alpen F1 (Syngenta)
CAU820 F1 (Tozer)
Cendis F1 (Vilmorin)
Jerome F1 (Elsoms)
Medallion F1 (Elsoms)
Trewint F1 (Royal Sluis)
Triomphant F1 (Clause)

The 7 varieties of Brussels sprout that were tested for susceptibility to TuYV in gauzehouses at the University of Warwick, Wellesbourne were as follows:

Dominator F1 (Elsoms)
Doric F1 (Elsoms)
Genius F1 (Syngenta)
Maximus F1 (Syngenta)
NZ16-4391 F1 (Nickerson-Zwaan)
Petrus F1 (Syngenta)
Speedia F1 (Zaden)

*Gauzehouse experiments at University of Warwick in 2010/11*

The 7 Brussels sprout and 7 cauliflower varieties were planted into 345 trays on 6$^{th}$ April 2010 and 28$^{th}$ June, 2010 respectively. Trays containing all varieties were infected with TuYV on 26$^{th}$ April, 2010 (sprouts) and 26$^{th}$ July, 2010 (cauliflower). This was done by transferring aphids (*Myzus persicae*) from TuYV-infected oilseed rape plants to the plants growing in the trays. An equal number of Brussels sprout and cauliflower plants were also infested with aphids (*M. persicae*) not carrying the virus, as control uninfected plants. The plants were subsequently drenched with Dursban and sprayed with Dovetail and Plenum to kill the aphids.

The soil in the gauzehouses was fertilised prior to planting and top-dressed in September, 2010. The Brussels sprouts were transplanted in to two gauzehouses with spacings of 24 inches in the rows and 20 inches between rows on 3rd June 2010. The cauliflower plants were also transplanted in to two further gauzehouses with the same spacings on 1st September, 2010. Batches of three plants of each cultivar per treatment (TuYV-infected and uninfected) were transplanted into each of the gauzehouses as plots. The experiment was designed as a split plot. Within each house, varieties were randomly allocated to plots within 3 replicate areas. Within each variety block, the plants were divided into 2 blocks of 3 and randomly allocated infected or not. Data were analysed by analysis of variance using Genstat. Means of data were taken to avoid problems with the data not being normally distributed. There was a total of 126 sprout, or cauliflower plants per gauzehouse, giving a total of 252 sprout or cauliflower plants for each experiment. One of the gauzehouses with Brussels sprouts in is shown in Fig. 1 and one with cauliflower in is shown in Fig. 2.

**Figure 1:** Gauzehouse no. 1 with Brussels sprouts growing in photographed on 1st December, 2010.

**Figure 2.** Gauzehouse no. 3 with cauliflower growing in photographed on 8th March, 2011.

Following transplanting, the gauzehouses were sprayed at intervals with the fungicides Rovral WP, Bravo 500, Repulse and Nativo. Every two weeks they were also given insecticide sprays alternating between Toppel and Dovetail in order to ensure no aphids infested the plants and compromised the two treatments (TuYV-infected and uninfected).

The Brussels sprouts and cauliflower plants were visually assessed for symptoms of virus infection at regular intervals.

Brussels sprout varieties were harvested as they matured. The height of variety Speedia plants was measured on 1st November, 2010 and sprouts harvested the following day (2nd November). Variety Maximus plants were harvested 29th November, 2010 and their heights measured on 1st December, 2010. The heights of the plants of the remaining varieties (Dominator, Doric, Genius, NZ16-4391 and Petrus) were measured on 7th March, 2011 and they were harvested the following day (8th March, 2011). The total weight of all the sprouts from each plant was recorded at harvest, the weight of marketable sprouts following removal of small (<25mm) and rotting sprouts for each plant was also recorded. Following harvest, the greenness of sprouts from each plant was scored on a scale of 1 – 9, where 1 was pale yellow and 9 was green (Fig. 3). After storage for 7 days in a lighting regime of 12 hours light and 12 hours dark at ~20$^{o}$C, the greenness of the sprouts was scored again, in order to get a measure of shelf life.

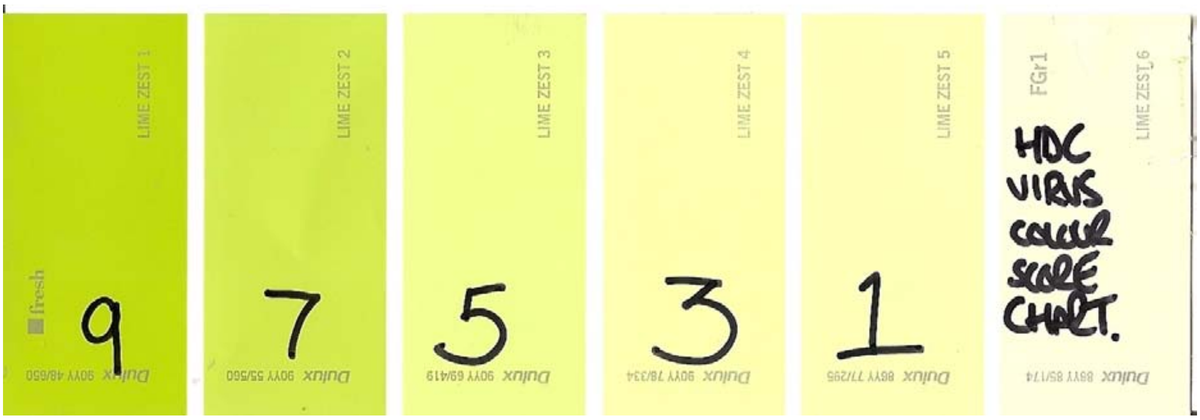


**Figure 3:** Colour chart used to estimate the greenness of sprout batches from each plant.

Cauliflower plants were harvested 20$^{th}$ April, 2011 and heads trimmed and weighed, with the exception of variety CAU820, which was harvested on 14$^{th}$ May, 2011.

*Serological testing of plants for virus infection*

In order to determine the amount of virus in plants, quantitative tests known as Enzyme-linked Immunosorbent Assays (ELISA) were carried out on leaves from plants that had been infected with TuYV.

On 6$^{th}$ July, 2010, 20$^{th}$ October, 2010 and 22$^{nd}$ February, 2011, leaf samples were taken from those Brussels sprout plants infected with TuYV. The leaves were macerated between electric rollers and the sap collected for testing for the presence of TuYV by Enzyme-linked Immunosorbent Assay (ELISA). A triple antibody sandwich (TAS)-ELISA format was used for the TuYV testing, using the same antisera as in the experiments carried out in 1999-2000 and as described by Hunter *et al*. (2002). The cauliflower plants were tested in the same manner on 5$^{th}$ August, 2010, 15$^{th}$ November, 2010, 3$^{rd}$ December, 2010 and 20$^{th}$ April, 2011.

Plants were also sampled from commercial cauliflower and Brussels sprout crops and tested by ELISA in order to determine the incidence of TuYV in the 2010/11 crop season. Leaves from twenty plants were collected whilst following a 'W' transect across each field. Cauliflower crops in Kent, Lincolnshire, Cornwall and the Isle of Wight were sampled and Brussels sprout crops in Scotland, Lincolnshire, Lancashire and Yorkshire. More details of the fields sampled can be found in Tables 8 and 9.

## Results

### *Visual assessment of plants*

Regular visual assessment of plants didn't reveal any virus-like symptoms in the leaves of infected Brussels sprout, or cauliflower plants, consistent with infections of other Brassica plants by this virus. However, it was clear to see that infected Brussels sprout plants were shorter / stunted relative to uninfected plants of the same variety (Fig. 4).

**Figure 4:** The reduced size of a Turnip yellows virus-infected Dominator Brussels sprout plant (right) relative to an uninfected Dominator plant (left) on 10th August 2010.

***The effect of Turnip yellows virus (TuYV) on the height of Brussels sprout plants.***

Measurements of the height of Brussels sprout plants at harvest clearly showed that TuYV reduced the height of plants (Table 1).

**Table 1:** The effect of Turnip yellows virus on the height of Brussels sprout plants.

| Variety | Mean height (cm) of uninfected plants at harvest | Mean height (cm) of infected plants at harvest | % reduction in height caused by TuYV |
|---|---|---|---|
| Speedia | 101 | 94* | 7 |
| Petrus | 97 | 88* | 9 |
| Genius | 91 | 83* | 9 |
| Maximus | 91 | 81* | 10 |
| Doric | 103 | 89* | 14 |
| Dominator | 100 | 84* | 16 |
| NZ16-4391 | 93 | 78* | 16 |

*Height of infected plants significantly less than height of uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 5.6.

As can be seen in Table 1, TuYV significantly reduced the height of infected plants relative to uninfected plants of the same variety. The minimum height reduction was 7% (Speedia) and the maximum was 16% (NZ16-4391 and Dominator).

***The effect of Turnip yellows virus (TuYV) on the yield of Brussels sprout plants.***

TuYV significantly reduced the marketable yield of sprouts from all of the varieties except Doric (Table 2). The marketable yield was those sprouts that remained after removing small (<5mm) and rotting sprouts.

**Table 2:** The effect of Turnip yellows virus on the marketable yield of Brussels sprout plants.

| Variety | Mean marketable weight (g) of sprouts from uninfected plants | Mean marketable weight (g) of sprouts from infected plants | % reduction in yield caused by TuYV |
|---|---|---|---|
| Doric | 969 | 761 | 22 |
| Speedia | 1482 | 1039* | 30 |
| Petrus | 1045 | 717* | 31 |
| Maximus | 879 | 580* | 34 |
| Genius | 1282 | 730* | 43 |
| Dominator | 1287 | 499* | 61 |
| NZ16-4391 | 1008 | 354* | 65 |

*Weight of sprouts from infected plants significantly less than weight from uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 281.

As can be seen in Table 2, the minimum yield reduction caused by TuYV was 22% (Doric), whereas the maximum was a massive 65% (NZ16-4391). The difference between infected and uninfected plants is clearly visible in Figures 5 - 7. Infected plants produced less sprouts per plant and smaller sprouts than uninfected plants (Figs. 5 – 7).

**Figure 5:** The effect of Turnip yellows virus on Brussels sprouts. An uninfected sprout plant of cultivar Genius is shown (top) and a virus-infected Genius plant (bottom).


**Figure 6:** The effect of Turnip yellows virus on Brussels sprouts. Sprouts harvested from three uninfected sprout plants of cultivar Genius (top) and sprouts harvested from three virus-infected Genius plants (bottom).


**Figure 7:** The effect of Turnip yellows virus on Brussels sprouts. Sprouts harvested from three uninfected sprout plants of cultivar Maximus (top) and sprouts harvested from three virus-infected Maximus plants (bottom).

TuYV also reduced the total weight of sprouts harvested from plants (includes the small [<5mm] and rotting sprouts) (Table 3), although differences were only statistically significant for 4 of the seven varieties.

**Table 3:** The effect of Turnip yellows virus on the total yield of Brussels sprout plants.

| Variety | Mean total weight (g) of sprouts from uninfected plants | Mean total weight (g) of sprouts from infected plants | % reduction in yield caused by TuYV |
|---|---|---|---|
| Speedia | 1854 | 1640 | 12 |
| Doric | 1643 | 1168* | 29 |
| Petrus | 1208 | 847 | 30 |
| Maximus | 1015 | 658 | 35 |
| Genius | 1415 | 862* | 39 |
| Dominator | 1478 | 690* | 53 |
| NZ16-4391 | 1262 | 552* | 56 |

*Weight of sprouts from infected plants significantly less than weight from uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 369.

The ranking of lines for percentage total yield reduction was similar to that for marketable yield reduction with the exception of the varieties Speedia and Doric.

***The effect of Turnip yellows virus (TuYV) on the yield of cauliflower plants.***

The yields of cauliflower plants from the gauzehouse experiment are shown in Table 4. Although there are large differences between the yields of infected and uninfected plants, due to the large variation in the data, the least significant difference was 515g, resulting in no significant differences. The plants were severely affected by the very cold temperatures we experienced at Wellesbourne (-14.1$^{0}$C). The adverse effect of the cold temperatures on the cauliflowers does not give us confidence in this data.

**Table 4:** The effect of Turnip yellows virus on the yield of cauliflower plants.

| Variety | Mean total weight (g) of heads from uninfected plants | Mean total weight (g) of heads from infected plants | % change in yield of infected plants relative to uninfected plants |
|---|---|---|---|
| CAU820 | 837 | 1308 | +56 |
| Cendis | 1791 | 1858 | +4 |
| Trewint | 1164 | 1138 | -2 |
| Triomphant | 1611 | 1561 | -3 |
| Medallion | 1551 | 1200 | -23 |
| Jerome | 1551 | 1118 | -28 |
| Alpen | 1058 | 742 | -30 |

*Weight of cauliflower heads from infected plants significantly different to weight from uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 515.

Most of the varieties showed a reduction, albeit not a statistically significant one, in weight following TuYV infection. As mentioned in the materials and methods section, the variety CAU was harvested very late, however, despite the lateness, the curds of many of the uninfected plants had not matured, which probably explains why the infected plants yielded more than the uninfected.

***The effect of Turnip yellows virus on the shelf life of Brussels sprouts.***

Estimates of the greenness of sprouts at harvest and subsequently following storage for one week, showed that in two varieties (Dominator and Petrus), sprouts from TuYV-infected plants lost more colour than those from uninfected plants of the same cultivar and hence had a statistically significantly shorter shelf life than those from uninfected plants (Table 5).

**Table 5:** The effect of Turnip yellows virus on the shelf life

| Cultivar | Mean loss of greenness on scale of 0-9 of sprouts from uninfected plants | Mean loss of greenness on scale of 0-9 of sprouts from infected plants | % reduction of shelf life caused by TuYV |
|---|---|---|---|
| Maximus | 0.8 | 0.8 | 0 |
| Speedia | 0.9 | 0.9 | 0 |
| NZ16-4391 | 2.6 | 2.6 | 0 |
| Genius | 1.1 | 1.7 | 8 |
| Doric | 2.9 | 3.4 | 8 |
| Petrus | 2.0 | 3.0* | 14 |
| Dominator | 2.1 | 3.3* | 15 |

*Loss of greenness of sprouts from infected plants significantly more than that from uninfected plants of the same variety. Least significant difference (L.S.D.) between two means for the difference to be significant at 5% is 0.8.

***The amount of Turnip yellows virus detected in the different Brussels sprout and cauliflower varieties.***

The ELISA tests on the Brussels sprout plants from the gauzehouse experiment indicated that there were significant differences in the amounts of the virus TuYV in the different varieties (Table 6).

**Table 6:** The mean ELISA values from the test carried out on 20th October, 2010 to investigate the amounts of Turnip yellows virus in the different Brussels sprout varieties.

| Variety | Mean ELISA value[1] |
|---|---|
| Speedia | 0.38 |
| Petrus | 0.38 |
| NZ16-4391 | 0.43 |
| Maximus | 0.91 |
| Dominator | 1.09 |
| Genius | 1.53 |
| Doric | 1.72 |
| Least significant difference[2] | 0.30 |

[1] This value indicates the quantity of TuYV detected in the sprout plants, the higher the value, the greater the amount of TuYV present.
[2]The least difference (L.S.D.) between two means for the difference to be significant at 5% is 0.30 (476 degrees of freedom).

As can be seen from Table 6, some of the sprout varieties had statistically significantly less TuYV in their leaves than other varieties.

The ELISA tests on the cauliflower plants from the gauzehouse experiment indicated that there were significant differences in the amounts of the virus TuYV in the different varieties (Table 7).

**Table 7:** The mean ELISA values from the test carried out on 20th April, 2011 to investigate the amounts of Turnip yellows virus in the different cauliflower varieties.

| **Variety** | **Mean ELISA value[1]** |
|---|---|
| Medallion | 0.76 |
| Triomphant | 0.81 |
| Alpen | 0.84 |
| Trewint | 0.84 |
| CAU820 | 0.96 |
| Cendis | 1.01 |
| Jerome | 1.04 |
| Least significant difference[2] | 0.14 |

[1] This value indicates the quantity of TuYV detected in the cauliflower plants, the higher the value, the greater the amount of TuYV present.

As for the sprout experiment, some of the cauliflower varieties had statistically significantly less TuYV in their leaves than other varieties.

***The incidence of Turnip yellows virus in commercial Brussels sprout and cauliflower crops.***

The incidence of TuYV infections of commercial Brussels sprout and cauliflower crops varied from region to region and from field to field (Tables 8 and 9). There wasn't a large difference between the overall incidence of TuYV in Brussels sprouts (17%) and cauliflower 22%). The highest incidence in sprouts (55% in Lincolnshire) wasn't much different to the highest level in cauliflower (60% in Lincolnshire).

Regionally, the highest incidences of TuYV in sprouts were in Lincolnshire (10 - 55%) and the lowest in Scotland (0 - 5%); Lancashire (5 - 20%) and Yorkshire (10 – 25%) had intermediate levels.

**Table 8:** The incidence of Turnip yellows virus in commercial Brussels sprout crops.

| Region | Field / grid reference | Variety | Date of sampling | Turnip yellows virus incidence (= % infection) in Brussels sprout crops |
|---|---|---|---|---|
| Lincolnshire | Butterwick | Cobus | 1 November 2010 | 10% |
| Lincolnshire | Swinesherd | Cobus | 1 November 2010 | 40% |
| Lincolnshire | Friskney | Maximus | 1 November 2010 | 55% |
| | | | | |
| Lancashire | Cropper's Lane | Clodius | 26 November 2010 | 20% |
| Lancashire | Poppy Lane | Genius | 26 November 2010 | 5% |
| Lancashire | Scarith Hill | Doric | 26 November 2010 | 10% |
| Lancashire | Edge Hill | NZ 4021 | 26 November 2010 | 15% |
| | | | | |
| Yorkshire | Colnabs Field | Doric | 29 November 2010 | 25% |
| Yorkshire | Mansions Field | Petrus | 29 November 2010 | 25% |
| Yorkshire | Chris' field | Batavus | 29 November 2010 | 10% |
| | | | | |
| Scotland | Rankeiar | Maximus | 1 November 2010 | 0% |
| Scotland | Kenly Green | Genius | 1 November 2010 | 5% |
| Scotland | Ravensby | Petrus | 1 November 2010 | 0% |
| | | | | |
| **All 13 fields** | | | | **17%** |

Regionally, there were high incidences of TuYV in cauliflowers in Lincolnshire (0 - 60%), Kent (15 - 55%) and Cornwall (30 - 50%); only low levels were detected on the Isle of Wight (0 - 10%).

**Table 9:** The incidence of Turnip yellows virus in commercial cauliflower crops.

| Region | Field / grid reference | Variety | Date of sampling | Turnip yellows virus incidence (= % infection) in cauliflower crops |
|---|---|---|---|---|
| Lincolnshire | Butterwick | Isadora | 1 November 2010 | 20% |
| Lincolnshire | Fosdyke | FT3062 | 1 November 2010 | 5% |
| Lincolnshire | Frieston Shore | Tintagel | 1 November 2010 | 0% |
| Lincolnshire | Frieston | Charif | 26 November 2010 | 25% |
| Lincolnshire | Holbeach St Marks | Jerome | 26 November 2010 | 20% |
| Lincolnshire | TF096453 | Maginot | 13 December 2010 | 10% |
| Lincolnshire | TF096453 | Belot | 13 December 2010 | 60% |
| Lincolnshire | TF093457 | Triomphant | 13 December 2010 | 5% |
| Kent | Crumps | Belot | 13 December 2010 | 15% |
| Kent | Front field | Chester | 13 December 2010 | 25% |
| Kent | Cottington | Charif | 13 December 2010 | 55% |
| Cornwall | Perranuthnoe Marazion | Jubarte | 13 December 2010 | 40% |
| Cornwall | Rose Goonhaven | Dionis | 13 December 2010 | 50% |
| Cornwall | Strawberry Lane Hayle | Alpen | 13 December 2010 | 30% |
| Isle of Wight | Field 1 | Keriso | 12 January 2011 | 0% |
| Isle of Wight | Field 2 | Alpen | 12 January 2011 | 10% |
| Isle of Wight | Field 3 | Tesminilo | 12 January 2011 | 10% |
| **All 17 fields** | | | | **22%** |

## Discussion

The lack of virus-like symptoms in the leaves of the TuYV-infected Brussels sprout and cauliflower plants was consistent with what we have seen in infections of cabbage and oilseed rape by Turnip yellow virus (TuYV). TuYV does cause internal tipburn symptoms in storage cabbage, but these symptoms are rarely evident in the external visible leaves, whilst the cabbages are growing. Because of the lack of leaf symptoms, most growers are unaware that their crops are infected by TuYV. Other viruses such as Turnip mosaic virus (TuMV) and Cauliflower mosaic virus (CaMV) do cause visible, characteristic and often severe leaf symptoms, so growers usually know they have a problem when their crops are infected by these viruses. However, unless they have their crops tested for the presence of TuYV, it is extremely unlikely they will know they have the infection in their crops.

The stunting of Brussels sprout plants caused by TuYV was clearly visible in our controlled experiments (Fig. 4) where we had infected plants growing in rows adjacent to uninfected plants of the same cultivar. However, in commercial crops where there are low incidences of the virus, this wouldn't be as apparent / visible. In commercial crops with high incidences, the infection would be likely to occur in patches with plants towards the outside of the patches infected later than the centre of the patch. We have shown that earlier infections of cabbage by TuYV reduced yield more than later infections, if this is also the case for Brussels sprouts, it is likely that in the middle of infected patches of sprouts, there would be stunted plants, with a gradual increase in size to the outside of the infected patch. So again, it is unlikely that growers would be aware of any stunting caused by virus infection. The measurements of sprout plant heights clearly confirmed the visible stunting of TuYV-infected plants; infected plants of all varieties were significantly shorter than their uninfected counterparts. There appeared to be a relationship between the degree of stunting of some varieties and the reduction in their sprout yield.

The effect of TuYV on the yield of marketable sprouts was surprisingly high, in excess of 60% in two varieties; even the least affected had their yields reduced by 22 - 30%. This clearly demonstrates that considerable savings could be made if it was possible to protect sprouts against TuYV infection. By controlling TuYV, it would be possible to produce current output on a much reduced acreage, thereby reducing inputs, freeing up land for other crops / purposes and increasing profits. Controlling the virus would also reduce wastage from small / rejected sprout buttons. With the exception of the variety Doric, there was a clear association between the effect of TuYV on the height of plants and the effect on yield. Those varieties that had their height reduced the most by TuYV also had their yields reduced the most.

As pointed out earlier, due to severely cold temperatures experienced at Wellesbourne during the cauliflower experiment in the winter of 2010/11, we don't have much confidence in the data on the effect of TuYV on cauliflower yields. The trend was for the virus to reduce yield of harvested heads.

The effect of TuYV on the shelf life of Brussels sprout varieties over a storage period of 7 days was only significant for the varieties Dominator and Petrus, where sprouts from infected plants lost colour more rapidly than did sprouts from uninfected plants.

There were significant differences between the amounts of TuYV detected in the different sprout and cauliflower varieties; the differences were greater in the sprouts than in the cauliflowers. There was no clear relationship between the amount of TuYV detected in the different sprout varieties and the effect of the virus on yield, although Speedia and Petrus had the lowest virus content and were two of the varieties where yield was reduced least by TuYV.

The incidences of TuYV detected in commercial sprout and cauliflower crops in the 2010/11 growing season were surprisingly high in view of the fact there were few aphids around in the summer and autumn of 2010. We found lower levels of TuYV in the oilseed rape crops planted in 2010 that we sampled (0% in Warwickshire and 17 - 27% in Lincolnshire) compared to 2009 where we saw up to 100% incidence of TuYV in commercial rape crops. This is particularly concerning, as in years when even average aphid numbers are around, there are likely to be very high incidences of TuYV in commercial Brussels sprout, cauliflower and other Brassica crops in some regions of the U.K. Further evidence for this is provided by samplings of commercial crops that we have carried out in the past, where we have seen 100% infection of cauliflower (and broccoli and cabbage) in Lincolnshire and 68% infection of Brussels sprouts in Lancashire. Even more concerning is the fact that such high levels of infection can occur very early following transplanting as we have seen this year, where most of a plot of Brussels sprout plants in a commercial sprout field were infected by TuYV within five and a half weeks of transplanting in to the field and 98% infected within seven and a half weeks of transplanting.

The fact that the virus is present in all the vegetable Brassica growing regions surveyed also indicates that there is the potential for yield losses in all regions.

The effect of TuYV on individual plants is possibly less than the effect of the viruses that cause severe leaf symptoms (Turnip mosaic virus [TuMV] and Cauliflower mosaic virus [CaMV]), however the incidences of TuYV in commercial crops is far higher than those of TuMV and CaMV, so despite the effects of TuYV not being immediately obvious / visible, it probably causes the most widespread and yield-reducing disease of vegetable Brassicas and oilseed rape in the U.K. in many years.

All the experimental work set out in the proposal has been carried out and the majority of the objectives of the project have been achieved. The incidence of Turnip yellows virus (TuYV) in commercial overwintered cauliflower and Brussels sprout crops in different growing regions has been determined over one growing season and more crops were sampled than outlined in the proposal. The susceptibility of different overwintered cauliflower and Brussels sprout varieties to TuYV has been determined and the effect of the virus on the yield and quality etc. of Brussels sprout has been assessed.

## Conclusions

The project has clearly shown that Turnip yellows virus infection of vegetable Brassicas severely affects yields; the degree of yield reduction in some varieties (up to 65%) was alarming.

The project has also shown that even in a year when there were very few aphids around, high levels of TuYV infection were detected in commercial Brussels sprout crops in some regions (up to 55% of plants sampled at random infected) and commercial cauliflower crops in some regions (up to 60% of plants sampled at random infected).

The data on the relative effect of TuYV on different varieties gives growers options if they wish to plant less susceptible varieties in anticipation of high levels of TuYV.

Experiments need to be carried out to ascertain when Brussels sprout and cauliflower plants in commercial crops get infected by TuYV – this work is under way in Phase 2 of the project (FV 365a).

There is an immediate need to investigate the efficacy of a range of insecticides in controlling TuYV infection of vegetable Brassicas – this work will also be carried out in Phase 2 of the project (FV 365a).

There is a pressing need to breed vegetable Brassica varieties (particularly processing cabbage, Brussels sprouts and winter cauliflower) with resistance to TuYV. We have identified sources of extreme resistance to TuYV in wild relatives of *Brassica oleracea* however, there is currently no funding to evaluate these resistances further and map the genes involved in the resistances and thereby exploit them

## Knowledge and Technology Transfer

Andy Richardson made a presentation on interim results from the project to the Brassica Growers Association R&D Committee meeting on 18th January, 2011.

Andy Richardson gave a presentation on the project at Elsoms Seeds' Brassica conference in January, 2011.

John Walsh made a presentation on the final results and outcomes of the project to the Brassica Growers Association at their meeting on 2nd June, 2011.

## Glossary

TuYV – Turnip yellows virus (formerly known as Beet western yellows virus)

TuMV – Turnip mosaic virus

CaMV – Cauliflower mosaic virus

## References

Hunter, P.J., Jones, J.E. and Walsh, J.A. (2002). The involvement of *Beet western yellows virus, Cauliflower mosaic virus* and *Turnip mosaic virus* in internal disorders of stored white cabbage. Phytopathology 92: 816-826.

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