Project title:	To identify pre-harvest, harvest and post-harvest management practices capable of reducing losses of pumpkins during storage
Project number:	FV 439
Project leader:	Debbie Rees, Produce Quality Centre, Natural Resources Institute (NRI), University of Greenwich.
Report:	Final report, February 2017
Previous reports:	Annual report, April 2015; Annual report, April 2016
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Location of project:	Natural Resources Institute, Jim Mount Postharvest facility, East Malling Grower sites: Oakley farms (Cambridgeshire), Dan Mackeldens (Kent)
Industry Representative:	David Murfitt, Oakley Farms (2014, 2015)
Date project commenced:	15 September 2014
Date project completed	28 February 2017

DISCLAIMER

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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CONTENTS

GROWER SUMMARY

Headlines

- A programme of field treatments, including fungicidal treatments focused on control of *Phoma* and powdery mildew, combined with mineral nutrition, can provide substantial benefits by increasing yield of marketable pumpkins with some additional benefits due to reduction in postharvest rots.

- The identification of *Phoma* and *Fusarium* within the crop has also led to the application for and granting of 2 EAMU's (Signum and Switch) giving growers chemical controls that were not available before the project.

Background

The market for carving pumpkins in the UK, currently estimated at £14-15M per year is growing at a rate of 20% annually. The exact levels of loss during storage are unclear, but at the start of this project were estimated to be 15-20% equating to an annual loss of £2-3M for decorative pumpkins alone.

Despite these high losses, at the start of this project there was little reliable information either on the main forms of loss for UK pumpkins (physiological, latent infection, post-harvest infection) or on the key factors (mineral nutrition, harvesting/post-harvest practices, storage environment/practices) affecting losses.

The overall aim of this project was to identify pre-harvest and post-harvest management practices capable of reducing losses of both edible and carving pumpkins, thereby providing a significant increase in profitability for the UK pumpkin industry. The approaches taken to achieve this were; to carry out storage trials in order to identify the main causes of loss, to test out field management practices that could increase yield and reduce losses, and to characterise the fruit from a range of pumpkin varieties, relating these to storability in order to identify those characteristics associated with good storability. Although an initial objective was to test out adaptations of storage strategies the economics of the pumpkin market do not allow farmers to invest in storage structures, so that this objective was not investigated, beyond assessing growers' stored bins to understand breakdown issues in diferent storage environments in 2014. More emphasis was placed on preharvest management.

Summary

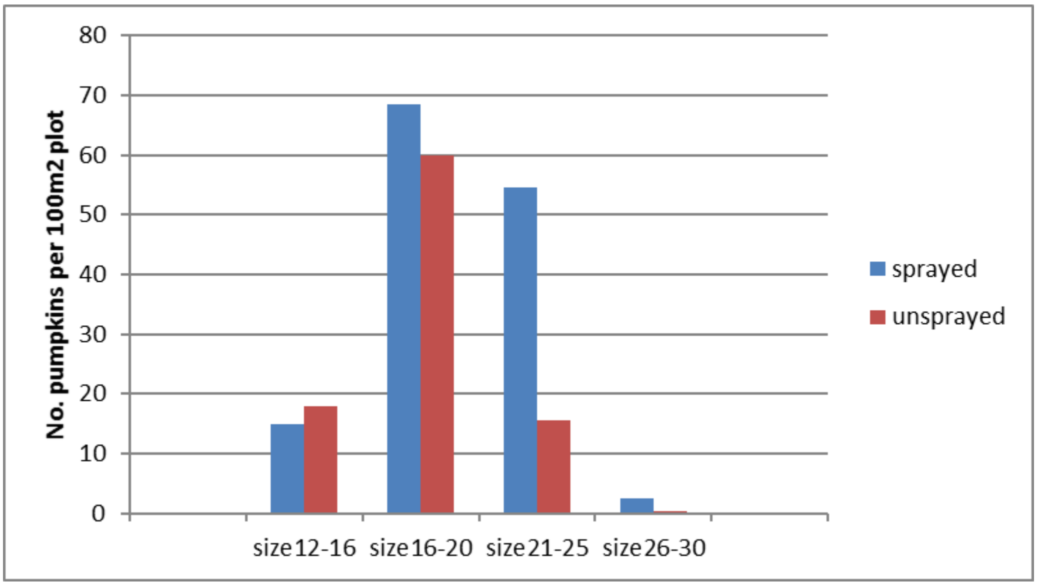
Given that the market for pumpkins is currently much stronger in the USA than in the UK, information on practices in the US was collated both from the literature and by direct communication with US growers and seed companies. It is notable that a strong emphasis is placed on chemical control of mildew in the US; the perception being that mildew damage of the stem increases the entry of rotting pathogens by that route into the pumpkin. A trial conducted in Cambridgeshire in 2015 indicated that powdery mildew control could increase yield in some varieties (Mars), but no effect on losses due to postharvest rots was observed.

However, a survey of rots in 2014 and 2015 identified the main cause of postharvest loss to be *Phoma cucurbitacearum.*

Figure A. Rotting of stored pumpkins due to *Phoma cucurbitacearum*

Contrary to the effects of spraying against powdery mildew alone, a spray programme tested in 2016, that combined treatment against *Phoma* and powdery mildew with mineral nutrition had positive effects on yield in trials in two very different locations. The yield of pumpkins classified into size categories from trials conducted in Cambridgeshire and Kent are shown in Figure B.

A.



B.

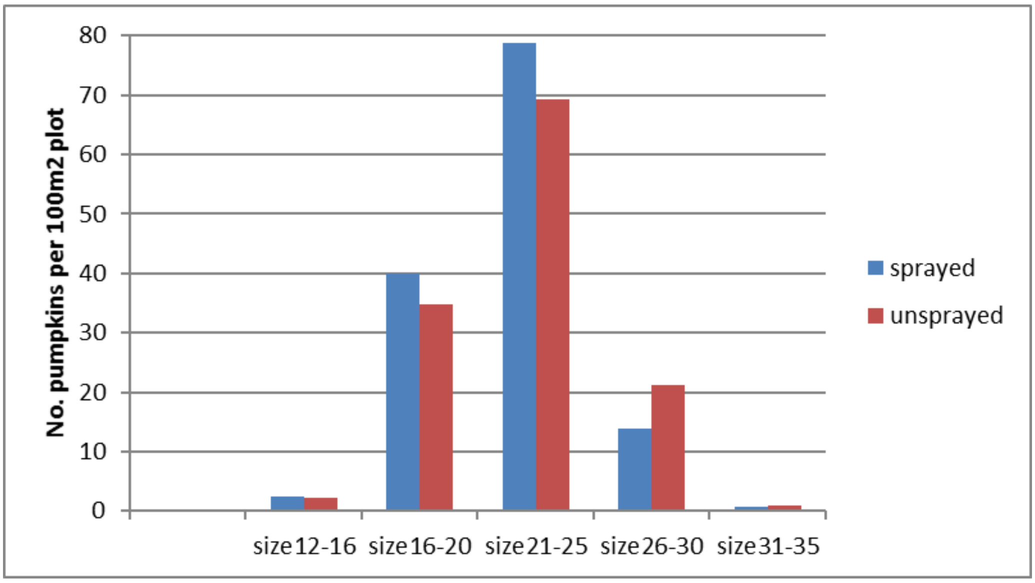


Figure B. Yield and size of pumpkins grown with and without a programme of fungicidal spray and mineral nutrition at two sites; A. Cambridgeshire, and B. Kent. Each data point is the mean of data from 6 or 4 100 m^2 plots.

At both sites the number and size of pumpkins were increased; with a very marked effect in Cambridgeshire. A simple cost benefit analysis for each site, assuming a cost of 80p per pumpkin indicated that the spray costs were more than compensated for in each case; thus in Kent a spend of £232 per Ha, gave a gain of £560, while in Cambridgeshire a spend of £341 per Ha gave a very substantial gain of £3760.

Harvested pumpkins were stored in bins under cover for 12 weeks, after which time there was a statistically significant difference in rates of rotting, with less rotting for the treated plots, the main impact being on incidence of *Phoma*. Although this period of storage is longer than UK pumpkin growers usually store, the results give an indication of probably impact for years of high storage losses.

The strategy of testing out the fungicidal treatment against *Phoma* in combination with mineral nutrition allowed us to maximise our chances of identifying a beneficial treatment within existing resources (specifically time inputs). If further work can be carried out with the support of growers in the coming seasons, it would be possible to refine field strategies, separating the effects of fungicide and mineral nutrition, in order to maximise the benefit to cost.

Characterisation of pumpkin varieties was carried out over three seasons; 2014, 2015 and 2016, with support from seed companies. As the market develops and seed companies try out different varieties, it was not possible to test the same varieties, nor use the same planting sites consistently over the three seasons. Nevertheless the information obtained during this project is to our knowledge the first time that UK pumpkin varieties have been characterised in this way and it has allowed the initiation of a database to provide indicators for the development of good storing varieties. Pumpkin fruit were characterised in terms of flesh firmness, skin strength, colour, thickness of flesh, dry matter content and composition (sugar profile) and mineral content. All of these characteristics were compared with observations of keeping qualities. There were some indications that calcium content related to good storability, but the characteristic that was most consistent within size ranges was dry matter content; high dry matter content related to improved storability. This observation also held when comparing the behaviour of varieties under different growing conditions. Pumpkin growers choose varieties depending on growing location; thus Racer is considered a good variety in Hampshire compared to Mars and Harvest Moon, but is considered bad in Cambridgeshire. This distinction is also seen in the comparison of dry matter content; Racer had the highest dry matter content of these three varieties in Hampshire, but the lowest in Cambridgeshire.

Financial Benefits

At two sites tested, a spray programme for control of *Phoma* and powdery mildew, combined with mineral nutrition, led to an increase in the number and size of pumpkins at harvest; with a very marked effect in Cambridgeshire. The programme relied on the use of Signum and Nimrod (both of which have approval for the use on field pumpkins). Mineral nutrition focused on calcium, boron, manganese, copper and magnesium sulphate. A simple cost benefit analysis for each site, assuming a cost of 80p per pumpkin indicated that the spray costs were more than compensated for in each case; thus in Kent a spend of £232 per Ha, gave a gain of £560, while in Cambridgeshire a spend of £341 per Ha gave a very substantial gain of £3760.

Action Points

The output from this project with most immediate significance for the industry is that there is potentially a very significant financial benefit from field treatment of pumpkins for fungal control and mineral nutrition. However in order to refine recommendations for field applications there is a need for a coordinated approach among growers to test strategies against unsprayed controls for a range of varieties in a range of locations.

Likewise a coordinated approach among seed companies to understand postharvest behaviour of new varieties would be of enormous potential to growers.

SCIENCE SECTION

Introduction

The market for carving pumpkins in the UK, currently estimated at £14-15M per year is growing at a rate of 20% annually. For supermarkets Halloween has now become the second major festive event after Christmas. The market for culinary pumpkins is growing at a similar rate albeit from a lower base. The levels of loss during storage are unclear, but at the start of this project were estimated to be 15-20% equating to an annual loss of £2-3M for decorative pumpkins alone.

Carving pumpkins need to be stored and cured for approximately 6 weeks from harvest, usually in mid-September, until the end of October. It would be commercially advantageous to store culinary pumpkins until Thanksgiving (third week in November), equivalent to 9-10 weeks or longer if possible.

In the UK, storage is currently in uncovered windrows in the field, windrows within greenhouses, or in bins within stores (usually without refrigeration). Usually no specific temperature or humidity control is used, but in some cases there is forced airflow to reduce the build-up of condensation. No ventilation within windrows is used.

Although losses are high at the start of this project there was little reliable information either on the main forms of loss (physiological, latent infection, post-harvest infection) for UK pumpkins or on the key factors (mineral nutrition, harvesting/post-harvest practices, storage environment/practices) affecting losses.

The overall aim of this project was to identify pre-harvest and post-harvest management practices capable of reducing losses of both edible and carving pumpkins, improve the uniformity and quality of pumpkins and reduce losses, thereby providing a significant increase in profitability for the UK pumpkin industry.

Growing region and variety

It has been observed that losses can vary by region, with lower storage losses reported for the variety Racer grown on the South coast compared to those under cultivation in East Anglia, and it has been suggested that warmer temperature improves curing (skin hardening and healing) and / or that it prevents night-time condensation (dews that can increase the risk of rots). Likewise it is known that storage potential varies by variety; Mars is a variety with higher flesh content and with longer storage potential than similar sized pumpkins with thinner flesh (pericarp). However, there has been no detailed study relating phenotypical characteristics with storage potential.

Pre-harvest disease

Powdery and downy mildew are known to lower yield and cause rots/plant loss in the field, respectively. Varietal resistance to powdery mildew is being bred for and is associated with fruit that retain dark green stems. Work has been done in the US on the impact of powdery mildew on crop storage and the recommendations are to run a spray program up until the point of harvest. Downy mildew was not identified within the trial but if present can be decimating within the crop with some worldwide regions having a forecasting system to guide growers as to when to spray to give the crop optimum protection.

US storage strategies

In the US more importance is given to storage conditions for culinary pumpkins than UK, presumably indicating a greater value of the US crop. The UK pumpkin industry can potentially benefit greatly by exploiting US knowledge. For example in some States it is recommended that pumpkins are stored on shelves with no contact between neighbouring fruits. Removing soil from the outside of the pumpkin is considered good practice and other sanitation measures including washing fruit in drenching tanks prior to storage reduces infection potential if the inoculum in the water flume can be controlled. Chlorine drenching can be effective only when soil contamination is removed prior to drenching. Some growers will only fresh lift and market direct from the field and will not wash any fruits to minimise the risk of spreading breakdown issues.

Ethylene

US research indicates that ethylene should be avoided during storage. Exposure to ethylene can increase rates of rotting and will also cause abscission of the stem, especially in less mature fruit.

Chilling injury

Pumpkins are chilling sensitive, thus storage for several months at 10°C and below may cause chilling injury. The key issue with chilling injured fruit is their textural quality loss due to alterations in membrane structure, which makes the produce more susceptible to rots and decay. On the other hand, for carving pumpkins short exposure to temperatures lower than 10°C is unlikely to cause damage that is of economic importance. Chilling injury may become a significant factor for the eating quality of culinary pumpkins due to the potentially longer storage periods. The challenge to extend the season for culinary pumpkins beyond November will require more sophisticated storage technology such as ethylene removal or use of SmartFresh (1-MCP) and better control over post-harvest diseases through the use of sanitising agents (ozone, hydrogen peroxide misting).

Curing/skin set

Curing or skin set can have a significant impact on improving the storage potential of fruit. In the US growers are advised to harvest at sufficient maturity, for example after senescence of the leaves, when the pumpkin skin has set (thickened and hardened). It has been noted that if disease kills the vines prematurely, there is a risk that the fruit will be harvested immature. US storage practices are designed to allow curing, thereby further strengthening the skin and healing harvest wounds, and so reducing the risk of pathogen invasion. It is therefore common practice by some growers to cure pumpkins for 10 to 20 days at 20 - 25°C with good ventilation (e.g. four air exchanges per day). Storage humidity is set at 65-85% to reduce weight loss but prevent moisture and rotting.

Overall project Aim

To identify pre-harvest, harvest and post-harvest management practices capable of reducing losses of both edible and carving pumpkins during storage.

Specific project objectives identified at the start of this project were:

1. To collate and disseminate information on management of the pumpkin crop in the US, and associated research relevant to the UK industry.
2. To determine and rank the main forms of post-harvest loss (tissue breakdown, latent infection, post-harvest infection, harvest maturity) currently affecting pumpkins in the UK.
3. To determine and rank the key factors affecting the storage potential of pumpkins in the UK (harvest maturity, mineral nutrition, harvesting/post-harvest practices, and storage environment/practices.)
4. To determine the varietal characteristics that affect storage potential (including size, skin toughness, pericarp thickness, dry matter content)
5. To identify and test pre-harvest management practices to improve storage potential.
6. To identify and test harvest/post-harvest management practices to improve storability, including the identification of maturity indicators to predict storage potential at harvest.

The first year of this project, 2014, was a very difficult year for pumpkin growers. The warm summer resulted in early fruit maturation, and forced the growers to keep the crop for longer than usual before marketing. As a result the level of losses in the field and in stores was high. Although limited responses were received, the losses quoted in questionnaires circulated to pumpkin growers as part of the project activities were between 7-35% in the field and 5-35%

in stores. In 2015 warm weather led to an early season, which was followed by a very wet August, which again led to very significant losses. In 2016, however, the season was later and dryer so that losses were less.

Activities by season.

This project started near the end of the field season in 2014, so during that season only limited activities could be carried out; these included:

- A preliminary survey of information on pumpkins from US sources, including direct interaction with growers.
- An initial trial carried out to characterise the quality of fruit from a range of pumpkin varieties, with the longer term aim to identify the impact of varietal characteristics on susceptibility to rots and storability.
- A preliminary storage trial to compare the storability of four commercial varieties.

The main activities carried out in 2015 to further the objectives were:

- A review of information from the literature and from the US, including a visit to major growers and seed companies.
- Trials to determine the effect of variety, growing location and powdery mildew control on keeping quality of pumpkins with the following objectives:
  - To test the hypothesis that powdery mildew infection of the stalk increases rot incidence.
  - To test the effect of harvest date on storability.
  - To relate pumpkin characteristics to storability.
- Characterisation of a wider range of pumpkin varieties.

By 2016 *Phoma* had been identified as the main rotting pathogen in the field and during storage. The focus was on the following activities:

- A field trial to determine the effect of fungicidal treatments against both *Phoma* and powdery mildew combined with mineral nutrition.
- Continuation of varietal characterisation.

Materials and methods

Review of information from the literature and from the US

Information on field management and postharvest handling of pumpkins was obtained from the scientific literature and from extension literature. Peter Waldock visited the US in September 2015, in order to obtain information from growers and seed companies in California, New York, Ohio and Pennsylvania.

2014: Preliminary storage trial conducted to compare four key varieties

A bin of each of four pumpkin varieties; Mars, Terraflynn, Magician and Gomez were stored by Dan Mackleden under cover, with no temperature control. The bins were assessed on 4th November 2014 for incidence of rots, and state of stalks. Samples were taken for identification of rotting pathogens.

2015: Determining the effect of variety, growing location and mildew control on keeping quality of pumpkins

A trial was planted in Cambridgeshire with two half acre plots of each of 3 pumpkin varieties; Racer, Mars and Harvest Moon. For each variety one plot was managed with and one without a powdery mildew control programme as summarised in Table 1 (Further information is in the 2015 annual project report).

Table 1. Powdery mildew control programme used for three variety trial in 2015

Date	Product Name	Active Ingredient	Dose Rate
06/07/15	Potassium Bicarbonate		6.0kg/ha
	Silwet L-77	Wetter	150ml/ha
15/07/15	Farm Fos 44	Potassium phosphite	3.0l/ha
	Nimrod	Bupirimate	600ml/ha
		Copper oxychloride*	2.0kg/ha
22/07/15	Potassium Bicarbonate		6.0kg/ha
	Activator 90	wetter	300ml/ha
31/07/15	Potassium Bicarbonate		6.0kg/ha
	Proleaf Vita	Trace elements	2.0l/ha
	Silwet L-77	Wetter	150ml/ha
17/08/15	Nimrod	Bupirimate	600ml/ha
		Copper oxychloride*	2.0kg/ha

**Included as a nutritional component.*

Crop walks were carried out through the season to assess incidence of pathogens and pests, and plant growth stage (Further information is given in the 2015 annual project report).

In order to assess the effect of maturity on keeping quality, a preliminary harvest was conducted on 17 September 2015, approximately 2 weeks before the commercial cutting date, in which 30 pumpkins, selected to be less mature than average, were harvested for each treatment, and placed in wooden “onion” storage bins (approximately 1 m x 1 m x 0.8 m).

At this point 6 pumpkins were selected from each treatment and were transported to NRI for quality assessment (see below) which was carried out on 21- 23 September 2015.

The main harvest took place on Wednesday 30th September 2015. Three 10 m x 10 m blocks were selected within each plot. All pumpkins within each block were harvested and the number of pumpkins recorded, categorised by size. The number of rotten pumpkins, with an identification of rot wherever possible, was recorded and representative samples of rotting pumpkins were taken to EMR for subsequent rot identification.

The saleable pumpkins from each block were stored in a wooden “onion” storage bin. At this point these bins and those set up in the early harvest were moved from the field and placed under cover in a glass house. 6 pumpkins were selected from each treatment were transported to NRI for quality assessment.

In order to obtain information on the effects of growing location on pumpkin quality, additional bins of pumpkins (Harvest Moon, Mars and Racer) grown in Hampshire near the South coast were transported to EMR at the end of October 2015 and stored under cover, and other bins of pumpkins (Harvest Moon only) grown in Kent were also stored under cover on farm specifically for this project.

All the stored bins were assessed in the first week of December for external appearance for saleability and for incidence and identity of rots. Further pumpkin samples were transported to NRI for quality assessment.

2016 Field trials to test fungicidal control against powdery mildew and Phoma

Two field trials were set up one in Cambridgeshire and one in Kent using one variety; Harvest Moon. At both sites the field was divided to give sprayed and unsprayed areas. A spray regime was started in July as detailed in Table 2.

Table 2. Applications of fungicide and nutrition used in field trial in Cambridgeshire and Kent in 2016

Site	Date	Fungicide	Nutrition
Cambridgeshire			
	27/7/2016	Signum (1.5 l/ha)	Calcium 1 l/ha, Boron 1 l/ha
	8/8/2016	Nimrod (600 ml/ha)	Calcium 1 l/ha, Copper Oxychloride 2 l/ha, Manganese (as per label)
	18/8/2016	Signum (1.5 l/ha)	Calcium 1 l/ha, Manganese (as per label)
Kent			
	18/7/2016	Signum (1.5 l/ha)	Calcium 1 l/ha, Boron 1 l/ha
	5/8/2016	Nimrod (600 ml/ha	Calcium 1 l/ha, full trace elements foliar feed
	20/8/2016	Pot Bicarb (5 l/ha) + silica wetting	Calcium 1 l/ha, Manganese (as per label), Bittersalts (magnesium sulphate) as per label

In early September, at each site 100 m^2 plots were marked out for both treatments

At commercial harvest time 6 sprayed plots and 6 unsprayed plots (4 unsprayed at the Kent trial) were harvested at each site and placed in bins that were transported to a storage site at East Malling. Harvest dates were 19th September in Kent and 21st September in Cambridgeshire.

At two time points (4th November and 16th December) the bins were assessed for visible rotting, and rotten pumpkins removed.

2014, 2015, 2016 Varietal Characterisation

In 2014 at least four pumpkins were provided by Tozer seeds, Dan Mackelden, Oakley Farms and Barfoots of a total of twelve pumpkin varieties; Mars, Becky, Cinnamon Girl, Jack Sprat, Small Sugar, Racer, Magician, Paint Ball, Terra Fin, Spitfire, Gomez, Harvest Moon. These were stored outside under ambient conditions prior to characterisation in November 2014.

In 2015 Tozer seeds grew a varietal evaluation trial with 34 varieties and approximately 12 plants (to produce 12 fruits) of each at Cobham. After curing in the field 6 fruit per variety were selected for analysis at NRI. The varieties were selected with advice from Tozer. Six of the varieties overlapped with the varieties assessed in 2014.

For 2016 a varietal trial was grown by NIAB. Pumpkins were provided of seven varieties: Harvest Moon, Spitfire, Gomez, Racer, Mars, Terra Finn, Magician, all of which were included in the trial in 2014

Four pumpkins for each variety were assessed for quality characteristics. 12 pumpkins per variety were kept and assessed for keeping qualities. To simulate practical storage conditions, the pumpkins were stored mixed in three wooden bins in an unheated store room (4 pumpkins per variety in each bin, bin = replicate).

Table 3. Varieties included in varietal trials

Variety	Seed supplier	Years included in trials		
Harvest Moon	CN Seeds	2014		2016
Becky		2014	2015	
small sugar		2014	2015	
sunlight			2015	
Tot A			2015	
Spitfire	Clause	2014		2016
Snowball			2015	
Gomez	Clause	2014		2016
Paintball		2014	2015	
Racer	Tozer	2014	2015	2016
Carrie			2015	
Mars	Tozer	2014	2015	2016
Rocket			2015	
Terra Finn	Sakata	2014		2016
Cinnamon Girl		2014	2015	
Magician	Clause	2014		2016
Hannibal			2015	
Jack Sprat		2014		

Pumpkin quality assessment

Skin colour was measured using a Minolta colour meter (*L*a*b** colour space) at 4 points around the fruit equator. This provided a measure of loss of green background (indicated by an increase in *a value) and the increase in yellowing (indicated by an increase in *b value).

Figure 1. The *L*a*b**, colour space and Minolta colour meter used to measure machine colour values.

Whole fruit firmness was measured using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a convex-tip probe; 8-mm diameter. The probe recorded resistance whilst travelling 8.0 mm at a speed of 0.83 mm s^{-1} and the maximum force (Newtons) recorded.

Samples were collected from a pumpkin cut into two halves longitudinally. The diameter of the pumpkin and thickness of flesh (pericarp) were both measured. Skin strength was measured on four cut sections of the equatorial strip using a TA.XT plus Texture Analyser (Stable Micro Systems, UK) equipped with a 2-mm diameter probe (puncture test) and a 50 kg load cell. The probe was driven 5.0 mm at a speed of 0.83 mm s^{-1} and the maximum force in Newtons was recorded. Flesh firmness was measured on four sections from the flesh side using an 8 mm probe using the same parameters.

Samples from the opposite eighths of the pumpkin (flesh with skin) were frozen and stored at -20 °C for subsequent mineral analysis. Samples of flesh were frozen in liquid nitrogen and stored at -80 °C for subsequent sugar analysis. Other samples were taken, weighed and dried in an oven to determine dry matter content.

*Mineral content (*nitrogen N; calcium Ca; potassium K; boron B; iron Fe; magnesium Mg; manganese Mn; phosphorus P; zinc Zn; and copper Cu) analyses were conducted by the Fruit Advisory Services Team (FAST).

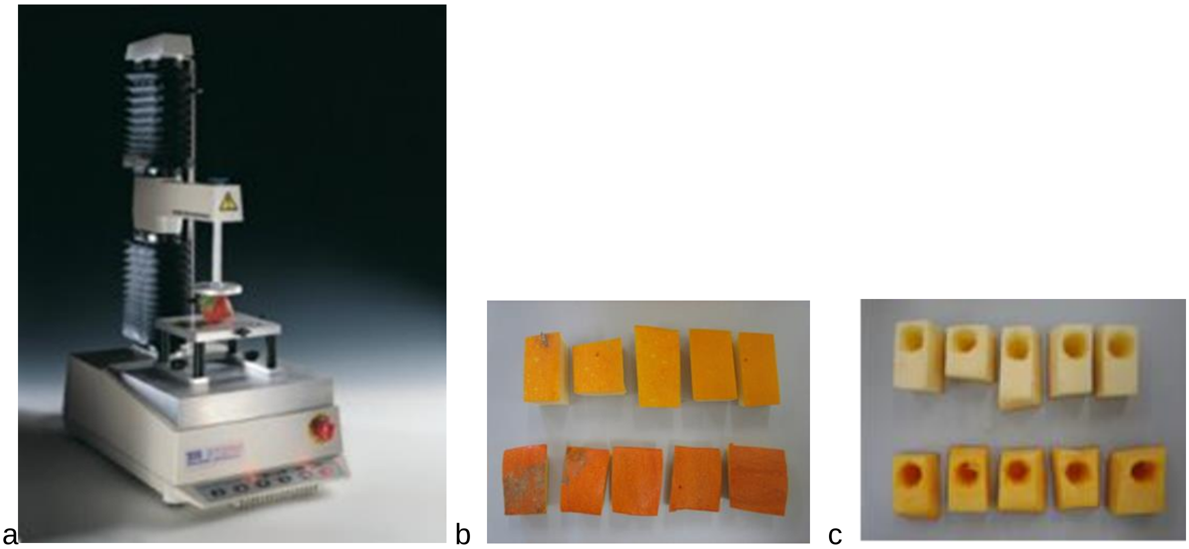


Figure 2. a) TA.XT plus Texture Analyser used to carry out texture measurements. Cut sections used for b) skin strength and c) flesh firmness assessment.

Collection and analysis of rot samples

Samples of rotting pumpkins were taken to EMR for identification of causative agents. Samples were taken from the leading edge of the affected tissue and plated onto potato dextrose agar (PDA). Growing cultures were then identified under the microscope by morphology. In specific cases molecular techniques (sequencing phylogenetically informative regions) were used.

Results

Review of information from the literature and from the US

The full report of a visit to the US carried out by Peter Waldock is included as Appendix 1 in the 2016 annual project report. The key findings relevant to the objectives of this project were:

- The US market for pumpkins is much larger per capita than in the UK. Decorative pumpkins are distinct from those used to make pumpkin pie. The latter are usually sold in processed form. Decorative pumpkins are cleaned (sometimes waxed) and are sold over a much longer period than in the UK, as American's will buy sequentially to display outside their houses. Consequentially American growers do not need to store pumpkins.
- Americans tend to prefer larger pumpkins than in the UK.
- American growers usually have an intensive spray programme against powdery mildew (every 7-10 days) as the visual quality of the stalk (handle) is regarded important as they perceive that rots enter the fruit through damaged stalks (examples of stalk damage by mildew are shown in Appendix 1).
- American growers have a variable fertilisation programme.
- Breeding programmes include focus on resistance to powdery mildew, and good stalk attachment to the fruit (examples are shown in Appendix 1).
- Varieties are defined in terms of their rate of maturation (unlike in the UK).

Identification of field and storage rots

The project started on 15 September 2014, at the point when many pumpkin fields were already being harvested, nevertheless as a preliminary survey, samples of rotting pumpkins were collected from the field and also from the storage trial conducted at Dan Mackelden in 2014, and were analysed to identify the rotting pathogens. The main pathogens identified that season were *Botrytis cinerea*, *Phoma cucurbitacearum*, *Rhizopus stolonifera*, *Colletotrichum coccodes*, *Fusarium acuminatum*, *Mucor hiemalis*. Diagnostic photographs of these rots are shown in Appendix 2. This was the first time that *P. cucurbitacearum* had been identified as a major cause of pumpkin losses in the UK.

The proportion of rots identified is given in Figure 3, together with a summary of the weighting of the rots for samples from East Anglia and the South East. This data should be treated with great caution as the samples were collected for identification purposes and were not proportional to the incidents observed. Nevertheless the notable difference between the two regions is probably an indication of a real difference.

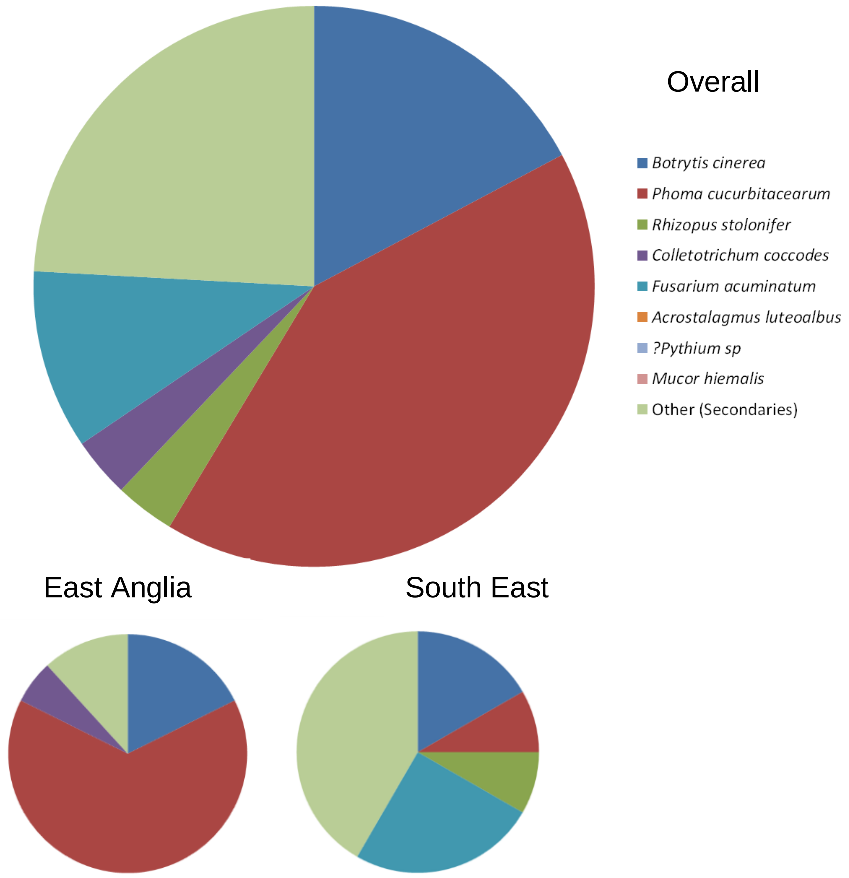


Figure 3. Preliminary rot survey 2014 - The rots identified as a proportion of all samples analysed, and separated into those collected in East Anglia and in the South East. This data is an indication of incidence only, as samples were collected for identification purposes and not for quantification of incidence.

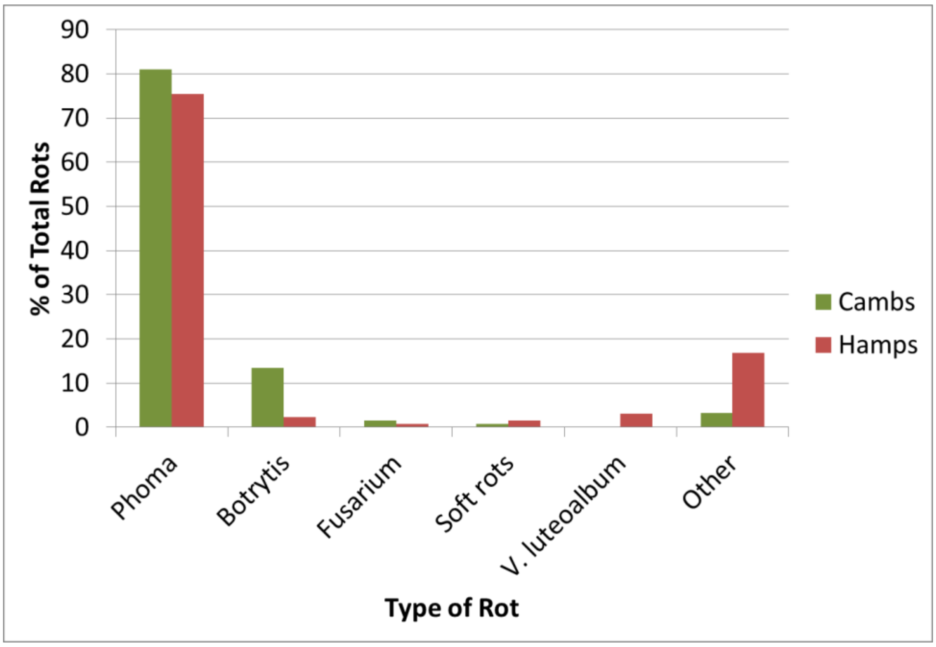


Figure 4. Incidence of rot species observed across three varieties of pumpkin in 2015. Comparison between Cambridgeshire and Hampshire. No statistics carried out due to lack of replication for the samples from Hampshire.

More quantitative surveys were conducted in 2015. Figure 4 summarises the species of rots identified during storage of three varieties of pumpkins (Mars, Harvest Moon and Racer) grown and stored in Cambridgeshire and Hampshire. No difference in incidence of rots by rot species was observed between the two locations with *Phoma* being the main rot in both locations, despite having markedly different crop rotations in each region. As a result of these observations, a spray programme against both *Phoma* and mildew was assessed for efficacy and economic value in the final year of this project (see below).

Figure 5. *Phoma* storage rot observed for pumpkins harvested in Cambridgeshire in 2015 and stored long-term to identify the main storage rots.

2014: Preliminary storage trial conducted to compare four key varieties

In 2014 a preliminary storage trial was conducted using a single bin of each of four varieties; Mars, Terraflyn Magician and Gomez, which were assessed after approximately one month of storage under cover. Individual pumpkins were assessed as saleable or unsaleable, and in almost all cases where a pumpkin was defined as unsaleable, it was due to rotting. Although, in this preliminary trial there was only one bin per variety and therefore a statistical analysis could not be carried out, there was a considerable different in % losses with Gomez having more than four times the loss (9% losses) compared to Mars (2% losses).

2015: Determining the effect of variety, growing location and mildew control on keeping quality of pumpkins

In 2015 a field trial was carried out in Cambridgeshire to determine whether fungicidal control of powdery mildew in the field, would have a significant effect in reducing postharvest rots by protecting the stem from damage. The hypothesis suggested from discussions with US pumpkin growers was that a damaged stem provides a route for fungal entry into the pumpkin fruit. This trial was conducted on three key varieties. Pumpkins were harvested on two dates to determine effect of harvest maturity on postharvest loss. The trial also provided a comparison with the postharvest behaviour of the same three varieties grown in Hampshire

Observations during growth

The observations made during crop walks in Cambridgeshire are described in detail in the 2015 Annual Report, but briefly, growth stage progressed between varieties fairly similarly through the season with Mars slightly ahead of the other varieties. Sprayed plots were slightly delayed in development at the first crop walk but subsequent crop walks were at the same growth stage as the unsprayed plots. The initial delay may have more to do with the field position rather than the treatment (these were unreplicated blocks). Powdery mildew was first observed on the 31/07/15 on unsprayed plots only. Powdery mildew was not observed on sprayed plots until 11/08/15. Disease pressure increased in unsprayed plots and was recorded as ‘heavy’ by the end of the season whilst only slight powdery mildew pressure was observed on the sprayed plots by the end of the season.

Harvest observations

A subset of fruit was harvested on 17 September 2015 approximately 2 weeks before commercial harvest time, and at a maturity stage considered young for commercial harvest (Figure 6). The commercial harvest was conducted on the 30th September 2015 (Figure 7).

Figure 6. Pumpkins harvested 2 weeks before commercial harvest and stored in a wooden “onion” storage bin.

Figure 7. Pumpkins harvested on 30 September (commercial harvest time) from 10m x 10m plots, and set out for assessment of size and rots.

The yield (in terms of number of pumpkins) was significantly increased for Mars variety sprayed against powdery mildew, but was not significantly affected in the two other varieties; Harvest Moon and Racer (Figure 8). Spraying also increased the size of the pumpkins for all three varieties (Figure 9 a - c)

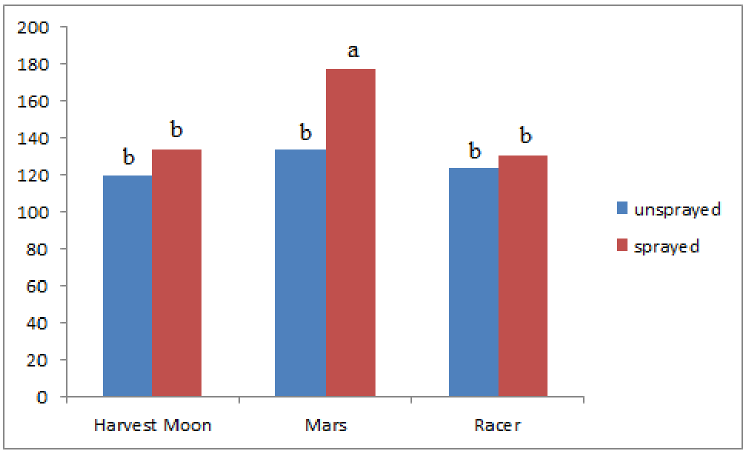


Figure 8. Yield of pumpkins (number) per 10m x 10m plot for three pumpkin varieties grown with and without spraying against powdery mildew. Different letters indicate significant difference (*P*<0.05) between the samples.

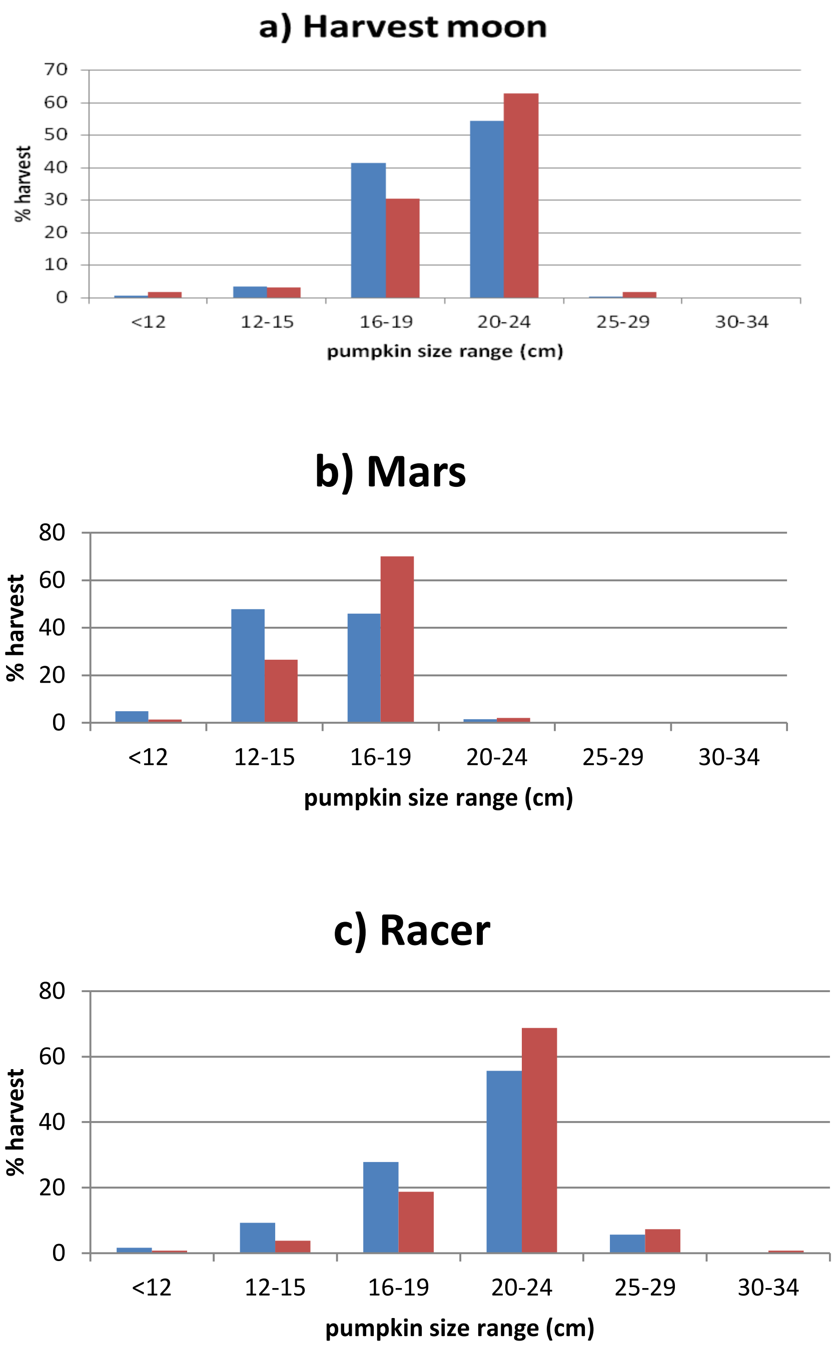


Figure 9. Harvested pumpkins categorised by size for each variety with (red) and without (blue) spraying against mildew.

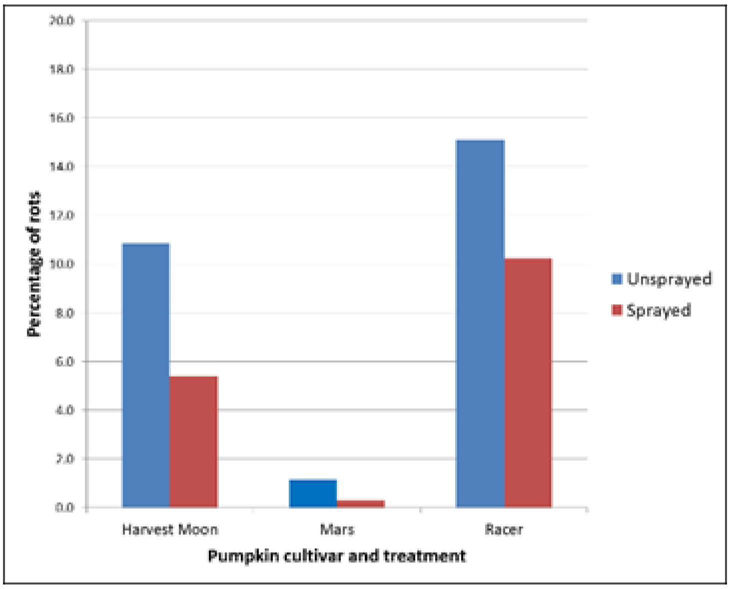


Figure 10. Percentage pumpkins with rots for each variety and treatment at harvest.

Table 4. Categorisation of rots at harvest in terms of position on pumpkin fruit.

		Total rots at harvest (%)	Position of rot as a proportion of total yield		
			Side	Stalk	Flower-end
Harvest Moon	Unsprayed	10.8	9.7	0.9	0.3
	Sprayed	5.4	5.2	0.2	0.0
Mars	Unsprayed	1.1	1.1	0.0	0.0
	Sprayed	0.3	0.0	0.3	0.0
Racer	Unsprayed	15.1	10.6	3.7	0.8
	Sprayed	10.2	6.7	3.6	0.0

The overall loss due to rots at the point of harvest was greatest in Racer and least for Mars (Figure 10). There was a trend for a reduction in rots for sprayed plots however due to the variability of the yield and rots by plot there was no statistically significant difference between varieties or between treatments. The majority of rots observed at harvest were positioned on the cheek (side) of the pumpkin fruit. Flower end rots were low and were not observed at all in sprayed plots (Table 4).

Assessment of rots and quality after storage

Figure 11. Storage of pumpkins in wooden "onion" bins under cover. During the storage period, the bins were stacked.

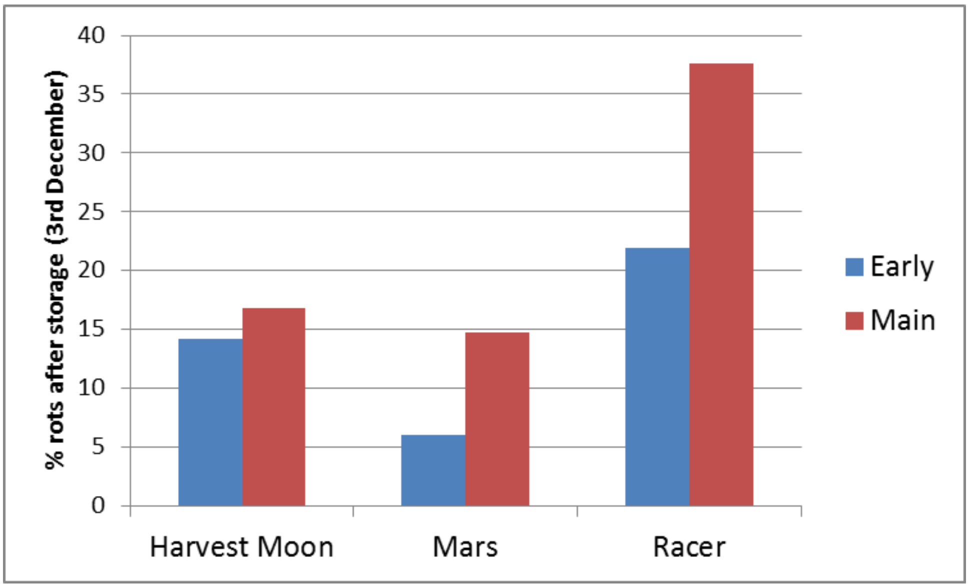


Figure 12. % rots after storage for three varieties and 2 harvest dates. Each data point is the mean of three replicates. 2 way ANOVA indicated significant varietal and harvest date effects. LSD = 12.3

More rots were found in the bins following storage of the main harvest (30th Sept 2015) relative to the early harvest (17th September2015) (Figure 12). However, this might be a consequence of the smaller number of pumpkins in the early harvested bins, so that this observation needs to be repeated, to find out if it is of commercial value. Unfortunately it was not possible to repeat this aspect of the trial in the final year of the project as field conditions brought the commercial harvest forward.

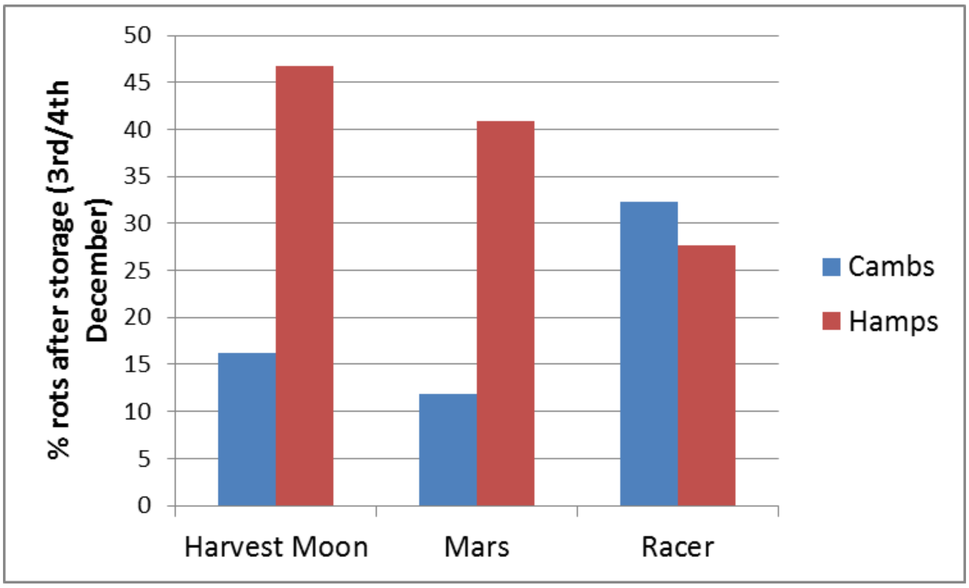


Figure 13. % rots after storage (on 3rd 4th December 2015) for three varieties and 2 growing locations. No statistical analysis was carried out as only a single bin was assessed for each variety from Hampshire.

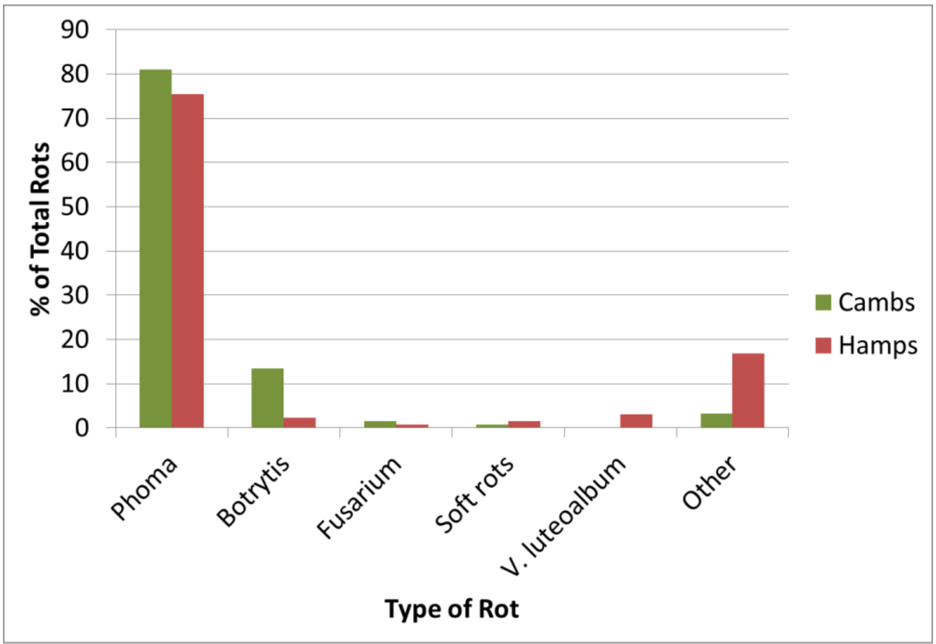


Figure 14. Incidence of rot species observed across three varieties of pumpkin. Comparison between Cambridgeshire and Hampshire. No statistics carried out due to lack of replication for the samples from Hampshire.

Figure 13 shows the % rots observed after storage for pumpkins from two growing locations; Cambridgeshire and Hampshire. A higher percentage of rots was observed for pumpkins from Hampshire compared to Cambridgeshire for Harvest Moon and Mars, while the difference was not so obvious for Racer. Although this result should be treated with caution as the storage conditions were not exactly the same, this does fit with the comments previously made by growers that different varieties suit different growing sites. No difference in incidence of rots by rot species was observed between the two locations (Figure 14) with *Phoma* being the main rot in both locations despite having markedly different crop rotations in each region.

There was no evidence for a benefit of powdery mildew control on rot incidence (Figure 15), and no indication that spray treatment had any effect on the species of rots found (Figure 16).

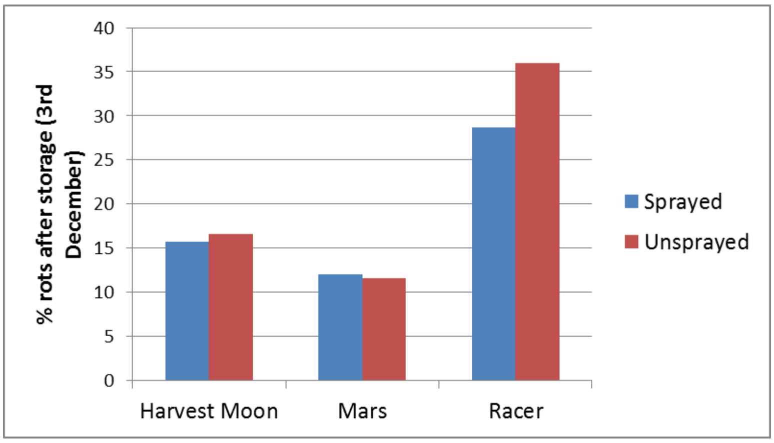


Figure 15. % rots after storage for three varieties with and without powdery mildew control. ANOVA indicated significant varietal effects but no significant treatment effects.

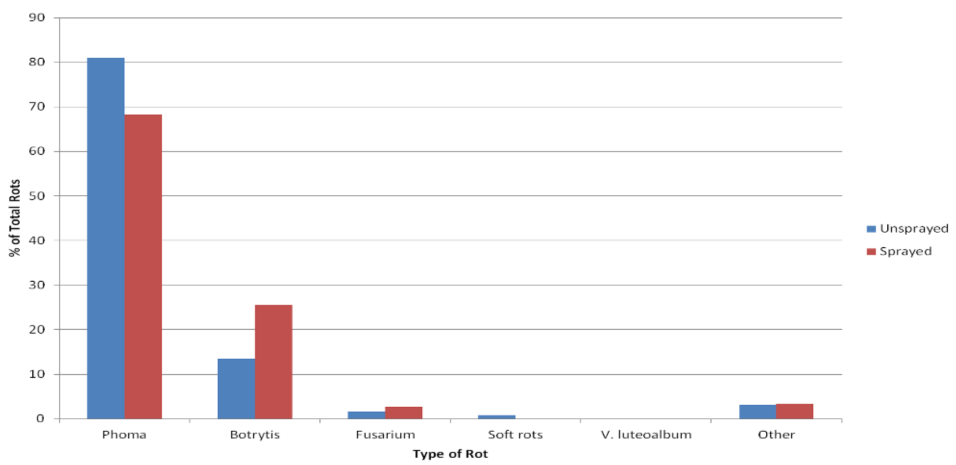


Figure 16. Incidence of rot species across three pumpkin varieties in Cambridgeshire trial, comparison between sprayed and unsprayed plots.

Quality assessment of pumpkins and relationships with keeping quality

Table 5. Mineral composition of the flesh of 3 pumpkin varieties grown with an without a spray programme against powdery mildew

	mg/100g Fresh weight					mg/Kg Fresh weight					%
Variety /treatment	**N**	**Ca**	**K**	**Mg**	**P**	**Cu**	**Fe**	**Mn**	**Zn**	**B**	**DMC**
Harvest Moon											
Sprayed	110.2	25.6	247.1	10.3	12.8	0.61	5.69	0.36	0.71	1.81	7.64
Unsprayed	111.8	27.5	267.3	10.7	14.3	0.41	4.56	0.35	0.71	1.72	7.97
Mean	111.0	26.5	257.2	10.5	13.5	0.51	5.13	0.35	0.71	1.76	7.81
Mars											
Sprayed	155.1	19.2	287.7	13.0	15.4	0.80	4.70	0.29	1.22	2.04	9.29
Unsprayed	116.1	19.4	322.7	9.9	12.3	0.42	4.94	0.18	0.77	2.07	6.87
Mean	135.6	19.3	305.2	11.4	13.8	0.61	4.82	0.23	1.00	2.06	8.08
Racer											
Sprayed	85.7	22.3	188.7	8.1	11.7	0.69	4.33	0.19	0.58	1.32	4.64
Unsprayed	80.0	23.2	191.3	7.6	8.6	0.29	5.13	0.16	0.50	1.37	4.22
Mean	82.8	22.8	190.0	7.9	10.1	0.49	4.73	0.17	0.54	1.34	4.43
Sprayed	117.0	22.4	241.2	10.5	13.3	0.70	4.90	0.28	0.84	1.72	7.19
Unsprayed	102.6	23.4	260.4	9.4	11.7	0.38	4.88	0.23	0.66	1.72	6.35
Varietal effect	ns	P< 0.001	p< 0.001	p= 0.03	ns	ns	ns	p= 0.018	ns	p< 0.001	p< 0.001
Treatment effect	ns	ns	ns	ns	ns	P <0.001	ns	ns	ns	ns	ns
LSD (variety x treatment)		5.3	63.1	3.8		0.21		0.2		0.42	2.08

Table 6. Mineral composition of the flesh of three varieties of pumpkin from different locations.

Variety/ Location	mg/100g Fresh Weight					mg/Kg Fresh Weight					%
	N	Ca	K	Mg	P	Cu	Fe	Mn	Zn	B	DMC
Harvest Moon											
Cambs	111.8	27.5	267.3	10.7	14.3	0.41	4.56	0.35	0.71	1.72	7.97
Hamps	76.6	15.1	154.4	8.0	8.2	0.33	2.09	0.49	1.51	1.24	4.36
Mean	94.2	21.3	210.9	9.3	11.2	0.37	3.33	0.42	1.11	1.48	6.17
Mars											
Cambs	116.1	19.4	322.7	9.9	12.3	0.42	4.94	0.18	0.77	2.07	6.87
Hamps	98.1	13.0	210.1	9.5	12.9	0.46	1.94	0.40	2.07	1.70	5.79
Mean	111.6	17.8	294.5	9.8	12.4	0.43	4.19	0.24	1.10	1.98	6.60
Racer											
Cambs	80.0	23.2	191.3	7.6	8.6	0.29	5.13	0.16	0.50	1.37	4.22
Hamps	63.1	31.8	213.3	11.2	7.8	0.26	1.91	0.44	1.15	1.52	4.79
Mean	73.2	26.7	200.1	9.1	8.3	0.28	3.84	0.27	0.76	1.43	4.45
Cambs	102.6	23.4	260.4	9.4	11.7	0.38	4.88	0.23	0.66	1.72	6.35
Hamps	75.7	20.3	183.3	9.3	8.8	0.33	2.00	0.46	1.48	1.41	4.74
Varietal effect	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	ns	ns	ns	$p < 0.001$	ns	$p = 0.05$	$p < 0.001$
location effect	$p < 0.001$	$p = 0.05$	$p < 0.001$	ns	ns	ns	$p < 0.001$	$p < 0.001$	$p < 0.001$	ns	$p < 0.001$
LSD (variety x location)	51.7	8.6	117.3				2.58	0.13	0.85	0.83	3.13

Table 7. Colour of skin and flesh for 3 pumpkin varieties grown with and without a spray programme against powdery mildew. Measurements were taken after early harvest, the main harvest and following 9 weeks of storage.

	Harvest Moon		**Mars**		**Racer**	
	Sprayed	**Unsprayed**	**Sprayed**	**Unsprayed**	**Sprayed**	**Unsprayed**
	L* skin					
Early harvest	59.5bc	57.1d	51.6bc	50.4c	53.0b	55.9ab
Main harvest	60.1b	57.7cd	51.1c	53.5a	57.4a	59.4a
After storage	64.4a	60.9b	53.1ab	54.2a	57.6a	59.2a
	a* skin					
Early harvest	25.7c	26.0bc	24.9a	20.9b	17.6c	19.9bc
Main harvest	28.3ab	28.5ab	24.7a	24.6a	23.5ab	24.6ab
After storage	29.4a	29.9a	27.2a	26.9a	27.8a	26.5a
	b* skin					
Early harvest	53.5b	48.3d	39.1ab	35.8b	40.3b	43.6ab
Main harvest	52.7bc	48.9cd	39.0ab	40.7a	47.1ab	49.8a
After storage	60.1a	53.3b	41.3a	41.8a	46.8ab	48.7a
	L* flesh					
Early harvest	72.3ab	74.0a	74.5a	75.0a	73.3a	72.1a
Main harvest	67.6c	66.9c	70.8b	74.3a	70.8a	70.7a
After storage	76.0a	69.0bc	69.0b	73.8a	72.8a	70.8a
	a* flesh					
Early harvest	2.8c	1.9c	3.4d	4.8d	-1.2c	0.0c
Main harvest	6.1b	5.4b	12.8b	8.6c	4.5b	3.4b
After storage	6.9b	11.3a	20.7a	14.1b	7.9a	9.9a
	b* flesh					
Early harvest	50.4cd	51.1bcd	73.7abc	72.8bcd	44.2b	46.2b
Main harvest	54.1bc	56.1ab	75.3ab	70.2d	47.2b	48.0b
After storage	47.9d	60.5a	76.3a	71.3cd	54.2a	56.4a

Table 8. Fruit characteristics for 3 pumpkin varieties grown with and without a spray programme against powdery mildew. Measurements were taken after early harvest, the main harvest and following 9 weeks of storage.

	Harvest Moon		Mars		Racer	
	Sprayed	**Unsprayed**	**Sprayed**	**Unsprayed**	**Sprayed**	**Unsprayed**
	Diameter (cm)					
Early harvest	22.6a	19b	17.5a	16.05b	19.35a	21.1a
Main harvest	21.3ab	20.1ab	17.2a	15.45b	20.95a	19.5a
After storage	19.9b	20.2ab	17.15a	16.35b	21.8a	20.95a
	Flesh thickness (cm)					
Early harvest	3.2a	2.7a	2.5a	2.4a	2.5a	2.5a
Main harvest	2.9a	2.8a	2.5a	2.3a	2.9a	2.5a
After storage	2.9a	3.0a	2.5a	2.2a	3.1a	2.7a
	Whole Fruit Firmness (N)					
Early harvest	46.1ab	50.92a	56.75ab	59.02a	35.75a	31.88a
Main harvest	46.62ab	52.97a	51.29ab	44.58bc	33.8a	26.64a
After storage	37.59b	47.3ab	34.5cd	29.31d	27.19a	32.04a
	Skin firmness (N)					
Early harvest	29.73a	33.72a	33.12a	30.51a	22.77a	22.87a
Main harvest	33.39a	32.76a	34.59a	27.34a	23.05a	20.58a
After storage	18.52b	30.86a	29.51a	30.67a	21.89a	22.97a
	Flesh firmness (N)					
Early harvest	103.5a	110.7a	131.92a	125.84ab	55.8a	61.62a
Main harvest	101.97a	105.98a	136.39a	115.2bc	60.69a	56.67a
After storage	63.64b	98.61a	129.8a	110.33c	58.1a	63.78a

Table 9. Fruit characteristics for three pumpkin varieties grown at different locations within the UK

	Harvest Moon			Mars		Racer	
Characteristic	**Hamps**	**Kent**	**Cambs**	**Hamps**	**Cambs**	**Hamps**	**Cambs**
L* skin	63.14a	63.99a	60.89b	55.08a	54.25a	56.59b	59.21a
a* skin	27.61ab	25.88b	29.90a	28.77a	26.95b	29.10a	26.46b
b* skin	60.90a	59.10a	53.29b	46.52a	41.84b	51.34a	48.74a
L* flesh	75.72a	76.81a	69.01b	75.75a	73.81b	75.28a	70.76b
a* flesh	4.97b	5.38b	11.33a	8.62b	14.05a	6.74b	9.92a
b* skin	41.04b	39.39b	60.51a	61.99b	71.27a	52.55b	56.40a
Diameter (cm)	22.46a	24.45a	21.72a	18.46a	18.52a	22.08a	23.73a
Height (cm)	18.68b	21.881	18.73b	14.90a	14.17a	17.05a	18.18a
Flesh thickness (cm)	3.0a	3.6a	3.0a	2.7a	2.2b	2.8a	2.7a
Whole fruit firmness (N)	29.07b	30.87b	47.3a	32.81a	29.31a	27.9a	32.04a
Skin firmness (N)	20.26b	23.89b	30.86a	32.79a	30.67a	25.57a	22.97a
Flesh firmness (N)	58.27c	71.43b	98.61a	105.41a	110.33a	61.77a	63.78a

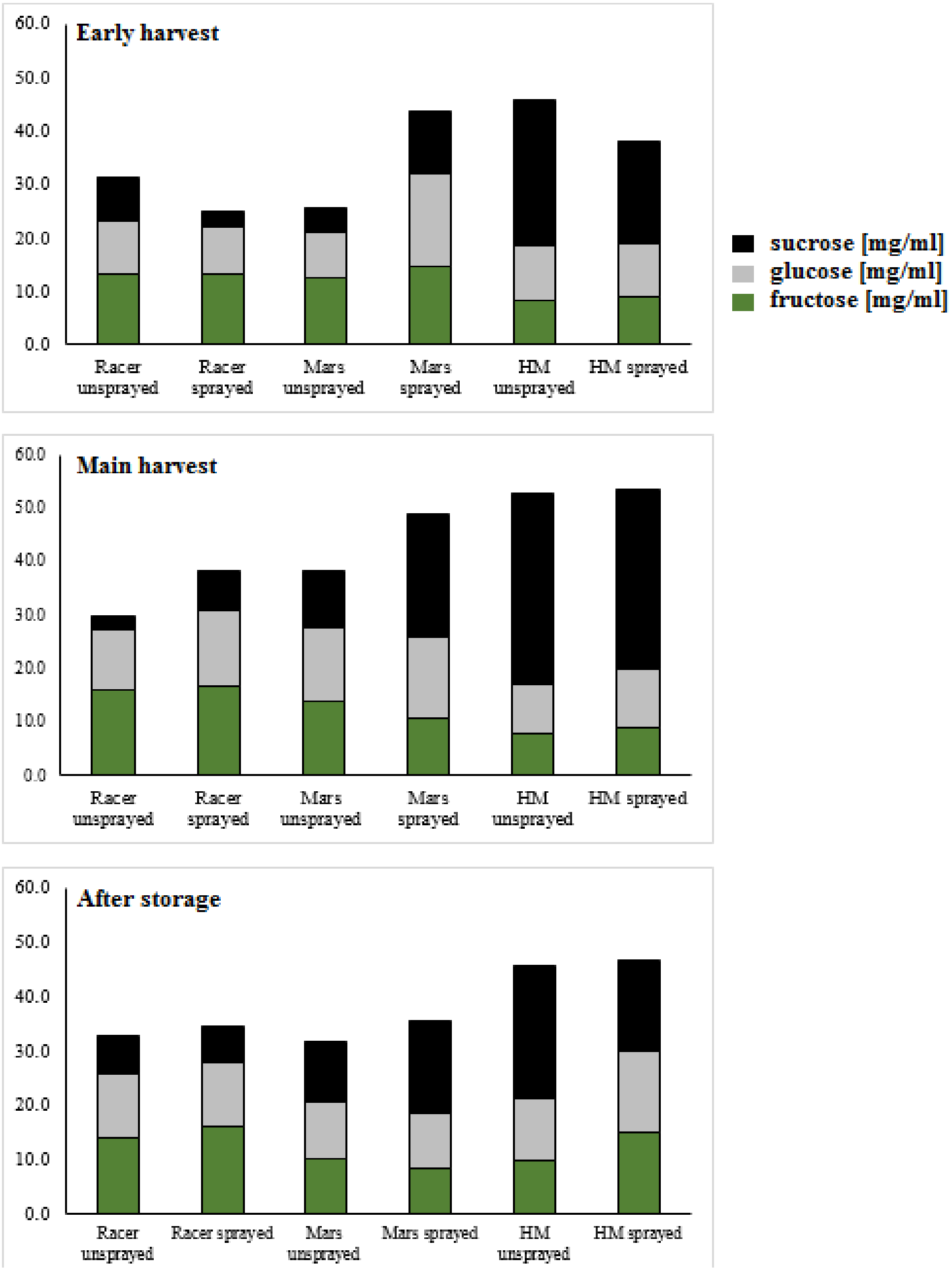


Fig. 17. Sugar content of three unsprayed and sprayed pumpkin varieties from early harvest, main harvest and after storage (2015). Each value is the mean of measurements on 6 fruit.

Tables 4 – 8 and Figure 17 summarise the characteristics of pumpkin fruits sampled from the trial on powdery mildew control conducted in Cambridgeshire and also of pumpkin fruits samples from Hampshire and from Kent. As observed previously Harvest Moon and Mars store better when grown in Cambridgeshire, but this is not the case for Racer. Harvest Moon and Mars have a higher dry matter content in Cambridgeshire, and likewise a higher calcium content, but this differential is not observed for Racer (Table 6).

Another observation is that treatments lead to a significant increase in the copper content of pumpkin flesh.

2016: Field trials to test effect of crop nutrition and fungicidal control against powdery mildew and Phoma

By the end of the second season of this project *Phoma* had been identified as the main rotting pathogen at harvest and during storage for all sites tested. In 2016 a trial was conducted in Cambridgeshire and in Kent to test the impact on losses of a spray programme focused against both *Phoma* and powdery mildew with additional mineral nutrition.

Fungicide and mineral treatments used

The fungicides used in this trial were Nimrod (Bupirimate) and Signum (Boscalid/ pyraclostrobin), which are both approved for use with outdoor pumpkins. The former is known to have activity against powdery mildew, while the latter is known to work against both powdery and downy mildew, as well as C*ladisporium* species and is expected to be active against Phoma.

Mineral nutrition focused on calcium, boron, manganese and magnesium sulphate. Boron and calcium were applied specifically to help with fruit set and fruit cellular structure development. Boron in particular is thought to improve pollen tube growth and fruit set. Copper was also incuded within the nutritional spray program and within the fruit assessments it was observed that it had increased the copper levels within the fruits. The addition of copper was justified as manganese has an antagonistic effect on copper availability and thus can impact on fruit formation. Copper is not approved as a plant protectant product on pumpkins but is recognised on other crops as having reasonable plant protection activities.

Calcium plays a key role in maintaining plasma membrane integrity via the cytoplasm, thus slowing disruption of cellular functions (Lester *et al.* 1998; Lester & Grusak 2001). It has an important role in cell wall structure, so that high calcium content usually leads to better maintenance of firmness. Severe calcium deficiency appears as water-soaked lesions in the blossom end of the fruit that later became necrotic (blossom-end rot); carpel separation from mesocarp tissue that formed air cavities at the stem end was also observed (Frost & Kretchman 1989).

Calcium (Ca) and Boron (B) are both components of the cell wall, so that a deficiency in either increases leakiness, and increases susceptibility to fungal rots. Ca inhibits certain enzymes released by fungi during infection to break down the lamella that holds plant cells together, and so is particularly important for host resistance. B is particularly important in the synthesis of the defence compounds and so is also important for host resistance.

Supplementation of manganese has been shown to be particularly beneficial for field pumpkins (Warncke, 2007). This is also recognised on some of the trial site as being deficient and pumpkins show manganese deficiency very quickly.

In Cambridgeshire applications were started 27th July. By 8th August powdery mildew was observed in the control plots. By September in control plots all older leaves and 30% younger leaves were affected by powdery mildew, whereas treated plants showed only small patches of disease. Treated plants had more mature pumpkins by this stage; 18 – 24 cm compared to 12 – 18 cm. Levels of rots were low at harvest with no significant difference in levels or pathogen identity in treated and untreated plots.

At the Kent site applications were started 18th July. By 20th August powdery mildew was observed. Disease incidence was greater in control plots (patches from 5 mm to partial leaf) than in treated plots (up to 5 mm), but was generally less severe than in Cambridgeshire. No clear difference in fruit maturity was seen during crop walks. As for Cambridgeshire the incidence of rots observed in pumpkins at harvest was low with no difference observed between treated and untreated.

Figures 18 and 19 show pumpkins harvested from control and sprayed plots in Cambridgeshire and Kent respectively. It is notable that at the point of harvest the colour had not developed in Cambridgeshire but was fully developed in Kent. Nevertheless during storage colour was fully developed by the end of October.

A.

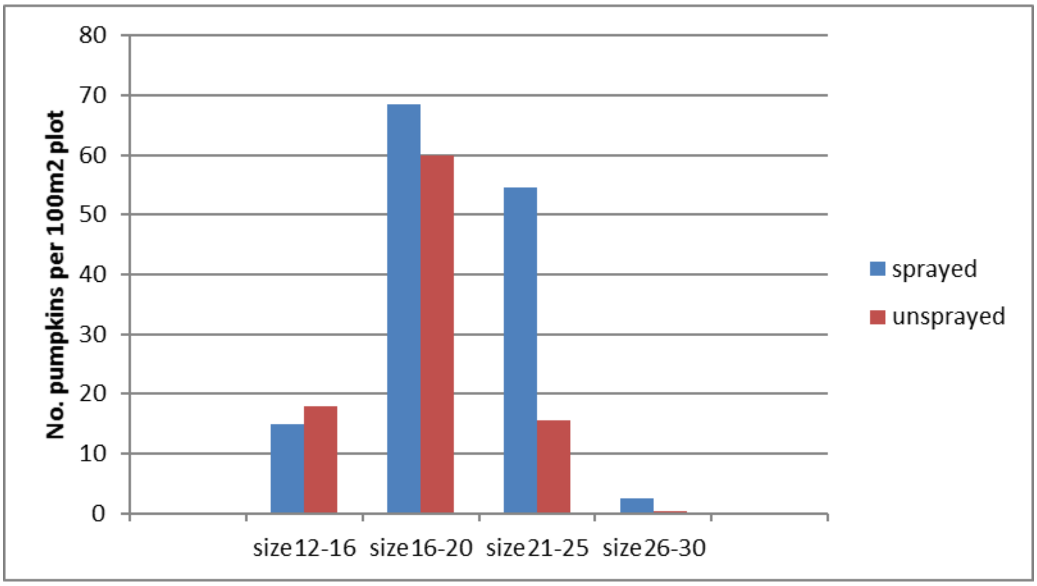
B.

Figure 18. Harvested plots from the trial site in Cambridgeshire A. unsprayed, B. sprayed.

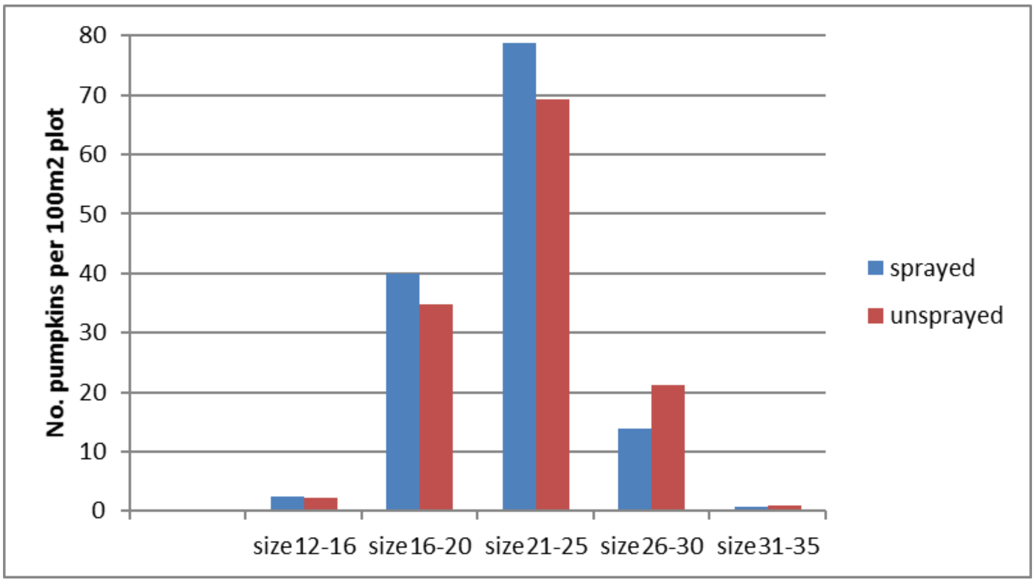
A.

B.

Figure 19. Harvested plots from the trial site in Kent A. unsprayed, B. sprayed.



A.



B.

Figure 20. Yield and size of pumpkins grown with and without a programme of fungicidal spray and mineral nutrition at two sites; A. Cambridgeshire, and B. Kent. Each data point is the mean of data from 6 or 4 100 m^2 plots.

Figure 20 shows the effect of the spray programme on pumpkin yield, in terms of both number and size of pumpkin fruits. At both sites the number and size were increased; with a very marked effect in Cambridgeshire. A simple cost benefit analysis of each site, assuming a cost of 80p per pumpkin indicated that the spray costs were more than compensated for in each case; thus in Kent a spend of £232 per Ha, gives a gain of £560, while in Cambridgeshire a spend of £341 per Ha gave a gain of £3760.

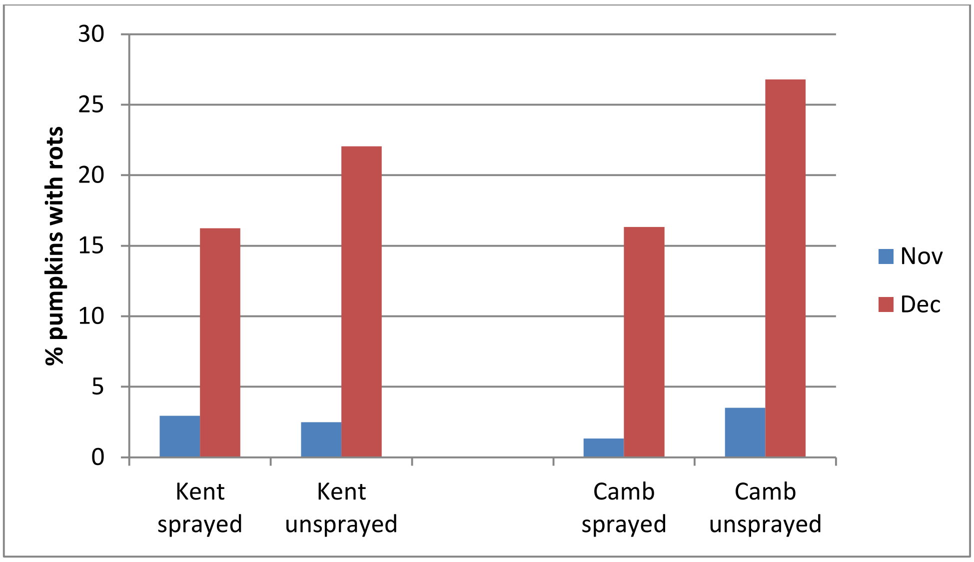


Figure 21. % pumpkins with rots on November 4th (6 weeks of storage) and December 16th (12 weeks of storage). Pumpkins (variety Harvest Moon) were grown in Cambridgeshire (Camb) or Kent. Each data point is the mean of 6 bins. The effect of the spray treatment on the % rots was statistically significant in December ($p = 0.004$)

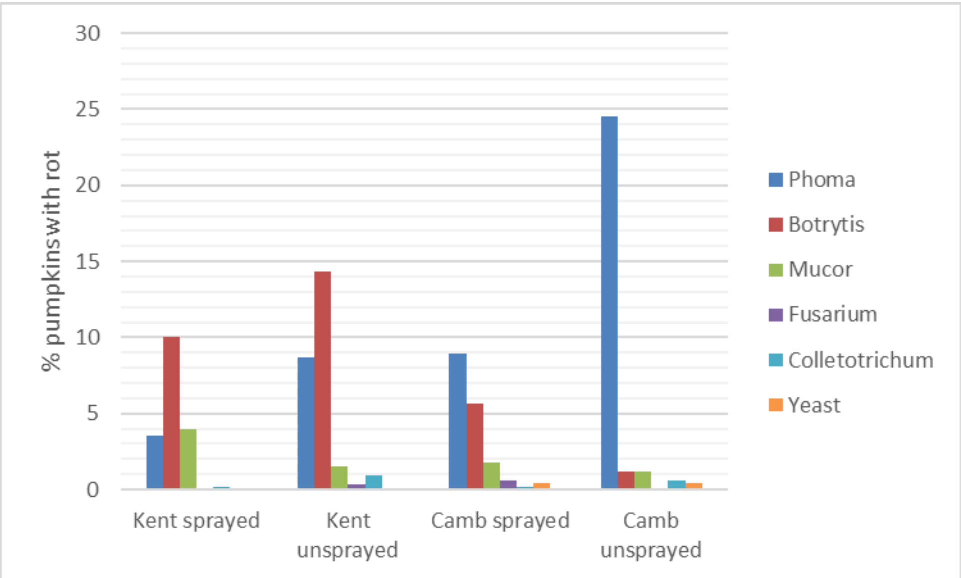


Figure 22. Profile of rotting pathogens for the two trial sites for sprayed and unsprayed plots.

Figure 21 shows the % rotten pumpkins following 6 and 12 weeks of storage. In the 12 week assessment there was a statistically significant reduction in rotting for the pumpkins harvested from sprayed plots. Figure 22, which shows the profile of rotting pathogens at 12 weeks, indicates that the spray programme reduced the losses due to *Phoma* at both sites as expected. Interestingly *Botrytis* was more prevalent than *Phoma* at the Kent site.

Pumpkin growers do not store carving pumpkins beyond the end of October. However, in 2016 pumpkins matured later than the previous two years, so that growers did not have to store as long as in some seasons. The reduction in postharvest rotting observed with *Phoma* control, may become economically important in seasons with early maturation and therefore the necessity to store for several weeks.

Table 10 summarises the pumpkin characteristics. There were no clear consistent effects of the spray programme on the characteristics measured including mineral content. Pumpkins from Kent were firmer with a high dry matter content, and a higher mineral content in a few cases (Cu, P, Zn, B)

Table 10. Fruit characteristics of unsprayed and sprayed Harvest Moon pumpkins from Cambridgeshire and Kent (2016).

Name	**Diameter (cm)**	**Height (cm)**	**Flesh thickness (cm)**	**Whole fruit firmness (N)**	**Skin firmness (N)**	**Flesh hardness (N)**	**DM %**
Cambridgeshire							
unsprayed	19.6b	17.4b	2.6b	17.12b	16.66b	54.18c	2.99b
sprayed	21.5ab	20.0ab	2.8ab	22.48b	20.18b	75.55a	3.77b
Kent							
unsprayed	23.6a	21.7a	3.3a	42.22a	31.97a	67.09ab	6.42a
sprayed	22.5ab	20.5ab	2.9ab	39.17a	28.12a	60.43bc	5.72a

Mineral content of flesh	N	P	K	Mg	Ca	Cu	Fe	Mn	Zn	B
	mg/100 g Fresh weight					mg/Kg Fresh weight				
Cambridgeshire										
unsprayed	93.9a	7.6b	204a	7.04a	24.1a	0.16b	3.74a	0.24a	0.34a	1.49a
sprayed	82.8a	7.6b	212a	6.74a	21.2a	0.23ab	4.15a	0.25a	0.32a	1.49a
Kent										
unsprayed	99.4a	16.4a	227a	8.83a	30.9a	0.40a	3.68a	0.27a	0.86a	2.07a
sprayed	88.7a	12.1ab	184a	8.90a	31.8a	0.36a	3.26a	0.27a	0.93a	1.91a
Mineral content of skin	N	P	K	Mg	Ca	Cu	Fe	Mn	Zn	B
	mg/100 g Fresh weight					mg/Kg Fresh weight				
Cambridgeshire										
unsprayed	269.5a	34.5b	170a	44.4a	84.8ab	0.86b	20.5a	2.72a	2.18b	2.77b
sprayed	247.8a	40.0b	234a	47.3a	75.7b	0.86b	30.0a	2.06a	2.46b	2.79b
Kent										
unsprayed	346.8a	85.6a	376a	70.7a	139.1a	1.26a	25.0a	2.87a	8.65a	4.37a
sprayed	293.9a	76.8a	308a	61.8a	121.0ab	0.99ab	23.4a	3.04a	6.38a	3.70ab

Comparison of different pumpkin varieties

Assessment of the postharvest characteristics of a range of pumpkin varieties (Table 11) was carried out over the three year period. To the best of our knowledge no such characterisation of UK varieties exists. The aim was to find out which characteristics relate to the keeping qualities, so that this information could be used for the varietal selection, and also improvement of crop management. Table 11 also includes preliminary information on the shelf-life characteristics of the varieties, (good shelf-life and poor shelf-life highlighted) which was obtained from observations of the losses during laboratory observations.

Table11. List of pumpkin varieties used in the Project (2014-2016).

Variety	Seed company	Years included in assessment			Shelf-life
Becky		2014	2015		Good
Carrie			2015		Poor
Cinnamon Girl		2014	2015		
CN PUM7805 F1	CN Seeds			2016	Good
Flynn	Sakata	2014		2016	Poor
Gladiator	Clause			2016	Poor
Gomez	Clause	2014		2016	Good
Hannibal			2015		Poor
Harvest Moon	CN Seeds	2014		2016	Medium
HMX4680	Clause			2016	Poor
Jack Sprat		2014			Poor
Kratos	Clause			2016	Good
Magician	Clause	2014		2016	Poor
Mars	Tozer	2014	2015	2016	Good
Paintball		2014	2015		Medium
Racer	Tozer	2014	2015	2016	Medium
Rocket			2015		Medium
Small sugar		2014	2015		Good
Snowball			2015		Good
Spitfire	Clause	2014		2016	Medium
SQ11333	Sakata			2016	Good
Sunlight			2015		Good
Terra Fin	Sakata			2016	
Tot A			2015		Good
TZ 4171	Tozer			2016	Poor
Zeus	Clause			2016	Good

Twelve pumpkin varieties were assessed in 2014 (Fig. 23) and 2015 (Fig.24), respectively, whereas sever varieties were assessed in the final year – 2016 (shown in Fig. 23). The varietal characteristics assessment included, fruit size, texture analyses (whole fruit firmness, skin strength, and flesh hardness), skin and flesh colour, dry matter content, sugar content and composition, mineral content.

Figure 23. Twelve pumpkin varieties assessed for postharvest characteristics in 2014. Seven of these were also assessed in 2016.


Becky

Carrie


Cinnamon Girl

Hannibal


Mars

Paintball

Racer

Rocket

Small Sugar

Snowball

Sunlight

Touch of Autumn

Figure 24. Twelve pumpkin varieties assessed for postharvest characteristics in 2015.

Size

The dimensions of the pumpkin fruit were determined as presented on Fig. 25

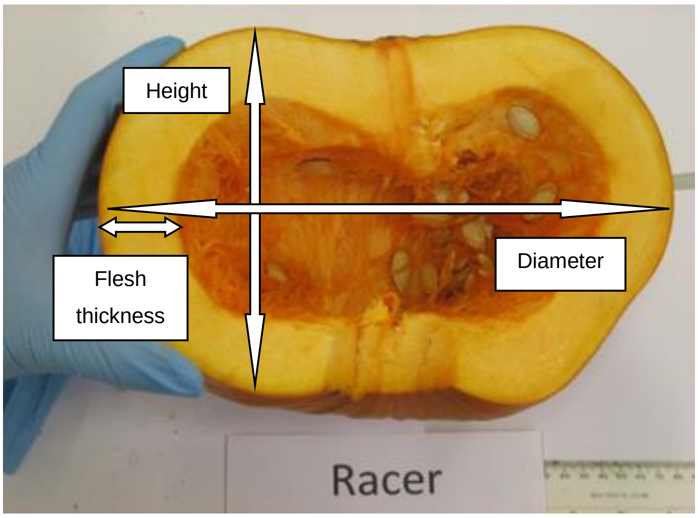


Figure 25. Dimensions (diameter, height, and flesh thickness) of pumpkins, measured as indicated on the diagram.

It can be seen from Table 12, 13 and 14 that pumpkins of different size were used in the varietal trials each year. These varied from small varieties, e.g. Becky and Cinnamon Girl, medium size varieties, e.g. Mars and Paintball to large varieties, e.g. Harvest Moon and Racer. Thus, it is not surprising that significant differences were observed for this parameter. The size of the pumpkin, however, had no significant effect on its storability, as pumpkins with both good (Small Sugar, Mars, Harvest Moon) and bad (Jack Sprat, Spitfire, Magician) keeping quality were observed across all the size groups.

Table 12. Dimensions of twelve pumpkin varieties (2014). Each value is the mean of measurements of 6 fruit.

Variety	Diameter [cm]	Height [cm]	Flesh thickness [cm]
Becky	16.0e	11.2d	2.4cd
Cinnamon Girl	16.7de	11.5d	1.8ef
Flynn	22.9ab	18.0b	2.5bcd
Gomez	19.5cd	17.1b	3.0ab
Harvest Moon	25.3a	21.7a	3.5a
Jack Sprat	14.5e	12.4cd	1.5f
Magician	23.7ab	19.3ab	2.9bc
Mars	20.3cd	15.1c	2.4cd
Paintball	18.7cd	15.0c	2.2de
Racer	24.5a	17.4b	3.5a
Small Sugar	16.5de	12.6e	2.4cd
Spitfire	21.2bc	14.3d	2.6bcd

Table 13. Dimensions of twelve pumpkin varieties (2015). Each value is the mean of measurements of 6 fruit.

Variety	Diameter [cm]	Height [cm]	Flesh thickness [cm]
Becky	15.25de	11.42de	2.3cd
Carrie	26.98ab	19.42b	3.4b
Cinnamon Girl	15.37de	12.20de	1.7d
Hannibal	29.12a	25.60a	4.5a
Mars	18.15cd	13.82cd	2.5c
Paintball	19.65c	15.03c	2.2cd
Racer	25.52b	19.08b	3.8ab
Rocket	27.78ab	25.17a	4.1ab
Small sugar	16.53cde	13.30cde	2.2cd
Snowball	13.68e	11.18e	1.8cd
Sunlight	18.05cd	13.38cde	2.2cd
Touch of Autumn	14.58e	12.37de	2.3cd

Table 14. Dimensions of seven pumpkin varieties (2016). Each value is the mean of measurements of 4 fruit.

Variety	Diameter [cm]	Height [cm]	Flesh thickness [cm]
Gomez	16.98b	14.55ab	3.0a
HM	22.00ab	17.92a	3.3a
Mag	23.02a	18.78a	3.1a
Mars	19.15ab	12.25b	2.9a
Racer	23.75a	17.65a	3.3a
Spitfire	19.02ab	11.92b	2.7a
Terra Fin	20.78ab	17.12a	2.4a

Firmness

The textural analyses were conducted for whole fruit firmness (compression test), skin strength (puncture test), and flesh hardness (compression test). The outputs from this assessment are presented below.

Whole fruit firmness

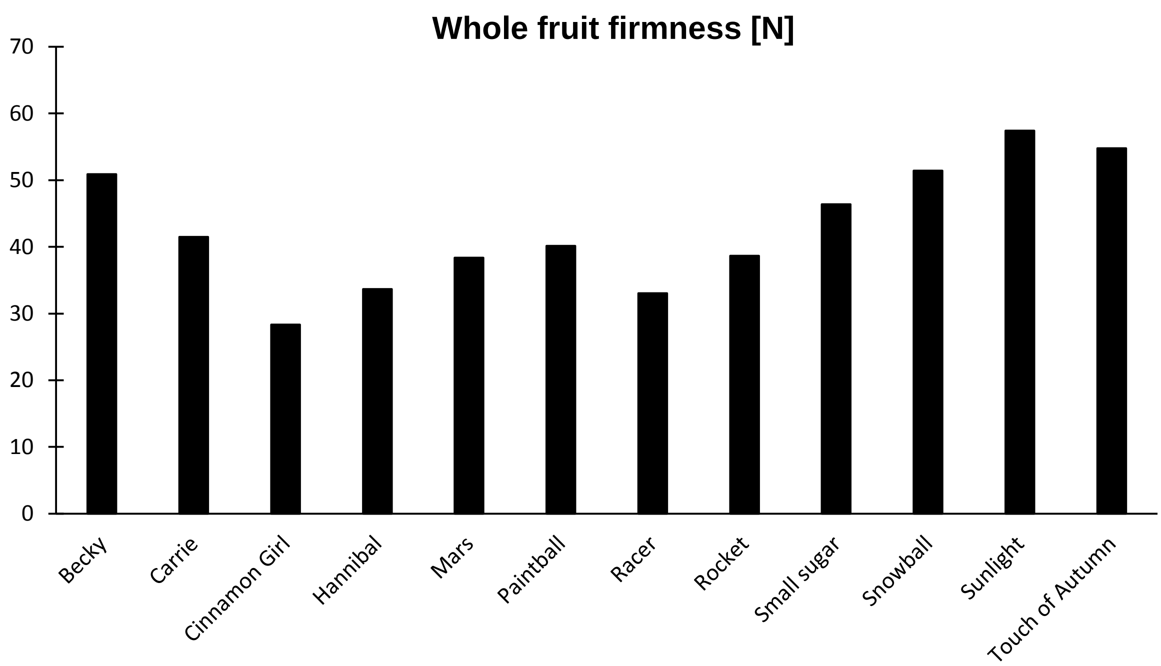
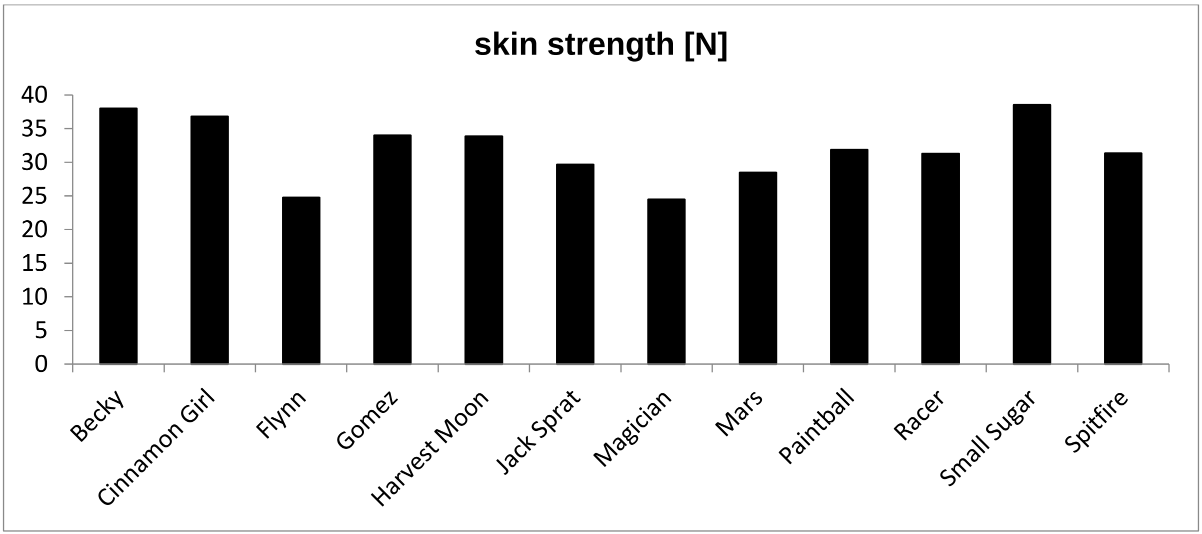


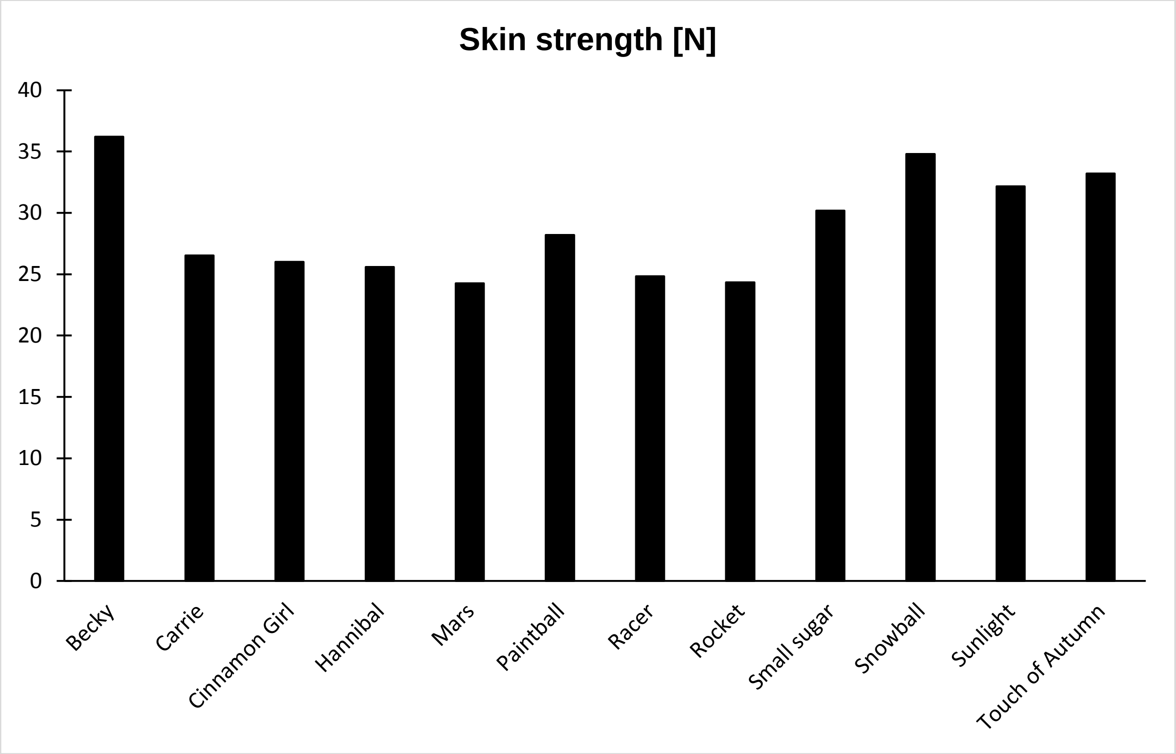
Figure 26. Whole fruit firmness measured with TA.XT plus Texture Analyser.

Whole fruit firmness seems to be a good indicator of high keeping quality pumpkins, especially for small size pumpkins. It can be seen that those of good keeping quality, i.e. Becky, Small Sugar, Snowball, Sunlight and Touch of Autumn were much firmer than bad keeping quality variety - Jack Sprat. Similarly, this parameter seemed to be suitable to judge the keeping quality of big pumpkins, where Harvest Moon and Rocket varieties were much firmer than Magician and Hannibal varieties, respectively. On the other hand, this parameter was not extremely useful for medium size pumpkins, where the whole fruit firmness was to some extent affected by the skin strength.

Skin strength

Skin strength seems to relate well to the keeping quality of pumpkins, however the direct comparisons can only be made within the pumpkin's groups of similar size, i.e. more force was needed to break the skin (puncture test) of Becky, Small Sugar, and Snowball than that of Jack Sprat. Similarly, the skin of Harvest Moon was harder to break compared with Magician variety. In case of medium size pumpkins the trend was not clear.





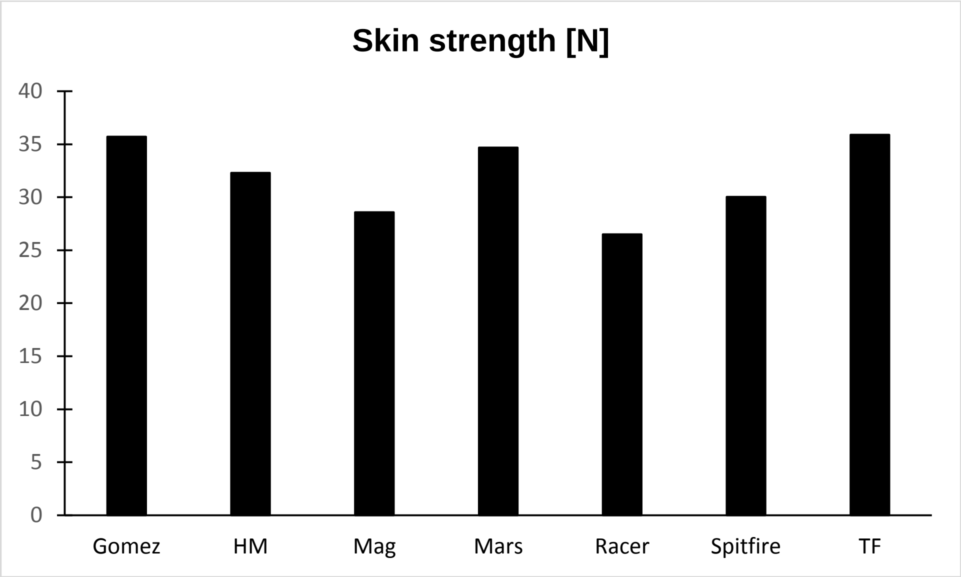
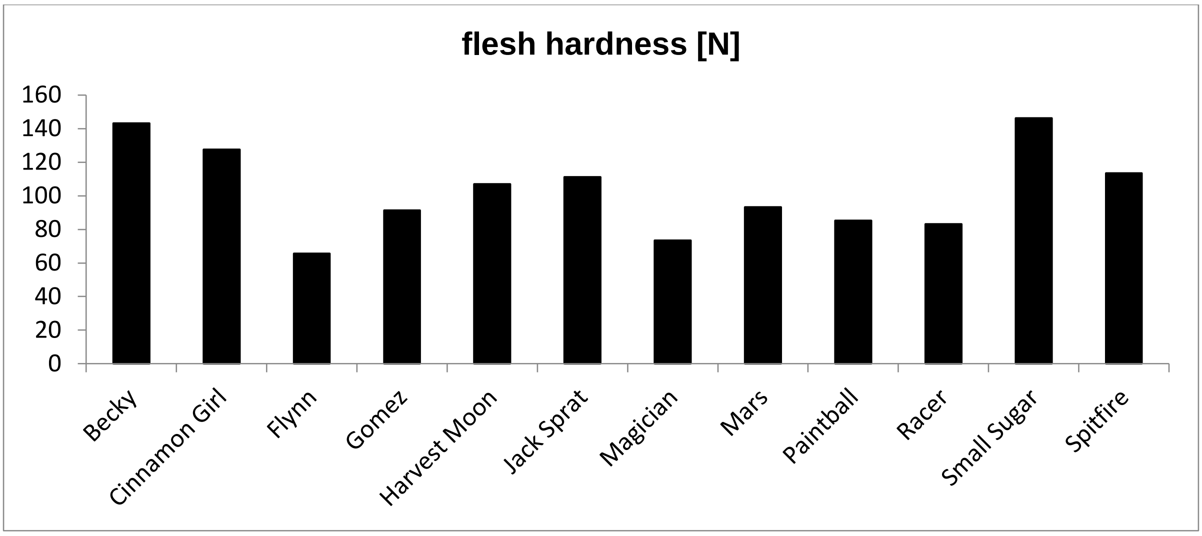
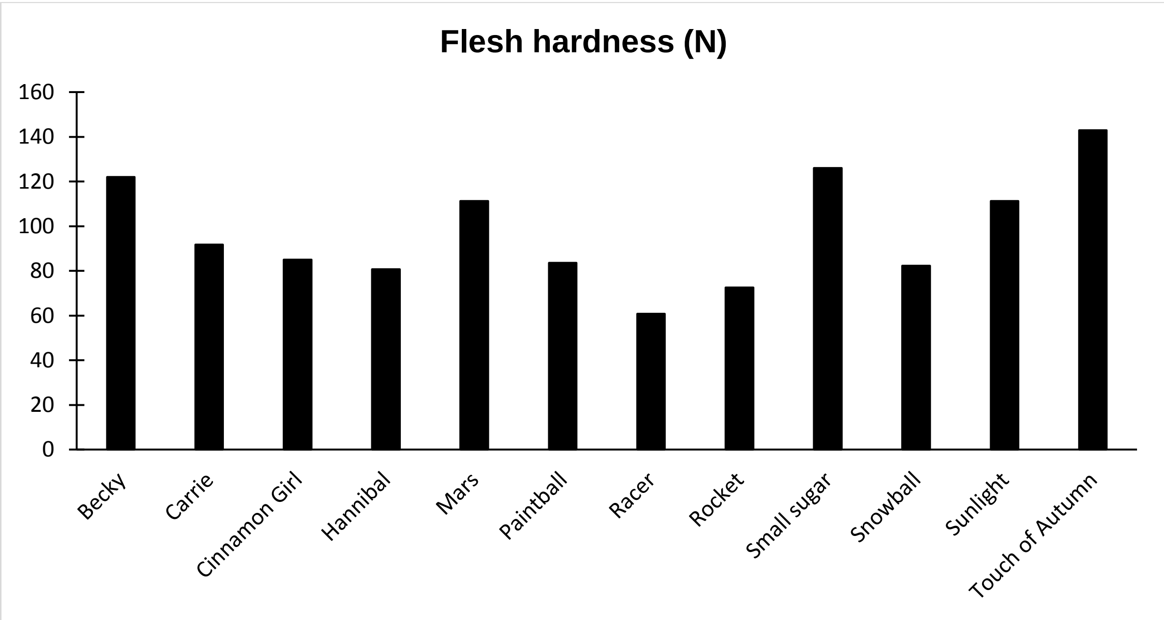


Figure 27. Skin strength measured with TA.XT plus Texture Analyser.

Flesh hardness

Flesh hardness related well to the keeping quality for the pumpkins of all sizes. This could be associated with the fact that harder flesh is often composed of higher density of cells, i.e. better attached to each other, making it more difficult to compress the tissue in the texture assay. With only little uncertainty we can conclude that it is a characteristic that says a lot about the quality of the pumpkin, however one must be aware that the direct comparisons can only be made among the pumpkins of similar size.





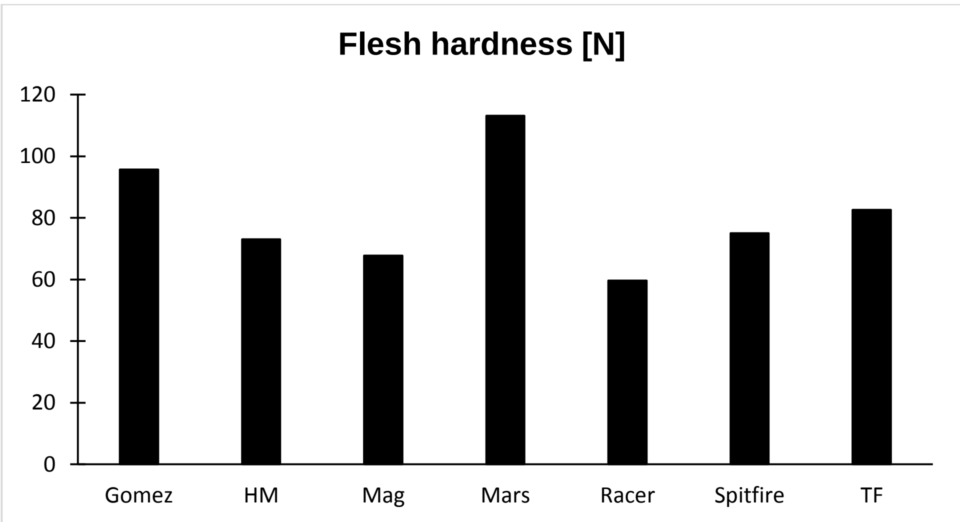


Figure 28. Flesh hardness measured with TA.XT plus Texture Analyser.

Colour

Skin

There were substantial differences in the skin colour of the pumpkins used in the trials. This however should not be surprising. Even though majority of pumpkins used in the trials were orange skin pumpkins, the varieties of other colours were also used, i.e. white skin Snowball, and yellow skin Sunlight. Significant differences were still observed among the orange skin pumpkins, mainly due to different lightness value (*L**) – some of the pumpkins being darker (e.g. Gomez, Mars) than other (Harvest Moon, Cinnamon Girl), and thus some differences in the red and yellow spectrum were also noticed. Skin colour however, did not relate to the keeping quality of pumpkins.

Table 15. Colour of the skin of twelve pumpkin varieties (2014). Each value is the mean of measurements of 6 fruit.

Variety	*L* skin*	*a* skin*	*b* skin*
Becky	56.4bcd	28.4cde	49.4def
Cinnamon Girl	58.1a	29.8bcd	54.0abcd
Flynn	59.6ab	28.5bcde	55.9ab
Gomez	53.3cd	28.6bcde	45.6ef
Harvest Moon	56.0bcd	30.0bc	50.0cdef
Jack Sprat	61.4a	30.6b	58.7a
Magician	56.8bc	29.3bcde	51.1bcde
Mars	56.5bcd	27.8d	50.5bcde
Paintball	58.7a	27.9bcde	54.7abcd
Racer	52.9d	27.5e	44.4f
Small Sugar	56.8bc	26.5e	49.6def
Spitfire	56.7bc	33.8a	51.5bcd

Table 16. Colour of the skin of twelve pumpkin varieties (2015). Each value is the mean of measurements of 6 fruit.

Variety	*L** skin	*a** skin	*b** skin
Becky	60.07bcd	28.97ab	55.22bcd
Carrie	56.25ef	29.06ab	50.76de
Cinnamon Girl	62.21bc	26.95abc	59.59bc
Hannibal	59.33cde	28.49ab	54.75bcd
Mars	50.95f	22.06c	40.30f
Paintball	55.65f	24.68bc	48.46e
Racer	58.14def	28.20ab	53.68cde
Rocket	63.29b	28.46ab	59.79b
Small sugar	56.28ef	23.11c	48.21e
Snowball	88.78a	-0.67e	20.43g
Sunlight	78.94a	10.44d	76.45a
Touch of Autumn	58.66def	31.16a	52.62de

Table 17. Colour of the skin of seven pumpkin varieties (2016). Each value is the mean of measurements of 4 fruit.

Variety	*L** skin	*a** skin	*b** skin
Gomez	54.70b	30.33bc	48.32b
HM	59.27a	30.62abc	56.50a
Mag	59.29a	32.00ab	56.30a
Mars	49.05c	26.81e	40.86c
Racer	57.31ab	27.96de	53.76a
Spitfire	58.64a	32.66a	53.56a
TF	57.27ab	29.02cd	52.21ab

Flesh

Even though flesh colour did not relate to the keeping quality of pumpkins, this characteristic has often been associated with the carotenoid content in the flesh, thus being of some interest in terms of human nutrition. Nonetheless, the focus of this research was on the keeping quality characteristics, thus nutritional aspect of pumpkins will not be discussed in more depth.

Table 18. Colour of the flesh of twelve pumpkin varieties (2014). Each value is the mean of measurements of 6 fruit.

Variety	*L* flesh*	*a* flesh*	*b* flesh*
Becky	65.7e	23.6a	76.4a
Cinnamon Girl	71.5abc	7.6efg	64.5bc
Flynn	71.1abcd	2.7g	49.9d
Gomez	73.6ab	8.8def	57.2cd
Harvest Moon	66.4de	12.4bcde	56.3cd
Jack Sprat	68.2cde	17.9b	68.5a
Magician	73.2ab	5.0fg	48.3d
Mars	71.5abc	6.9efg	48.8d
Paintball	70.1abcde	10.4cdef	54.9cd
Racer	65.4e	13.5bcd	57.1cd
Small Sugar	69.0bcde	15.7bc	72.1ab
Spitfire	74.5a	7.4efg	63.1bc

Table 19. Colour of the flesh of twelve pumpkin varieties (2015). Each value is the mean of measurements of 6 fruit.

Variety	*L** flesh	*a** flesh	*b** flesh
Becky	73.78cde	14.50a	76.17a
Carrie	70.94efg	8.62b	54.13ef
Cinnamon Girl	79.01a	1.25f	52.65efg
Hannibal	73.80cde	7.55bcd	51.17efg
Mars	76.65abc	5.00de	68.50b
Paintball	72.78def	8.51bc	55.67de
Racer	70.00fg	6.64bcde	48.93fg
Rocket	69.11g	6.51bcde	47.78g
Small sugar	74.66bcd	5.50cde	65.22bc
Snowball	78.29a	-2.06g	32.25h
Sunlight	76.98ab	4.34ef	50.86efg
Touch of Autumn	77.14ab	5.29de	60.61cd

Table 20. Colour of the flesh of seven pumpkin varieties (2016). Each value is the mean of measurements of 4 fruit.

Variety	*L** flesh	*a** flesh	*b** flesh
Gomez	71.32bc	10.37b	61.16b
HM	72.23abc	7.84c	47.86cd
Mag	72.67abc	4.68d	44.10d
Mars	70.36c	13.63a	68.81a
Racer	74.79ab	7.69c	46.45cd
Spitfire	75.45a	7.02c	60.09b
TF	71.85abc	3.86d	48.01c

Dry matter content

Dry matter content seems to relate well to the keeping quality of pumpkins, mainly due to the fact that dry matter content correlated well with all textural characteristics, i.e. whole fruit firmness, skin strength, and flesh hardness. This could be associated with the fact that high dry matter content means there is less water to be lost during subsequent storage.

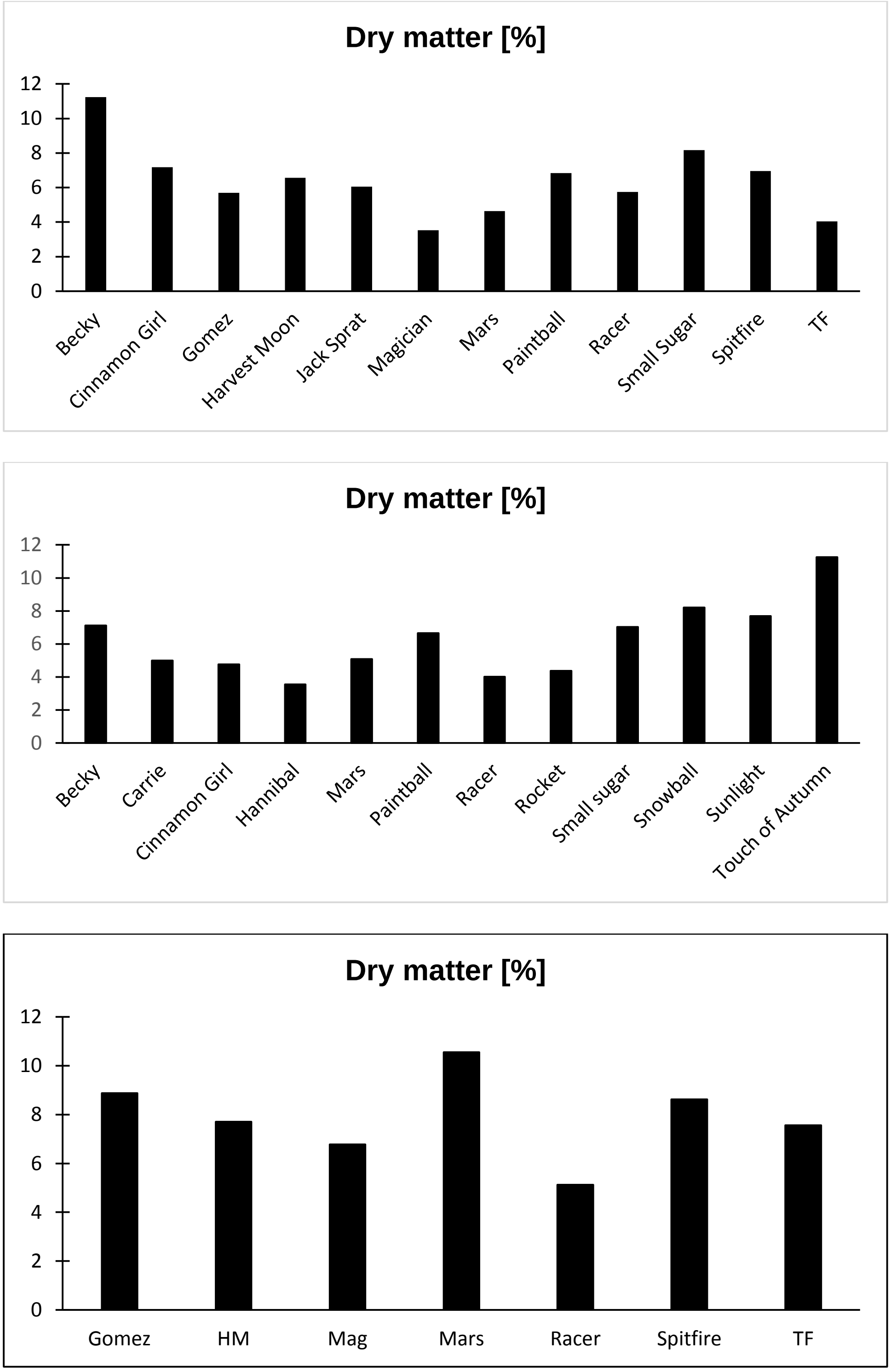
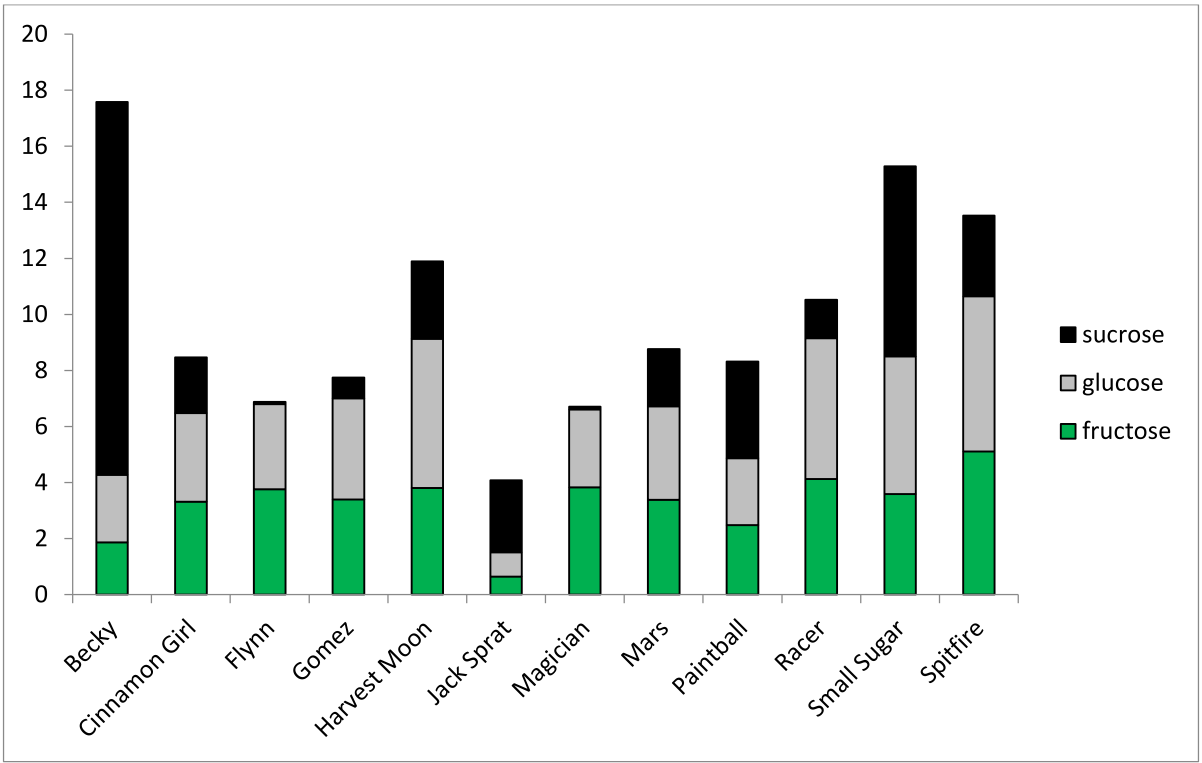


Figure 29. Dry matter content.

Sugar content

Pumpkin varieties differed in their sugar content and composition. There is however no clear correlation between sugar content and the keeping quality. Some of the differences among varieties were due to size of the fruit, e.g. big fruit with lower dry matter content would have lower sugar content due to dilution factor.



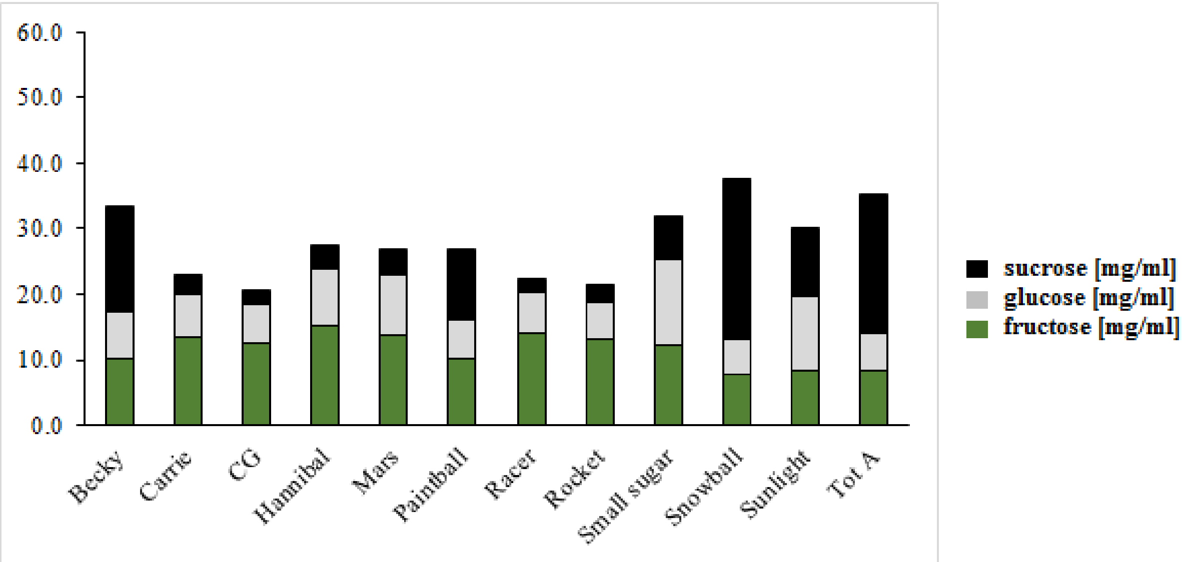


Figure 30. Sugar content of twelve pumpkin varieties (2014, 2015). Each value is the mean of measurements on 6 fruit.

Mineral composition

Table 21. Mineral composition of pumpkin fruit of twelve varieties (2014).

Variety	N	Ca	K	Mg	P	Cu	Fe	Mn	Zn	B
	mg/100g fresh weight					mg/kg fresh weight				
Becky	219	40.6	518	21.81	74.14	0.57	8.19	0.89	2.14	4.00
Cinnamon Girl	233	24.8	480	19.53	55.78	0.49	8.15	0.44	1.63	3.26
Flynn	91	46.8	217	12.73	14.37	0.40	2.85	0.45	1.30	1.68
Gomez	175	29.3	245	15.06	25.96	0.58	4.18	0.44	1.78	2.78
Harvest Moon	205	32.2	269	16.54	48.30	0.39	4.06	0.87	1.65	1.92
Jack Sprat	188	42.6	714	17.21	71.55	0.58	6.71	0.32	1.22	3.06
Magician	112	31.6	177	12.26	18.33	0.35	8.91	0.65	1.25	1.42
Mars	117	24.4	256	11.83	29.02	0.41	6.19	0.53	1.53	1.57
Paintball	150	25.8	386	17.22	61.56	0.38	4.08	0.66	1.16	2.40
Racer	181	31.7	230	16.10	37.49	0.40	7.11	0.85	1.93	2.20
Small Sugar	119	28.5	556	19.35	55.17	0.53	5.69	0.71	1.66	3.08
Spitfire	137	19.3	486	18.70	62.49	0.55	4.33	0.75	1.72	2.69

Table 22. Mineral composition of pumpkin fruit of twelve varieties (2015).

Variety	N	Ca	K	Mg	P	Cu	Fe	Mn	Zn	B
	mg/100g fresh weight					mg/kg fresh weight				
Becky	100	15.1	367	6.38	28.55	0.22	3.23	0.17	0.46	2.29
Carrie	129	17.1	283	12.44	24.64	0.23	1.99	0.30	0.88	1.44
Cinnamon Girl	62	16.9	288	4.97	17.52	0.13	1.70	0.07	0.34	1.90
Hannibal	69	18.0	142	7.22	17.00	0.18	2.24	0.20	0.35	1.03
Mars	107	15.5	261	8.99	27.15	0.27	2.90	0.18	0.81	1.48
Paintball	130	29.3	374	12.64	33.63	0.16	3.17	0.27	0.42	1.95
Racer	75	18.9	193	7.88	18.94	0.15	1.95	0.28	0.49	1.25
Rocket	100	26.5	241	9.34	22.08	0.16	2.39	0.41	0.64	1.14
Small Sugar	79	16.1	364	7.38	23.68	0.20	2.58	0.17	0.32	2.04
Snowball	99	31.1	393	15.68	30.16	0.21	3.07	0.26	0.63	2.00
Sunlight	90	12.4	324	15.70	29.54	0.19	2.27	0.19	0.63	2.68
Touch of Autumn	182	16.1	444	17.70	54.49	0.50	3.60	0.31	1.45	2.47

Table 23. Mineral composition of pumpkin fruit of seven varieties (2016).

Variety	N	Ca	K	Mg	P	Cu	Fe	Mn	Zn	B
	mg/100g fresh weight					mg/kg fresh weight				
Flesh										
Gomez	104	43.4	483	18.94	22.86	0.63	4.75	0.33	0.94	3.57
HM	94	59.0	234	14.04	13.74	0.42	4.16	0.33	0.63	2.24
Magician	60	38.2	282	14.34	14.79	0.37	2.87	0.24	0.53	2.46
Mars	116	33.1	457	21.80	28.09	0.72	4.59	0.48	1.37	3.47
Racer	87	31.0	263	9.53	18.18	0.52	5.23	0.33	1.17	2.32
Spitfire	98	37.4	508	16.43	19.44	0.66	5.60	0.31	1.01	3.29
TF	65	68.7	341	18.92	16.55	0.54	4.01	0.36	0.61	2.82
Skin										
Gomez	487	119.3	817	53.68	63.55	2.25	19.78	1.37	3.55	6.22
HM	373	145.4	435	56.18	63.62	1.29	34.08	3.29	4.23	4.29
Magician	284	85.3	619	31.81	48.62	1.20	17.93	1.17	2.38	4.51
Mars	545	117.3	781	75.93	89.88	3.94	25.50	1.86	6.93	5.63
Racer	386	130.6	312	100.09	46.48	2.01	24.22	3.75	3.42	4.30
Spitfire	476	96.5	756	37.15	55.56	2.34	36.10	1.85	3.41	4.75
TF	459	98.7	640	63.12	60.99	2.02	27.75	3.97	4.66	5.22

There were significant differences in mineral composition among the varieties tested. However, it seems that it is only the content of potassium and boron that could be associated with good keeping quality of pumpkins. This should not be surprising, as boron plays a role of the structural element of plant cell wall making them stronger by cross-linking with rhamnogalacturonan monomers, whereas higher potassium content is involved in keeping the integrity of cell membranes.

Discussion

The markets for both carving and culinary pumpkins in the UK are growing. Supermarkets are promoting Halloween and the associated products, and although there is a limited capacity for sales of carving pumpkins, the perception is that this has not yet been reached. In the case of culinary pumpkins, the current market is at a lower level and the potential expansion is much greater.

Although UK pumpkin growers clearly have a great deal of experience, and knowledge of the response of different pumpkin varieties to growing conditions, information is currently not well documented. The potential gain from a well-structured programme to assess growing practices and varietal characteristics is high.

At the start of this project the perception was that UK growers could gain much from the experience of growers in the US in terms of both growing practices and storage. In fact US growers do not store decorative pumpkins, as the consumers there tend to buy pumpkins for home display over a relatively long time period. Discussion with UK growers indicated that the economic case for developing more sophisticated storage strategies was not strong. As a result this project has focused more on growing practices and varietal assessment.

The original objectives are discussed below in terms of the extent to which the project addressed each one.

1. **To collate and disseminate information on management of the pumpkin crop in the US, and associated research relevant to the UK industry.**

The information was obtained through discussion with key US practitioners and researchers, and also examination of websites. This information was used to inform project activities.

2. **To determine and rank the main forms of post-harvest loss (tissue breakdown, latent infection, post-harvest infection, harvest maturity) currently affecting pumpkins in the UK.**

For the first time, *Phoma cucurbitacearum* has been identified as the main rotting pathogen, and main cause of postharvest loss for pumpkins. Furthermore, although no formal assessment has been carried out, the experience of the project team has highlighted the impact of physical damage (puncturing) of the pumpkin surface tissues. During assessments of storage bins, it was striking that unless a pumpkin had a physical surface wound, it was unlikely to succumb to rots from neighbouring fruits i.e. nests of rots as observed, for example, in apple stores, were not observed in pumpkin bins.

3. **To determine and rank the key factors affecting the storage potential of pumpkins in the UK (harvest maturity, mineral nutrition, harvesting/post-harvest practices, and storage environment/practices.)**

An initial indication in 2015 that earlier harvest reduces postharvest rotting was not tested in 2016. Field and storage trials conducted in 2016 suggest that treatment with Calcium and Boron reduces postharvest rots. However, the trials tested fungicides and mineral nutrition in parallel, so that further trials will be necessary to determine the relative advantages. Storage practices were not studied in detail as little economic justification could be found.

4. **To determine the varietal characteristics that affect storage potential (including size, skin toughness, pericarp thickness, dry matter content)**

For the first time, a catalogue is being produced of characteristics of the pumpkin fruit for a range of varieties, and related to keeping qualities. Within size categories high dry matter content appears to related to storability.

5. **To identify and test pre-harvest management practices to improve storage potential.**

Field management practices involving fungicidal treatment against Phoma, combined with mineral nutrition, can have a significant effect on postharvest losses due to rots.

6. **To identify and test harvest/post-harvest management practices to improve storability, including the identification of maturity indicators to predict storage potential at harvest.**

Despite an indication in 2015 that earlier harvest reduces postharvest rots, this still needs to be tested in further seasons.

Conclusions

- *Phoma cucurbitacearum* has been identified as the main rotting pathogen, and main cause of postharvest loss for pumpkins.
- There is no evidence that a programme of fungicidal treatment to control powdery mildew alone in order to protect the stem reduces postharvest losses.
- A programme of field treatment that combines control of both powdery mildew and *Phoma* with mineral nutrition increases yields in terms of pumpkin number and size, and significantly reduces postharvest rot incidence.
- This project has started to catalogue fruit characteristics for a range of pumpkin varieties (decorative and culinary). Within size ranges the characteristic that is most clearly related to good keeping qualities is high dry matter content of the flesh.

The way forward

A programme of trials could be conducted by growers in order to collate information over more seasons and more variable climatic conditions.

Knowledge and Technology Transfer

- A presentation was made on the first year of results to the Outdoor Cucurbits Group on 13th January 2015.
- Marcin Glowacz attended the International Symposium on Cucurbits in Cartagena, Spain in June 2015 and gave a presentation entitled “Physicochemical characteristics of twelve pumpkin varieties grown in UK” This was funded by the University of Greenwich.
- Peter Waldock gave a presentation on the project progress to the Outdoor Cucurbits Grower Group R&D meeting in January 2016.
- Debbie Rees and Peter Waldock gave a presentation on the project progress to the Outdoor Cucurbits Grower Group R&D meeting in January 2017.
- Two articles on this project have been published in AHDB Grower; “Addressing the challenges of pumpkin storage” in 2016 and “Increasing the profitability of pumpkin growing” in 2017.

Aknowledgements

This project would not have been possible without generous support from Oakley Farms, Dan Mackeldens and Barfoots. We are also grateful for access to trials run by NIAB.

References

Frost, D. J. and D..W. Kretchman. 1989. Calcium deficiency reduces cucumber fruit and seed quality. Journal of the American Society of Horticultural Science 114(4):552-556.

Lester, G. E. and M. A. Grusak. (2001). Postharvest application of chelated and nonchelated calcium dip treatments to commercially grown Honey Dew melons: Effects on peel attributes, tissue calcium concentration, quality, and consumer preference following storage. Horticultural Technology. 11(4):561-566.

Lester, G. E., V. M. Baizabal-Aguirre, L. E. Gonzalez de la Vara and W. Michalke. (1998). Calcium-Stimulated protein kinase activity of the hypodermal-mesocarp plasma membrane from preharvest-mature and Postharvest Muskmelon. Journal of Agriculture and Food Chemistry 46:1242-1246.

Warncke, D.D. (2007) Nutrient management for cucurbits: Melons, pumpkins, cucumber and squash. Indiana CCA Conference Proceedings.

Appendices

Appendix 1: Report on a fact finding visit to the USA by Peter Waldock. Pumpkins 'It's all about the handle'

Appendix 2. Key pathogens isolated from pumpkin samples provided to East Malling Research and Crop Walkers Guide

Appendix 3: 2016 Field Observations for trials to test effect of crop nutrition and fungicidal control against powdery mildew and Phoma.