Interim Report 2018-19

Efficacy of sprout suppressants used alone, or in combination, to control sprouting of stored potato

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Sutton Bridge Crop Storage Research

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Contents

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1. Introduction

Effective sprout control is critical to the year-round supply of ware potatoes and the industry has largely become reliant on chlorpropham (CIPC) for this. In official figures from 2016[1], CIPC accounted for 82% of treatments to stored potatoes, while ethylene and spearmint oil accounted for 15% and 3% respectively.

The EFSA routine review of CIPC, which should have completed in 2017, identified a number of data gaps and the European Commission recommended that the compound no longer be approved. The decision to not renew approvals was published on 18 June 2019 and all EU member states will be required to withdraw approvals for formulations containing CIPC by 8 January 2020. Final use of CIPC products must be completed by 8 October 2020. The final use by date for the UK, determined by the Chemical Regulation Division of the Health and Safety Executive, has not yet been set, but this cannot be later than 8 October 2020.

The aim of this project was to investigate whether treatments using alternative sprout suppressants, or the combined use of alternatives, provides effective sprout control. Other than CIPC, there are currently products containing one of three active substances registered for control of sprouting in stored potatoes in the UK. The active substances are ethylene, maleic hydrazide and spearmint oil. They are generally considered less effective than CIPC, may have adverse effects on other qualities of the stored crop and, in all cases, are more

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[1] Hinchcliffe, A., I. Barker, D. G. Garthwaite & G. Parrish (2016). Pesticide Usage Survey Team FERA, Pesticide Usage Survey Report 275, Potato stores in the United Kingdom. Sand Hutton, York YO41 1LZ, UK.

costly[2]. In addition to the UK registered alternative sprout suppressants, application of 1,4-dimethylnaphthalene (marketed as 1,4-SIGHT) was assessed. This is available in several EU member states, but has not been registered in the UK.

There is insufficient data on the use of alternative (non-CIPC) sprout suppressants and it is unclear these products can provide effective control in all potato storage scenarios where CIPC is currently employed. This study is aimed at the assessment of potatoes stored for processing, a similar study is being carried out for potatoes stored for the fresh-pack market (AHDB Project Ref: 11140057).

2. Materials and methods

Crop, treatments and experimental design

Stocks of five processing cultivars, Innovator, Maris Piper, Performer, Royal and VR808, were each sourced from independent sites treated in the field with maleic hydrazide (MH) at 3 kg active substance per hectare. At each site MH untreated plots were shielded from the sprayer using clear polythene sheeting pegged to the ground on all sides. After spraying, the sheeting was left until dry and carefully removed. The untreated strip and a nearby MH treated strip were divided into a series of four adjacent replicate plots and harvested by hand.

During storage the ten stocks were subjected to a further eight sprout suppressant/temperature regimes in separate six tonne capacity controlled environment rooms (CERs). The storage treatments were: chlorpropham (CIPC), 1,4-dimethylnaphthalene (DMN), ethylene (*Restrain*), spearmint oil (*Biox-M*) and untreated. Certain combined treatments of spearmint oil and ethylene were included. Ethylene with spearmint oil, applied only before a sampling occasion, and regular spearmint oil applications combined with

[2] Kalt, W. , Prange, R. K., Daniels-Lake, B. J., Walsh, J. , Dean, P. and Coffin, R. (1999). Alternative compounds for the maintenance of processing quality of stored potatoes (Solanum tuberosum). Journal of Food Processing and Preservation, 23: 71-81.

ethylene. All the above treatments were held at target temperatures of 9.0 °C with the addition of an extra treatment of the latter combination at 7.0 °C. Four replicate sample nets for each of three sampling occasions were buried approximately three tubers down in MH treated Maris Piper bulk material in fully randomised positions amongst six pallet boxes.

Store set up and control

All CERs were configured for positive ventilation (Fig.1). Boxes were stacked tightly in three columns of two, against a plenum chamber. Pressurised air discharged from the plenum was blocked at ground level and forced through the middle slot. At the opposite end of the stack, the aperture between boxes was blocked to promote air-flow through the crop. A temperature probe was buried in each box to monitor crop temperature. Store air was recirculated through a conditioning duct for automatic refrigeration or heating as necessary. Store air was automatically sampled and ventilated where necessary to prevent a build-up of carbon dioxide beyond 0.3 %.

Fig. 1. Boxes stacked two high, three deep against a plenum, at the back of the store, for positive 'letterbox' ventilation.

Pull down and applications

Stores were loaded on 18th October 2018 and steadily pulled down from an average temperature of approximately 15 °C to the appropriate holding temperature ±0.5 °C at a rate of 0.5 °C per day. A steady soft rotting problem associated with the bulk crop was managed by careful humidity sensor monitoring and visual crop inspection. It was never considered necessary to engage automatic humidification.

CIPC [*Aceto* 50M, MAPP 14134] was applied as a hot fog using a *Swingfog SN50* [*Motan*], fitted with a 1.0 mm nozzle, at 12 g/tonne a.s. on 8th November 2018, 25th January 2019 and 22nd March 2019. The plenum chamber was fogged directly with a slowed store fan used to positively assist the fog through the plenum aperture at 0.72 ms^{-1} both during application and then for 6 hours. The fridge coil was physically isolated to prevent fog condensation. Afterward the clear store was ventilated by unsealing and opening the front door for 5 minutes and then returning to automatic control.

DMN [supplied by *DormFresh Ltd*] was applied using a *Cedax Electrofog EWH-3000* [*Xeda*], at a target product temperature of 250 °C, directly into the plenum chamber (Fig. 2). The stores were switched off but a slow fan recirculated store air during, and for 30 minutes after, application. The stores then remained off and still for 24 hours before unsealing and returning to automatic control. Starting on 1st November 2018, DMN was applied at a decreasing dose rate with two occasions at 20 ml/tonne, two occasions at 15 ml/tonne and one at 10 ml/tonne.

Fig. 2. CEDAX Electrofog EWH-3000 for application of spearmint oil and DMN.

Ethylene control was initiated in all relevant treatments on 9th November 2017, using *Restrain* ethylene generators [*ICA740,* Restrain Company Ltd, Breda, Netherlands] measured and recorded by sensor units [*ICA730*]. The pre-programmed soft start was utilised to preserve processing quality by reducing physiological stress. This comprised 4 day steps at 0.1, 0.2 and 0.3 ppm followed by 2 day steps at 0.5, 1 and 2 ppm and only then the continuous target concentration of 10 ppm. As the generator was designed for large scale storage, ethylene fuel was diluted to 20 % by adding deionised water and physical fuel throughput reduced to the minimum setting of 0.16 litres per day.

Spearmint oil [*Biox-M*, MAPP 16021] was also applied using the *Electrofog*, directly into the plenum chamber, at a target product temperature of 185 -190 °C. The store was switched off but a slow fan recirculated store air continuously during application and for 48 hours afterward. The store was then unsealed and returned to automatic control. Spearmint was applied at 60 ml/tonne on 14th November 2018 and a further 5 occasions.

Dates and rates of all applications are shown in the Appendix.

Sampling and assessment

Samples were taken at intake (18th October 2018) and after 3, 6, and 8 months of storage (15th January, 8th April and 18th June 2019 respectively). For each sample the longest sprout length was measured on all tubers of a 25 potato sub-sample. Fry colour was measured for potatoes processed as chips (French fries) for Innovator, Maris Piper, Performer and Royal and crisps for VR808.

For crisping 300 g of slices between 1.22 and 1.47 mm thick were taken from 30 mechanically peeled tubers and washed in water for 45 seconds. Each sample was then fried for 3 minutes in oil heated up to 177 °C at the start of frying. After frying the sample was weighed and then crisps with defects (a dark discolouration larger than a 5 mm diameter circle) removed and weighed. The remaining blemish free sample was then assessed objectively three times using a HunterLab D25NC colour quality meter [Stotto, Mountsorrel, Leics., UK].

Chips were processed as single 3/8th inch square longitudinal sections from each of 20 sound tubers and fried for 90 seconds in oil heated up to 190 °C at the start of frying. The fry colour of individual strips was assessed subjectively by comparison with a USDA standard colour chart [Munsell Color, Baltimore, Maryland, USA] under standard artificial white light. The USDA assessment scale used for assessing chips (light to dark - 000, 00, 0, 1, 2, 3 & 4) was linearized 1 to 7 (SBCSR scale) and reported as a mean. Scores of 1 to 3 are good; scores of 4 and 5 acceptable and higher scores rejected.

In addition, 100 maleic hydrazide untreated tubers of the five varieties were taken at store loading for dormancy measurement. The samples were held in paper sacks in a 15°C store at a target humidity of 95% RH. Stocks were assessed approximately weekly for sprout length and the number of tubers showing sprouting at 3 mm or above recorded. Relative dormancy was represented by the number of days taken for half of the tubers to cross the 3 mm sprout threshold.

3. Results

Dormancy

The period of dormancy of MH untreated samples of each cultivar is shown in Table 1. Dormancy was shortest in cv Maris Piper, at 48 days, and longest in cvs VR808 and Performer, 71 and 88 days respectively.

Table 1. Dormancy (days) of varieties in trial

variety	dormancy period
Innovator	65
Maris Piper	48
Royal	58
Performer	88
VR808	71

Maleic hydrazide residue concentration

Three replicate samples of twelve tubers were analysed at intake and at the three sampling occasions from store. The mean residue concentrations are shown in Table 2.

The lowest concentration of MH was in cv Performer (5.9 mg kg^{-1}) and this was significantly lower (*p=0.002*) than cvs Maris Piper and Royal, which had similar residue levels (*p=0.354*). VR808 had significantly higher MH levels (p=0.0003) and Innovator significantly higher levels still (p=0.0057).

Table 2. Mean maleic hydrazide residue concentration (mg kg^{-1}).

cultivar	MH residue	standard deviation
Innovator	37.4	24.61
Maris Piper	8.6	2.21
Royal	7.8	1.97
Performer	5.9	1.81
VR808	15.2	4.88

Sprouting

Sprouting was assessed at approximately 3 month intervals and is presented for the final sampling occasion in Figs 3-7 for Innovator, Maris Piper, Performer, Royal and VR808 respectively.

Overall sprouting levels were greatest in Performer and Royal, intermediate in Innovator and Maris piper and shortest in cultivar VR808. Of the post-harvest treatments sprouting was most effectively controlled across all varieties using DMN, with mean maximum sprout length generally less than or much less than 5mm.

Ethylene was more effective at controlling sprouting of cvs Maris Piper and VR808 with mean sprout length of 5-10mm, than cvs Royal and Performer where sprout length was approximately 15-25mm. Spearmint oil treatment (BIOX-M) resulted in similar levels of sprout growth in cvs Innovator, Maris Piper, Royal and Performer with sprout length in the range 12-20mm. Control was better in cv VR808 with mean sprout length of 8mm.

The combination of spearmint oil and ethylene [BIOX-M + Ethylene[3]] generally resulted in better sprout control than spearmint oil and ethylene alone. Results of this treatment were also typically better than the combination Ethylene + BIOX-M[4].

The combination treatment of spearmint oil and ethylene stored at 7C, compared with 9C, resulted in a reduced level of sprout growth. However, differences were often slight and not generally significant.

In-field application of maleic hydrazide resulted in very effective control of sprouting of cvs Innovator and VR808. Application of MH to Performer was relatively ineffective with sprouting of MH-treated samples only slightly less than and MH-untreated samples, across all store treatments.

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[3] The full BIOX-M label rate with ethylene

[4] Ethylene with three applications of BIOX-M prior to each sampling occasion.

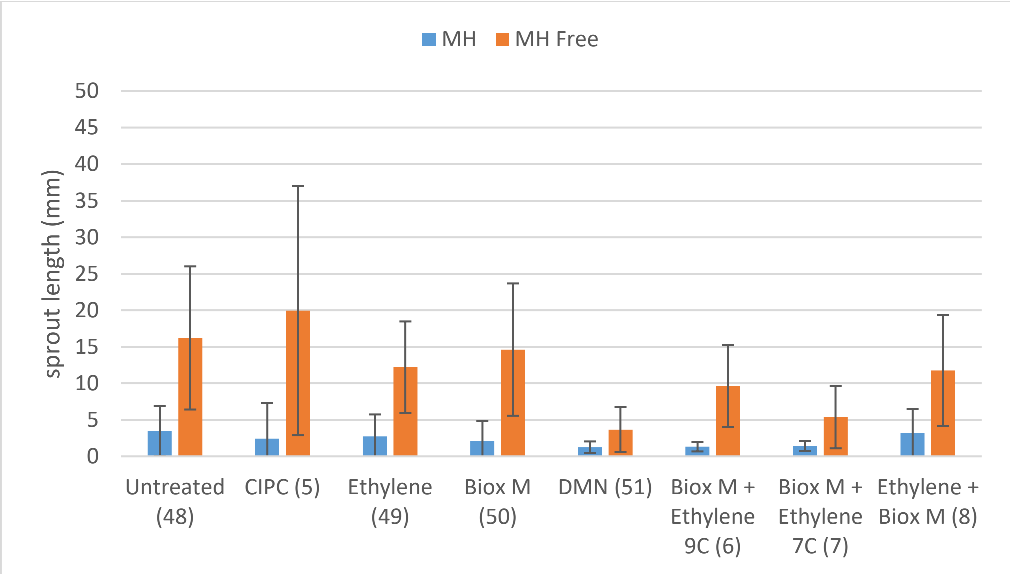

Fig. 3 Mean maximum sprout length (+/- standard deviation) of cv Innovator.

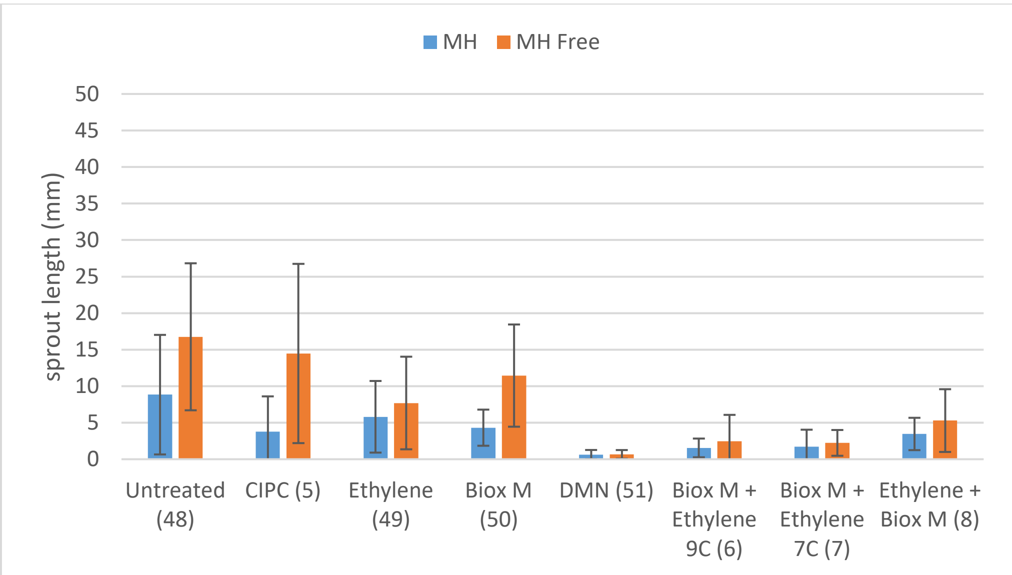

Fig 4. Mean maximum sprout length (+/- standard deviation) of cv Maris Piper.

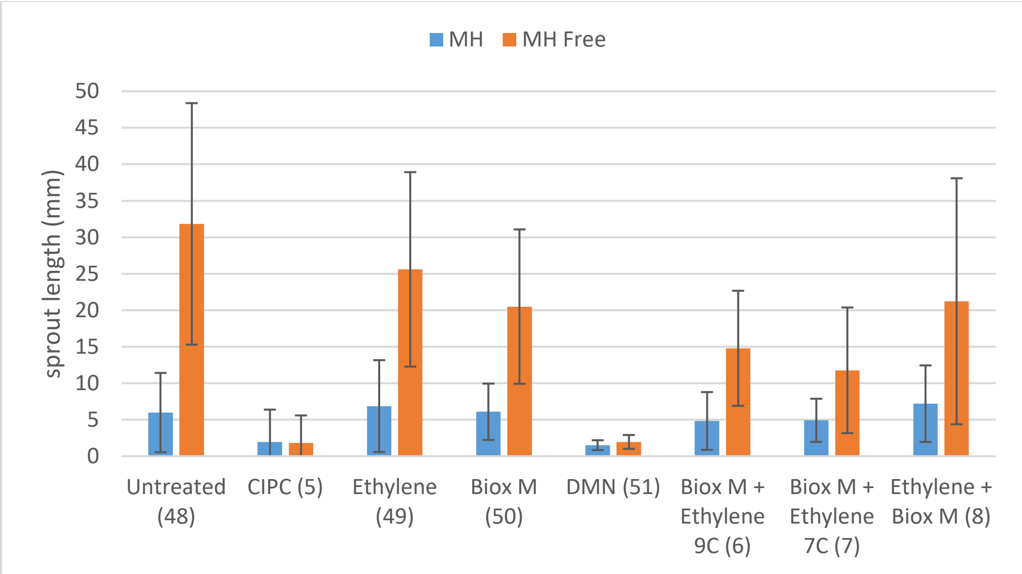

Fig. 5. Mean maximum sprout length (+/- standard deviation) of cv Royal.

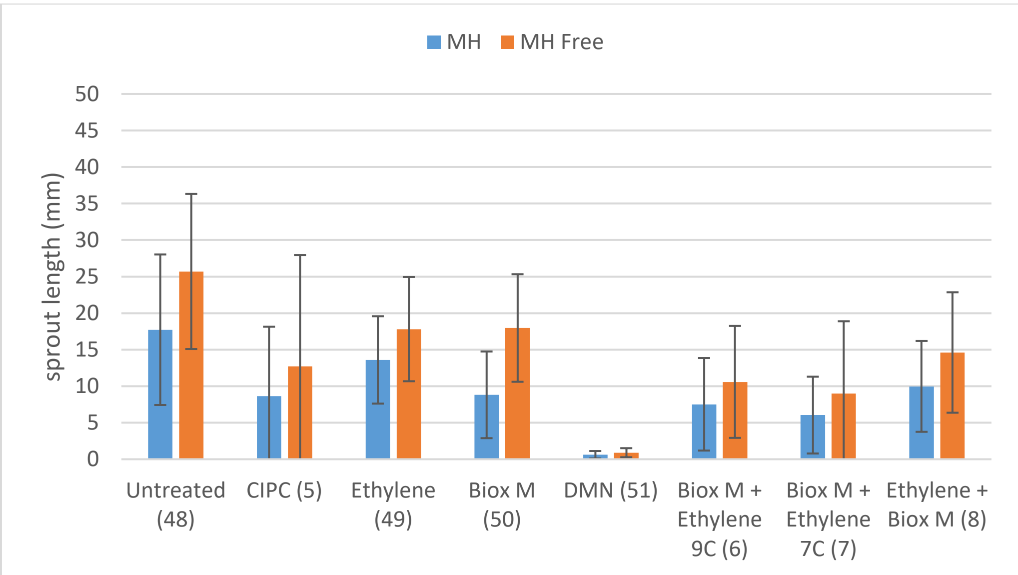

Fig 6. Mean maximum sprout length (+/- standard deviation) of cv Performer.

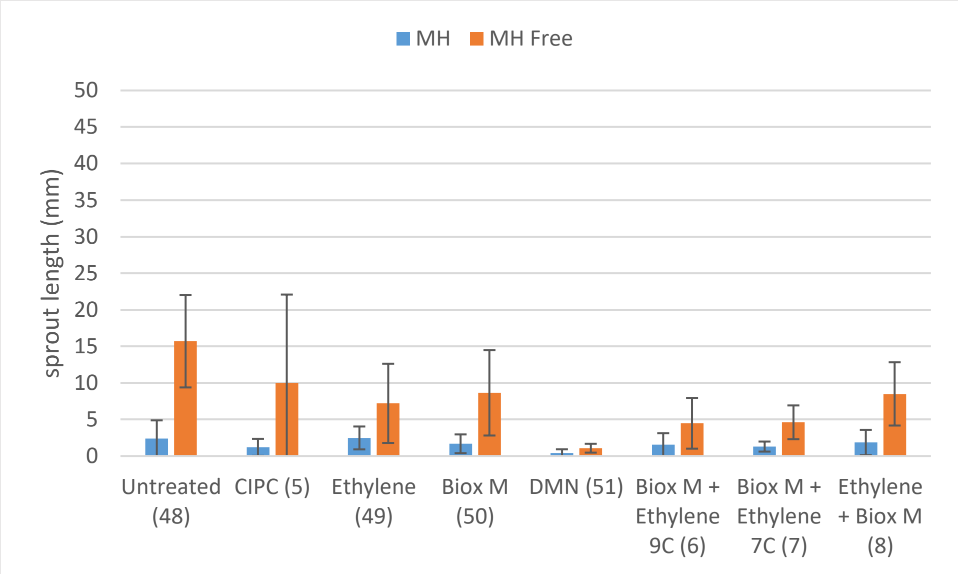

Fig. 7. Mean maximum sprout length (+/- standard deviation) of cv VR808.

Fry quality

Fry colour of chip/French fry cultivars was assessed using the USDA scale 'linearised' 1 to 7 for USDA categories 000, 00, 0, 1, 2, 3 and 4 respectively. Results are shown for the final sampling occasion, with all data shown in the appendix.

Fry quality of cv Innovator (Fig. 8) was generally good throughout storage with colour equivalent to USDA categories 00 and 0. The use of MH did not give rise to a difference in fry colour. There was a tendency for fry colour to be slightly darker in the treatments with ethylene and during storage at 7°C, but differences were not significant.

Fry colour of cv Maris Piper (Fig. 9) was good throughout storage, with mean scores of approximately 2, equivalent to USDA category 00. No differences were apparent as a result of sprout suppressant or storage temperature.

Performer fry colour (Fig. 10) was in the range 3.1 to 4.0 equivalent to USDA categories 0 and 1. There was a tendency for colour to be slightly darker from ethylene and during storage at

7C. Differences though were very slight and in the case of ethylene, confined to the early storage period.

Fry colour of Royal (Fig. 11) was in the range 2.9 to 4 consisting largely of strips with USDA scores 0 and 1. Storage treatments did not give rise to significant effects and fry colour was generally of a good, commercially acceptable standard.

Cultivar VR808 was processed as crisps. Fry defect levels in VR808 were generally very low, well below 10% on all occasions and across all treatments. Hunter L values (fry colour) were generally acceptable (>L58) but there was a tendency for fry colour to be slightly darker when ethylene had been used, however this was not a consistent effect.

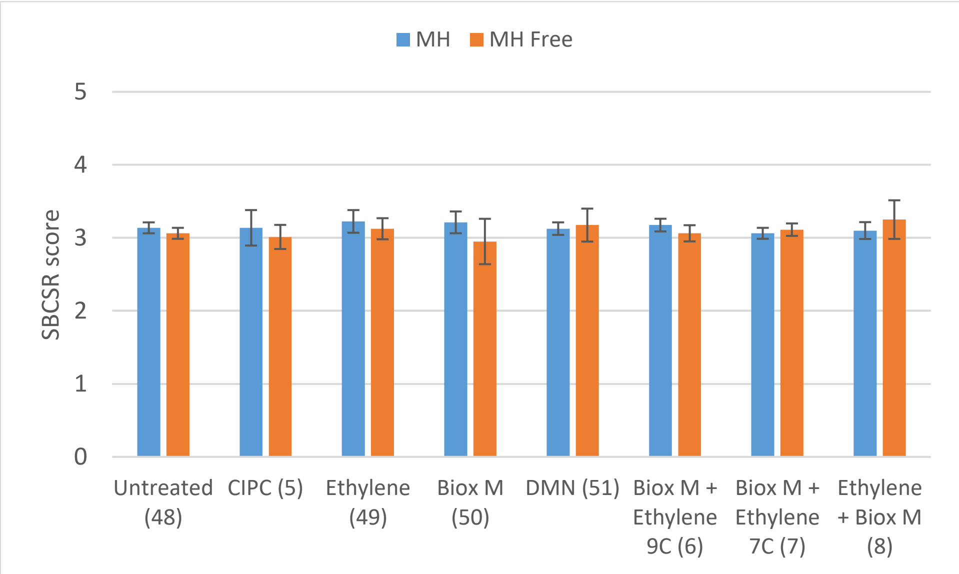

Fig. 8. Fry colour (SBCSR score, +/- standard deviation) of cv Innovator.

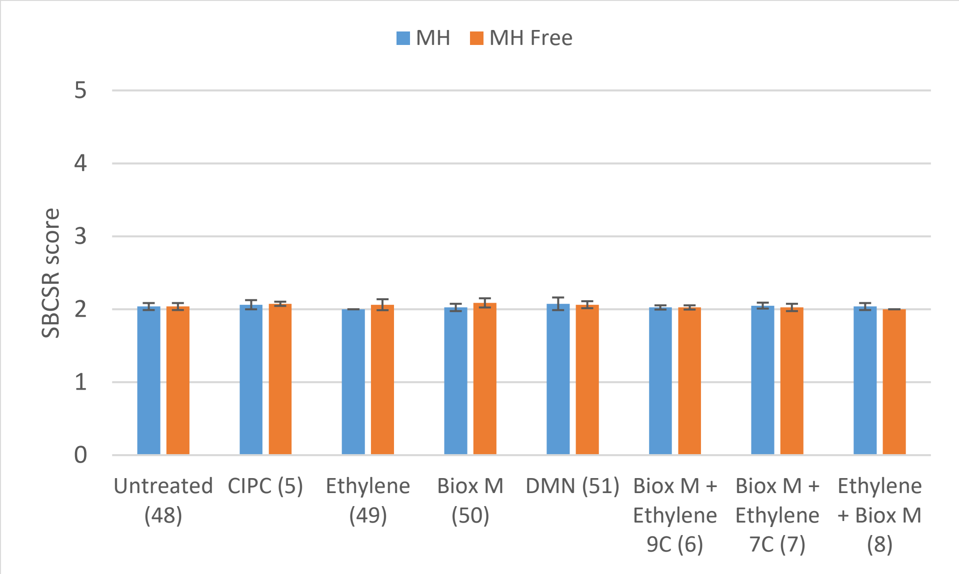

Fig. 9. Fry colour (SBCSR score, +/- standard deviation) of cv Maris Piper.

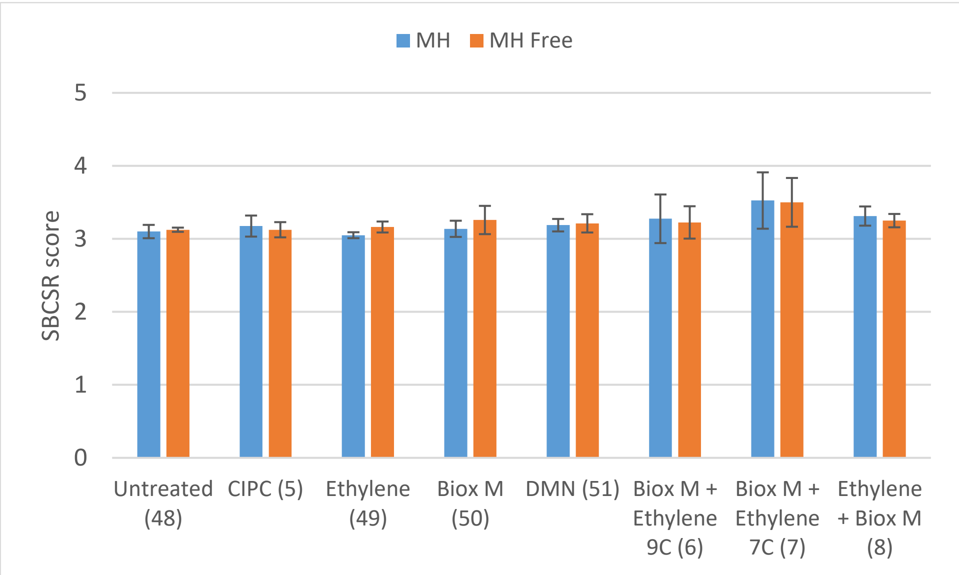

Fig. 10. Fry colour (SBCSR score, +/- standard deviation) of cv Performer.

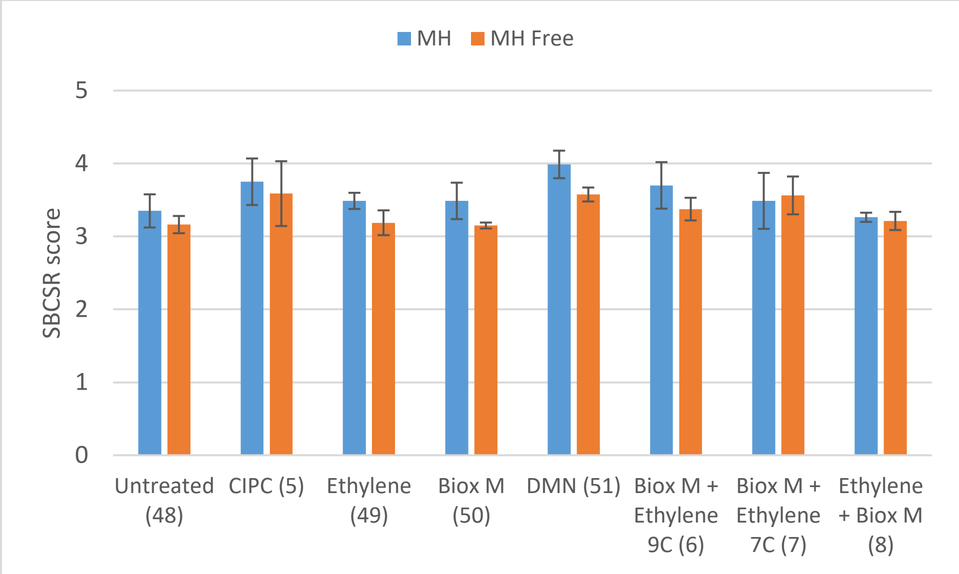

Fig. 11. Fry colour (SBCSR score, +/- standard deviation) of cv Royal.

4. Discussion

Approvals for chlorpropham will be withdrawn from all EU member states by Oct 8, 2020. The purpose of these trials was to determine how sprouting of processing potatoes during storage can be controlled in the absence of CIPC.

In the first year of work, maleic hydrazide could not be applied to common source material and therefore conclusions could not be drawn about its relative efficacy. In the 2018-19 season, areas in fields were covered during application, keeping some plots MH untreated. The relative efficacy of MH can thus be judged.

Maleic hydrazide had an important effect on sprout growth as a standalone treatment, and also in combination with other sprout suppressants. MH was particularly effective in cvs Innovator and VR808, where applications resulted in high residue concentrations (mean 37.4 and 15.2 mg kg^{-1} respectively). Additional, post-harvest treatment(s) were not required to limit sprout growth of these stocks to a commercially acceptable standard. In contrast, MH had little effect with cv Performer, with application resulting in the lowest residue concentration of all the cultivars (5.9 mg kg^{-1}) and relatively little sprout control. Cultivars Maris Piper and Royal were intermediate in residue concentration (8.6 and 7.8 mg kg^{-1} respectively). With these cvs, MH was effective, but additional treatments were required to maintain low sprouting levels.

Of the post-harvest treatments, DMN was the most effective, as in year 1. Cultivar and pre-treatment with MH were not important factors in the success of sprout control when using DMN. Ethylene, spearmint oil and their combination reduced sprout growth, but were influenced by other factors to a greater extent compared with DMN and CIPC.

While sprout control using ethylene and spearmint oil was satisfactory in cv Maris Piper, control of sprouting was not very effective in cvs Royal and Performer.

Processing quality was assessed in all varieties during storage. Fry colour (and fry defects in the crisping cultivar VR808), were not affected, and quality was generally of a good, commercially acceptable standard. Ethylene has been reported to result in a temporary darkening in colour ('sugar spike'). In this trial darkening was sometimes observed but this was slight and transient.

5. Conclusions

Of the post-harvest treatments examined, DMN resulted in the most effective control with cultivar and MH treatment having little effect on sprout control efficacy. With ethylene and spearmint oil (and their combination), responses were more variable. Control was not generally effective and dependent on cultivar or MH treatment.

Points for discussion and knowledge exchange

The new sprout suppressants are costly and, in addition, volatile. Regular ambient ventilation will result in greater losses and therefore higher costs. After CIPC, MH is the next most cost-effective sprout suppressant. Effective use of MH is going to be important to help reduce the increase in storage costs from use of the new alternatives.

- It is itself an effective sprout suppressant when residue levels are sufficient.
- There is synergy, with less post-harvest treatment required
- MH is non-volatile, so not subject to the same losses. This is important for ambient stores, CO_2 control and drying of rot problems.

6. Appendices

A. Study diary

Table 3: Diary of study events 2018-19

Date	Activity
26/09/2018	VR808 lifted
02/10/2018	Innovator lifted
09/10/2018	Maris Piper lifted
10/10/2018	Performer and Royal lifted
18/10/2018	**All stores loaded**
01/11/2018	DMN 1st application (20 ml/t)
08/11/2018	CIPC 1st application (12g/t)
09/11/2018	All ethylene 18 day ramps started (final target concentration 10 ppm)
14/11/2018	*Biox-M* 1st application to *Biox-M* only treatment (60 ml/t)
22/11/2018	*Biox-M* 1st application to *Biox-M*/ethylene treatment 9°C (60 ml/t)
22/11/2018	*Biox-M* 1st application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
06/12/2018	DMN 2nd application (20 ml/t)
19/12/2018	*Biox-M* 2nd application to *Biox-M* only treatment (60 ml/t)
19/12/2018	*Biox-M* 2nd application to *Biox-M*/ethyle treatment 9°C (60 ml/t)
19/12/2018	*Biox-M* 2nd application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
02/01/2019	*Biox-M* 1st application to ethylene/*Biox-M* treatment - pre sampling (60ml/t)
14/01/2019	**Sampling occasion 1**
23/01/2019	DMN 3rd application (15 ml/t)
25/01/2019	CIPC 2nd application (12g/t)
06/02/2019	*Biox-M* 3rd application to *Biox-M* only treatment (60 ml/t)
06/02/2019	*Biox-M* 3rd application to *Biox-M*/ethylene treatment 9°C (60 ml/t)
06/02/2019	*Biox-M* 3rd application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
06/03/2019	DMN 4th application (15 ml/t)
20/03/2019	*Biox-M* 4th application to *Biox-M* only treatment (60 ml/t)
20/03/2019	*Biox-M* 4th application to *Biox-M*/ethylene treatment 9°C (60 ml/t)
20/03/2019	*Biox-M* 4th application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
22/03/2019	CIPC 3rd application (12g/t)
03/04/2019	*Biox-M* 2nd application to ethylene/*Biox-M* treatment - pre sampling (60ml/t)
08/04/2019	**Sampling occasion 2**
25/04/2019	DMN 5th application (10 ml/t)
01/05/2019	*Biox-M* 5th application to *Biox-M* only treatment (60 ml/t)
01/05/2019	*Biox-M* 5th application to *Biox-M*/ethylene treatment 9°C (60 ml/t)
01/05/2019	*Biox-M* 5th application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
29/05/2019	*Biox-M* 6th application to *Biox-M* only treatment (60 ml/t)
29/05/2019	*Biox-M* 6th application to *Biox-M*/ethylene treatment 9°C (60 ml/t)
29/05/2019	*Biox-M* 6th application to *Biox-M*/ethylene treatment 7°C (60 ml/t)
05/06/2019	*Biox-M* 3rd application to ethylene/*Biox-M* treatment - pre sampling (60ml/t)
17/06/2019	**Sampling occasion 3**

B. Data – sprouting (longest sprout, mm)

	SO1				SO2				SO3						
Innovator	MH	sd	MH free	sd	MH	SD	MH free	SD	MH	sd	MH free	sd	MH mean	MH free mean	Grand mean
Untreated (48)	**2.0**	1.21	**4.1**	3.20	**2.2**	0.52	**15.0**	7.07	**3.5**	3.45	**16.2**	9.80	**2.6**	**11.8**	**7.2**
CIPC (5)	**1.0**	0.84	**1.0**	0.87	**2.2**	0.37	**14.1**	6.76	**2.4**	4.85	**20.0**	17.07	**1.9**	**11.7**	**6.8**
Ethylene (49)	**1.5**	0.91	**2.6**	1.97	**2.6**	0.55	**13.6**	0.83	**2.8**	2.99	**12.2**	6.25	**2.3**	**9.5**	**5.9**
Biox M (50)	**1.4**	0.70	**2.6**	2.17	**1.9**	0.54	**10.5**	4.76	**2.1**	2.72	**14.6**	9.05	**1.8**	**9.3**	**5.5**
DMN (51)	**0.8**	0.57	**1.2**	0.75	**0.1**	0.08	**2.8**	1.53	**1.3**	0.79	**3.7**	3.07	**0.7**	**2.6**	**1.6**
Biox M + Ethylene 9C (6)	**0.6**	0.84	**1.6**	1.84	**1.4**	0.27	**5.1**	2.74	**1.3**	0.65	**9.6**	5.62	**1.1**	**5.4**	**3.3**
Biox M + Ethylene 7C (7)	**0.6**	0.76	**0.6**	0.70	**2.2**	0.67	**7.4**	3.81	**1.4**	0.71	**5.4**	4.28	**1.4**	**4.5**	**2.9**
Ethylene + Biox M (8)	**1.0**	0.88	**1.3**	1.15	**1.4**	0.26	**4.2**	0.93	**3.2**	3.34	**11.8**	7.60	**1.9**	**5.8**	**3.8**

	SO1				SO2				SO3						
Maris Piper	MH	sd	MH free	sd	MH	SD	MH free	SD	MH	sd	MH free	sd	MH mean	MH free mean	Grand mean
Untreated (48)	**5.7**	6.04	**7.7**	8.27	**8.5**	1.51	**17.1**	7.88	**8.8**	8.18	**16.8**	10.06	**7.7**	**13.8**	**10.8**
CIPC (5)	**1.2**	1.29	**1.4**	1.77	**3.6**	1.27	**21.9**	7.76	**3.8**	4.82	**14.5**	12.27	**2.8**	**12.6**	**7.7**
Ethylene (49)	**3.6**	5.40	**2.3**	2.58	**4.9**	1.41	**5.2**	0.76	**5.8**	4.90	**7.7**	6.34	**4.8**	**5.1**	**4.9**
Biox M (50)	**2.9**	2.54	**2.5**	2.78	**4.5**	1.74	**8.8**	3.09	**4.3**	2.47	**11.5**	7.00	**3.9**	**7.6**	**5.8**
DMN (51)	**0.8**	0.91	**0.4**	0.59	**0.1**	0.09	**0.0**	0.06	**0.6**	0.63	**0.7**	0.59	**0.5**	**0.4**	**0.4**
Biox M + Ethylene 9C (6)	**0.6**	1.06	**1.4**	2.16	**1.7**	1.35	**2.1**	1.12	**1.6**	1.28	**2.5**	3.60	**1.3**	**2.0**	**1.6**
Biox M + Ethylene 7C (7)	**0.8**	1.44	**1.0**	1.29	**3.2**	0.49	**4.5**	1.28	**1.7**	2.34	**2.2**	1.77	**1.9**	**2.6**	**2.2**
Ethylene + Biox M (8)	**1.7**	2.53	**1.9**	1.82	**1.3**	0.19	**2.2**	0.39	**3.5**	2.21	**5.3**	4.29	**2.2**	**3.1**	**2.6**

	SO1				SO2				SO3						
Performer	MH	sd	MH free	sd	MH Treated	SD	MH Free	SD	MH	sd	MH Free	sd	MH mean	MH free mean	Grand mean
Untreated (48)	**1.2**	1.36	**1.3**	1.37	**13.1**	3.00	**16.4**	7.76	**17.7**	10.30	**25.7**	10.61	**10.7**	**14.5**	**12.6**
CIPC (5)	**0.0**	0.10	**0.0**	0.10	**3.6**	1.93	**5.6**	2.64	**8.7**	9.48	**12.7**	15.24	**4.1**	**6.1**	**5.1**
Ethylene (49)	**0.9**	1.01	**1.3**	1.10	**9.7**	2.13	**12.9**	4.88	**13.6**	5.98	**17.8**	7.13	**8.0**	**10.7**	**9.4**
Biox M (50)	**1.1**	1.46	**0.8**	1.06	**6.3**	2.41	**8.1**	2.69	**8.8**	5.93	**18.0**	7.37	**5.4**	**9.0**	**7.2**
DMN (51)	**0.1**	0.28	**0.1**	0.22	**0.2**	0.18	**1.2**	1.26	**0.6**	0.51	**0.9**	0.62	**0.3**	**0.7**	**0.5**
Biox M + Ethylene 9C (6)	**0.5**	1.19	**0.3**	0.62	**4.3**	2.08	**7.2**	1.66	**7.5**	6.33	**10.6**	7.66	**4.1**	**6.1**	**5.1**
Biox M + Ethylene 7C (7)	**0.2**	0.58	**0.3**	0.53	**6.3**	2.92	**11.5**	4.43	**6.0**	5.26	**9.0**	9.90	**4.2**	**6.9**	**5.5**
Ethylene + Biox M (8)	**0.9**	1.25	**0.8**	0.83	**3.7**	1.27	**3.9**	1.98	**10.0**	6.22	**14.6**	8.25	**4.9**	**6.4**	**5.6**

Royal	MH	sd	MH free	sd	MH	SD	MH free	SD	MH	sd	MH free	sd	MH mean	MH free mean	Grand mean
Untreated (48)	2.4	1.69	3.7	2.37	6.9	0.73	27.6	3.33	6.0	5.43	31.8	16.54	5.1	21.0	13.1
CIPC (5)	1.0	0.71	0.9	1.00	1.6	0.48	4.3	2.66	2.0	4.44	1.8	3.77	1.5	2.3	1.9
Ethylene (49)	1.7	1.12	2.6	1.67	4.8	0.97	16.2	2.97	6.9	6.29	25.6	13.32	4.5	14.8	9.6
Biox M (50)	2.2	2.07	1.8	1.38	5.4	0.71	12.5	2.29	6.1	3.86	20.5	10.57	4.6	11.6	8.1
DMN (51)	0.4	0.67	0.8	0.79	0.1	0.12	3.4	3.56	1.5	0.68	2.0	0.95	0.7	2.0	1.4
Biox M + Ethylene 9C (6)	0.7	0.96	0.9	1.03	5.3	3.51	7.1	3.15	4.8	3.96	14.8	7.88	3.6	7.6	5.6
Biox M + Ethylene 7C (7)	0.4	0.67	0.4	0.64	6.0	1.13	14.3	2.55	4.9	2.96	11.8	8.61	3.8	8.8	6.3
Ethylene + Biox M (8)	1.2	0.97	1.4	1.05	4.1	0.82	7.4	0.85	7.2	5.24	21.2	16.85	4.2	10.0	7.1
	SO1				SO2				SO3						
VR808	MH	sd	MH free	sd	ʌIH Treatec	SD	MH Free	SD	MH	sd	MH Free	sd	MH mean	MH free mean	Grand mean
Untreated (48)	1.2	0.74	2.9	3.63	2.4	0.32	13.2	2.11	2.4	2.50	15.7	6.31	2.0	10.6	6.3
CIPC (5)	0.7	0.52	1.0	0.81	0.8	0.45	2.8	1.11	1.2	1.16	10.0	12.10	0.9	4.6	2.8
Ethylene (49)	1.0	0.88	1.3	0.97	1.9	0.20	7.2	1.39	2.5	1.57	7.2	5.41	1.8	5.2	3.5
Biox M (50)	0.8	1.37	1.3	1.05	1.2	0.14	5.5	1.35	1.7	1.28	8.6	5.84	1.2	5.2	3.2
DMN (51)	0.3	0.44	0.2	0.52	0.0	0.00	0.4	0.43	0.4	0.50	1.1	0.61	0.2	0.5	0.4
Biox M + Ethylene 9C (6)	0.4	0.59	0.5	0.61	1.6	0.51	4.3	1.18	1.6	1.57	4.5	3.47	1.2	3.1	2.1
Biox M + Ethylene 7C (7)	0.2	0.39	0.5	0.63	2.4	0.93	6.7	1.72	1.3	0.69	4.6	2.30	1.3	3.9	2.6
Ethylene + Biox M (8)	0.6	0.61	0.9	0.92	1.3	0.13	2.3	0.60	1.9	1.73	8.5	4.32	1.3	3.9	2.6

B. Data – fry colour French fries

SBCSR score 1-7 [equivalent to USDA 000, 00, 0, 1, 2, 3, 4]

	SO1				SO2				SO3				means		
Innovator	MH	SD	MH free	SD	MH	SD	MH free	SD	MH	sd	MH free	sd	**MH**	**MH free**	**Gr mean**
Untreated	2.0	0.03	2.1	0.06	2.3	0.30	2.7	0.49	3.1	0.08	3.1	0.08	**2.5**	**2.6**	**2.5**
CIPC (5)	2.1	0.04	2.1	0.04	2.1	0.12	2.4	0.49	3.1	0.24	3.0	0.17	**2.4**	**2.5**	**2.5**
Ethylene (49)	2.1	0.07	2.1	0.08	2.6	0.57	2.3	0.25	3.2	0.16	3.1	0.14	**2.6**	**2.5**	**2.6**
Biox M (50)	2.0	0.05	2.0	0.03	2.6	0.49	2.5	0.41	3.2	0.15	3.0	0.31	**2.6**	**2.5**	**2.6**
DMN (51)	2.1	0.15	2.0	0.08	2.3	0.13	2.2	0.07	3.1	0.09	3.2	0.23	**2.5**	**2.5**	**2.5**
Biox M + Ethylene 9C (6)	2.0	0.02	2.1	0.07	2.7	0.42	2.6	0.38	3.2	0.09	3.1	0.11	**2.6**	**2.6**	**2.6**
Biox M + Ethylene 7C (7)	2.4	0.46	2.4	0.44	2.6	0.54	2.7	0.42	3.1	0.08	3.1	0.09	**2.7**	**2.7**	**2.7**
Ethylene + Biox M (8)	2.1	0.10	2.0	0.02	2.9	0.23	2.9	0.52	3.1	0.12	3.3	0.26	**2.7**	**2.7**	**2.7**
min	2.0		2.0		2.1		2.2		3.1		3.0		**2.4**	**2.5**	**2.5**
max	2.4		2.4		2.9		2.9		3.2		3.3		**2.7**	**2.7**	**2.7**
mean	2.1		2.1		2.5		2.5		3.1		3.1		**2.6**	**2.6**	**2.6**

	SO1				SO2				SO3				means		
Maris Piper (B)	MH	SD	MH free	SD	MH	SD	MH free	SD	MH	sd	MH free	sd	**MH**	**MH free**	**Gr mean**
Untreated (48)	2.0	0.00	2.0	0.08	2.0	0.00	2.1	0.08	2.0	0.05	2.0	0.05	**2.0**	**2.1**	**2.0**
CIPC (5)	2.0	0.03	2.1	0.07	2.0	0.03	2.1	0.07	2.1	0.06	2.1	0.03	**2.0**	**2.1**	**2.1**
Ethylene (49)	2.0	0.05	2.0	0.03	2.0	0.05	2.1	0.09	2.0	0.00	2.1	0.08	**2.0**	**2.1**	**2.0**
Biox M (50)	2.0	0.02	2.1	0.10	2.0	0.08	2.1	0.08	2.0	0.05	2.1	0.06	**2.0**	**2.1**	**2.1**
DMN (51)	2.0	0.08	2.0	0.05	2.0	0.08	2.1	0.08	2.1	0.09	2.1	0.05	**2.1**	**2.1**	**2.1**
Biox M + Ethylene 9C (6)	2.0	0.00	2.0	0.05	2.0	0.00	2.0	0.05	2.0	0.03	2.0	0.03	**2.0**	**2.0**	**2.0**
Biox M + Ethylene 7C (7)	2.0	0.05	2.2	0.05	2.0	0.03	2.1	0.04	2.1	0.04	2.0	0.05	**2.0**	**2.1**	**2.1**
Ethylene + Biox M (8)	2.1	0.08	2.1	0.10	2.1	0.04	2.1	0.09	2.0	0.05	2.0	0.00	**2.1**	**2.1**	**2.1**
min	2.0		2.0		2.0		2.0		2.0		2.0		**2.0**	**2.0**	**2.0**
max	2.1		2.2		2.1		2.1		2.1		2.1		**2.1**	**2.1**	**2.1**
mean	2.0		2.1		2.0		2.1		2.0		2.0		**2.0**	**2.1**	**2.1**

Performer	SO1 MH	SD	MH free	SD	SO2 MH	SD	MH free	SD	SO3 MH	sd	MH free	sd	means MH	MH free	Gr mean
Untreated (48)	3.2	0.21	3.3	0.05	3.5	0.28	3.4	0.27	3.1	0.09	3.1	0.03	**3.3**	**3.3**	**3.3**
CIPC (5)	3.1	0.12	3.4	0.24	3.4	0.18	3.3	0.46	3.2	0.14	3.1	0.10	**3.2**	**3.3**	**3.2**
Ethylene (49)	3.4	0.14	3.3	0.17	3.5	0.35	3.4	0.22	3.1	0.04	3.2	0.08	**3.3**	**3.3**	**3.3**
Biox M (50)	3.4	0.12	3.2	0.13	3.6	0.28	3.4	0.30	3.1	0.11	3.3	0.19	**3.4**	**3.3**	**3.3**
DMN (51)	3.3	0.06	3.2	0.11	3.4	0.08	3.5	0.18	3.2	0.09	3.2	0.13	**3.3**	**3.3**	**3.3**
Biox M + Ethylene 9C (6)	3.4	0.16	3.4	0.07	3.5	0.37	3.6	0.43	3.3	0.33	3.2	0.22	**3.4**	**3.4**	**3.4**
Biox M + Ethylene 7C (7)	3.9	0.17	3.6	0.21	3.8	0.38	3.7	0.23	3.5	0.39	3.5	0.33	**3.7**	**3.6**	**3.7**
Ethylene + Biox M (8)	3.6	0.17	3.5	0.02	4.0	0.28	4.0	0.21	3.3	0.13	3.3	0.09	**3.7**	**3.6**	**3.6**
min	3.1		3.2		3.4		3.3		3.1		3.1		**3.2**	**3.3**	**3.2**
max	3.9		3.6		4.0		4.0		3.5		3.5		**3.7**	**3.6**	**3.7**
mean	3.4		3.4		3.6		3.5		3.2		3.2		**3.4**	**3.4**	**3.4**

Royal	SO1 MH	SD	MH free	SD	SO2 MH	SD	MH free	SD	SO3 MH	sd	MH free	sd	means MH	MH free	Gr mean
Untreated (48)	3.1	0.19	3.1	0.03	3.1	0.03	3.1	0.18	3.4	0.23	3.2	0.12	**3.2**	**3.1**	**3.1**
CIPC (5)	3.0	0.18	3.1	0.04	3.0	0.14	3.1	0.10	3.8	0.32	3.6	0.44	**3.2**	**3.2**	**3.2**
Ethylene (49)	3.1	0.10	3.1	0.09	3.2	0.05	3.1	0.18	3.5	0.11	3.2	0.17	**3.3**	**3.1**	**3.2**
Biox M (50)	3.0	0.19	3.1	0.09	3.2	0.02	3.2	0.10	3.5	0.25	3.2	0.04	**3.2**	**3.2**	**3.2**
DMN (51)	2.9	0.43	3.1	0.19	3.0	0.09	3.0	0.18	4.0	0.19	3.6	0.10	**3.3**	**3.2**	**3.3**
Biox M + Ethylene 9C (6)	3.0	0.09	3.2	0.14	3.1	0.23	3.2	0.12	3.7	0.32	3.4	0.16	**3.3**	**3.3**	**3.3**
Biox M + Ethylene 7C (7)	3.3	0.15	3.5	0.24	3.3	0.13	3.2	0.05	3.5	0.38	3.6	0.26	**3.4**	**3.4**	**3.4**
Ethylene + Biox M (8)	3.2	0.15	3.3	0.15	3.3	0.07	3.2	0.06	3.3	0.06	3.2	0.13	**3.2**	**3.2**	**3.2**
min	2.9		3.1		3.0		3.0		3.3		3.2		**3.2**	**3.1**	**3.1**
max	3.3		3.5		3.3		3.2		4.0		3.6		**3.4**	**3.4**	**3.4**
mean	3.1		3.2		3.1		3.1		3.6		3.4		**3.3**	**3.2**	**3.2**

D. Data – fry quality crisps

VR808	SO1				SO2				SO3				means		
Fry Defects (%Wt.)	MH	SD	MH free	SD	MH	SD	MH free	SD	MH	sd	MH free	sd	**MH**	**MH free**	**Gr mean**
Untreated (48)	0.0	0.00	0.0	0.00	0.0	0.00	0.2	0.36	2.6	2.99	2.9	3.65	**0.9**	**1.0**	**0.9**
CIPC (5)	1.3	2.59	0.0	0.00	0.0	0.00	0.4	0.73	0.0	0.00	1.9	2.39	**0.4**	**0.8**	**0.6**
Ethylene (49)	0.0	0.00	1.0	2.07	0.2	0.34	0.0	0.00	3.1	6.12	0.9	1.79	**1.1**	**0.6**	**0.9**
Biox M (50)	0.7	1.31	0.0	0.00	0.6	1.28	0.0	0.00	3.4	3.77	4.4	4.48	**1.6**	**1.5**	**1.5**
DMN (51)	0.0	0.00	0.0	0.00	0.3	0.66	0.0	0.00	2.3	2.95	0.7	1.34	**0.9**	**0.2**	**0.6**
Biox M + Ethylene 9C (6)	1.2	1.35	0.0	0.00	0.0	0.00	0.0	0.00	4.4	5.62	0.5	1.07	**1.8**	**0.2**	**1.0**
Biox M + Ethylene 7C (7)	2.6	3.08	1.4	2.02	0.0	0.00	0.8	1.03	4.0	2.77	0.0	0.00	**2.2**	**0.8**	**1.5**
Ethylene + Biox M (8)	3.3	6.08	1.0	2.06	1.6	1.54	0.0	0.00	4.1	6.29	5.9	8.34	**3.0**	**2.3**	**2.6**
max	3.3		1.4		1.6		0.8		4.4		5.9		**3.0**	**2.3**	**2.6**
min	0.0		0.0		0.0		0.0		0.0		0.0		**0.4**	**0.2**	**0.6**
mean	1.1		0.4		0.3		0.2		3.0		2.1		**1.5**	**0.9**	**1.2**

VR808	SO1				SO2				SO3				means		
Hunter L value	MH	SD	MH free	SD	MH	SD	MH free	SD	MH	sd	MH free	sd	**MH**	**MH free**	**Gr mean**
Untreated (48)	65.9	2.17	66.3	1.77	65.2	1.26	65.5	1.67	61.5	1.02	65.8	2.15	**64.2**	**65.9**	**65.0**
CIPC (5)	66.5	2.86	65.5	3.07	63.5	2.47	64.7	1.96	61.7	1.75	64.6	1.12	**63.9**	**64.9**	**64.4**
Ethylene (49)	66.1	1.57	66.3	0.94	63.4	2.20	65.4	1.66	58.5	1.46	62.6	1.09	**62.7**	**64.8**	**63.7**
Biox M (50)	65.4	2.56	67.0	1.53	63.5	1.38	64.2	1.03	59.4	3.11	64.1	1.09	**62.7**	**65.1**	**63.9**
DMN (51)	66.0	1.89	66.0	2.61	64.3	1.33	64.9	1.97	60.1	1.28	63.2	1.27	**63.5**	**64.7**	**64.1**
Biox M + Ethylene 9C (6)	64.8	0.96	66.4	2.75	63.2	2.08	64.3	1.20	58.3	4.07	61.9	0.98	**62.1**	**64.2**	**63.2**
Biox M + Ethylene 7C (7)	62.9	1.95	64.7	2.80	64.0	2.24	63.2	1.91	60.0	1.92	64.1	0.62	**62.3**	**64.0**	**63.1**
Ethylene + Biox M (8)	63.6	2.90	65.3	2.70	63.8	2.18	64.5	1.42	58.4	2.47	62.2	1.33	**61.9**	**64.0**	**63.0**
max	66.5		67.0		65.2		65.5		61.7		65.8		**64.2**	**65.9**	**65.0**
min	62.9		64.7		63.2		63.2		58.3		61.9		**61.9**	**64.0**	**63.0**
mean	65.1		65.9		63.9		64.6		59.7		63.6		**62.9**	**64.7**	**63.8**