Interim Report 2019-20

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

A. Briddon & G.P. Stroud
Sutton Bridge Crop Storage Research

Project Ref: 11140043

Contents

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

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 potato processing industry especially is dependent on the availability of growth regulators because storage at lower temperature (c. 3-6°C) cannot be used because of its effect on quality[2].

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 were required to withdraw approvals for formulations containing CIPC by 8 January 2020. In the UK, the final use by date, determined by the Chemical Regulation Division of the Health and Safety Executive, was set for 8 October 2020. After this date it became illegal to store or use products containing chlorpropham.

The aim of this project was to investigate whether treatments using alternative sprout suppressants, or the combined use of alternatives, provided 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,

---

[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.

[2] Blenkinsop, R.W., Leslie J. Copp, Rickey Y. Yada, and Alejandro G. Marangoni (2002). Changes in compositional parameters of tubers of potato during low-temperature storage and their relationship to chip processing quality. Journal of Agricultural and Food Chemistry 50 (16),4545-4553.

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 costly[3].

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 received full registration in the UK. An emergency approval was granted in the UK for DMN, for specified processing varieties after long term storage in the 2020-21 storage season. The approval was limited to a total of 192,200 tonnes of potatoes grown in 2020 and to be processed in 2021, although much less is expected to be used.

Application of 3-decen-2-one is also being assessed. 3-decen-2-one is marketed as SmartBlock®[4] by approval holder Amvac in the USA and other countries. Registration of SmartBlock in the EU[5] is underway.

There is little data on the use of alternative (non-CIPC) sprout suppressants and it is not clear current 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 four processing cultivars, Innovator, Maris Piper, Performer and Royal, were each sourced from independent sites treated in the field with maleic hydrazide (MH) at 3 kg active substance per hectare. At each site four separate MH untreated plots were shielded from

---

[3] 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.

[4] https://www.amvac.com/products/smartblock

[5] https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/j.efsa.2015.3932

spraying using polythene sheeting pegged to the ground on all sides. After spraying, the sheeting was left until dry and then carefully removed. The untreated strips and the follow-on MH treated rows were harvested by hand. For a fifth variety, VR808, MH treated and untreated crops from the same crop could not be obtained and so were lifted from different field sites.

During storage the ten stocks (five varieties + and – MH) were subjected to a further nine sprout suppressant 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*), 3-decen-2-one (SmartBlock®) and untreated. A combined treatment of spearmint oil and ethylene was included. The above treatments were all ventilated to maintain a target carbon dioxide level of 0.3 %. DMN and spearmint oil stores were sealed for 48 hours post application but additional treatments were included with a 72 hour post application store seal period and carbon dioxide ventilation thresholds of 1 %. CIPC treatments were fully ventilated after 7 hours and SmartBlock® after 24 hours. All treatments were held at a target holding temperature of 9.0 °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 among 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 and foam lined battens were screwed to vertical joins to ensure a good seal. 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 hourly and ventilated where necessary to prevent a build-up of carbon dioxide beyond set-point. All stores were fitted with overlapping polythene curtains to minimise product loss through essential store inspection and maintenance.

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 29 October 2019 and steadily pulled down from an average temperature of approximately 11 °C to 9 °C at a rate of 0.3 °C per day. A steady soft rotting problem associated with the bulk crop was managed by careful humidity sensor monitoring and visual crop inspection. When rot incidence increased, automatic humidification (set-point 93% relative humidity) was disabled for all stores (29 June 2020).

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 8 November 2019, 29 January 2020 and 14 April 2020. The plenum chamber was fogged directly with a slow store fan used to positively assist the fog through the plenum aperture at 0.72 ms^{-1} both during application and then for 6-7 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 a period before unsealing and returning to automatic control. Starting on 6 November 2019, DMN was applied at a decreasing dose rate with one occasion at 20 ml tonne^{-1}, two occasions at 15 ml tonne^{-1} and three at 10 ml tonne^{-1}.

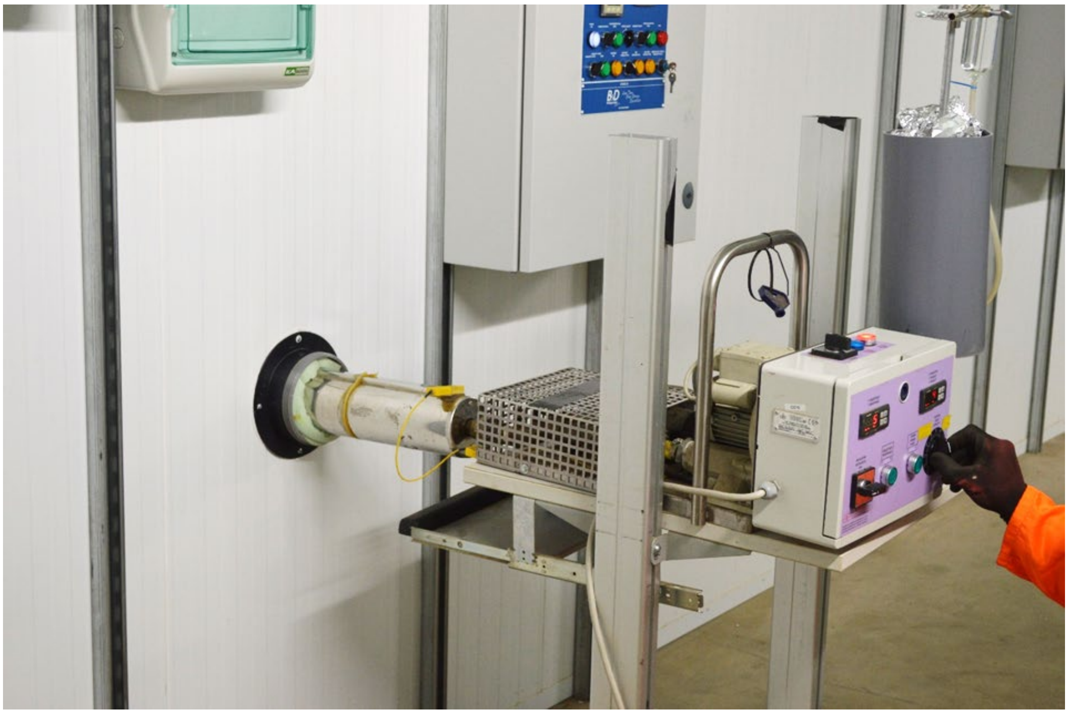

Fig. 2. CEDAX Electrofog EWH-3000 for application of spearmint oil, DMN and SmartBlock.

Ethylene control was initiated in all relevant treatments on 25 November 2019, using *Restrain* ethylene generators [*B200,* Restrain Company Ltd, Breda, Netherlands] measured and recorded by sensor units [*BECHT*]. 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.

SmartBlock, 3-decen-2-one [supplied by Amvac Chemical Corporation, Los Angeles, CA 90023 U.S.A.], was applied using the *Electrofog* at a target product temperature of 175 °C, directly into the plenum chamber. Four 100 ml tonne^{-1} doses were applied starting at first variety sprouting onset and then every 60 days. The treated store was sealed for 24 hours after application with positive, slow fan recirculation. SmartBlock treatments were only applied to MH field treated stocks.

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 the subsequent seal period. The store was then unsealed and returned to automatic control. A standard dose of 60 ml $tonne^{-1}$ was used but occasionally 90 ml $tonne^{-1}$ was applied where increased sprouting was evident. Dates and rates of all applications are shown in the Appendix. The maximum permitted cumulative dose was 360 ml $tonne^{-1}$ and this was reached for all treatments.

Sampling and assessment

Samples were taken at intake and after 3, 6, and 8 months of storage (8 January 2020; 27 April 2020 and 29 June 2020 respectively, sampling occasions [SO] 1, 2 and 3). 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, MH untreated tubers were sampled in the field for each of the five varieties for dormancy measurement. Samples of 50 tubers were placed in paper sacks and held at 15°C. Samples were assessed regularly for sprout length and any showing 3 mm or more counted and discarded. Relative dormancy was represented by the number of days taken, from harvest, for half of the sample tubers to cross the 3 mm sprout threshold.

Residues of MH in the treated plots were measured at lifting and during storage. Four samples of 12 tubers were taken in the field from each replicate field plot. The stored samples were buried in the untreated treatment store and sampled on three occasions. One sample was taken from each MH untreated plot, to confirm shielding success, at intake only.

High incidences of internal sprouting were noticed in some samples. Approximately 100 tuber samples were selected from each stock/treatment combination both with and without MH field treatment and these were all cut into quarters longitudinally and any incidence of internal sprouting recorded.

3. Results

Dormancy & maleic hydrazide residue levels

The period of dormancy of MH untreated samples of each cultivar is shown in Table 1. Dormancy was shortest in cv VR808, at 44 days, and longest in cv Performer, at 130 days.

Table 1. Apparent dormancy (days) of varieties in trial.

variety	dormancy period
Innovator	69
Maris Piper	91
Performer	130
Royal	78
VR808	44

Four replicate samples of 12 tubers were taken at intake and at each sampling occasion from store, and analysed for maleic hydrazide residue levels. The mean residue concentration of samples is shown in Table 2. Concentrations were relatively low in cultivars Maris Piper, Royal and VR808, moderate in cv Performer and relatively high in cv Innovator. Differences between varieties were generally significant (one-way ANOVA, *p*=0.0004 or less). Residue values did not change during storage. The apparent increase in residue concentration during storage of cv Innovator was not statistically significant (one-way ANOVA, *p*=0.130). Raw data is shown in the Appendix.

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

cultivar	MH residue	standard deviation
Innovator	22.3	8.58
Maris Piper	6.5	2.34
Performer	13.9	2.49
Royal	5.1	1.40
VR808	8.6	1.87

Sprouting

Sprouting was assessed at intake, and after storage for approximately 3, 6 and 8 months (10, 26 and 35 weeks respectively). There was no sprouting in any variety at store loading. Results for the final sampling occasion are shown in Figures 3-7 for cultivars Innovator, Maris Piper, Performer, Royal and VR808 respectively. Sprouting was greatest in cv. Innovator, with mean sprout length close to 50 mm in untreated samples, moderate in cvs. Maris Piper, Performer and Royal, with sprout length in the range 35-45mm, and least in cv.VR808 with mean sprout length close to 30mm.

Sprout control of MH treated samples of cv. Innovator was very effective with sprout length less than 10mm in untreated and ethylene treated samples and less than 5mm in CIPC, Biox-

M, DMN and SmartBlock® treated samples. Sprout control of MH free samples was relatively poor with all treatments resulting in mean sprout lengths greater than 10mm.

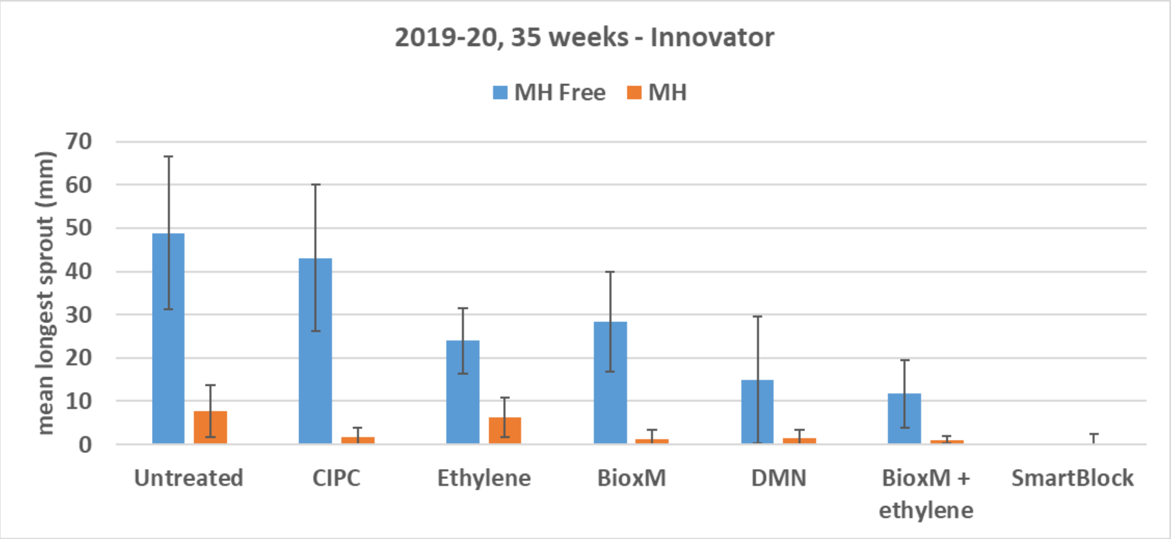

Fig. 3. Mean maximum sprout length (+/- standard deviation) of cv Innovator.

Treatment of cv. Maris Piper with maleic hydrazide resulted in a reduction in sprout length but differences between MH treated and MH untreated samples were generally small. All post-harvest treatments resulted in mean sprout length of less than 10mm when crop was pre-treated with MH.

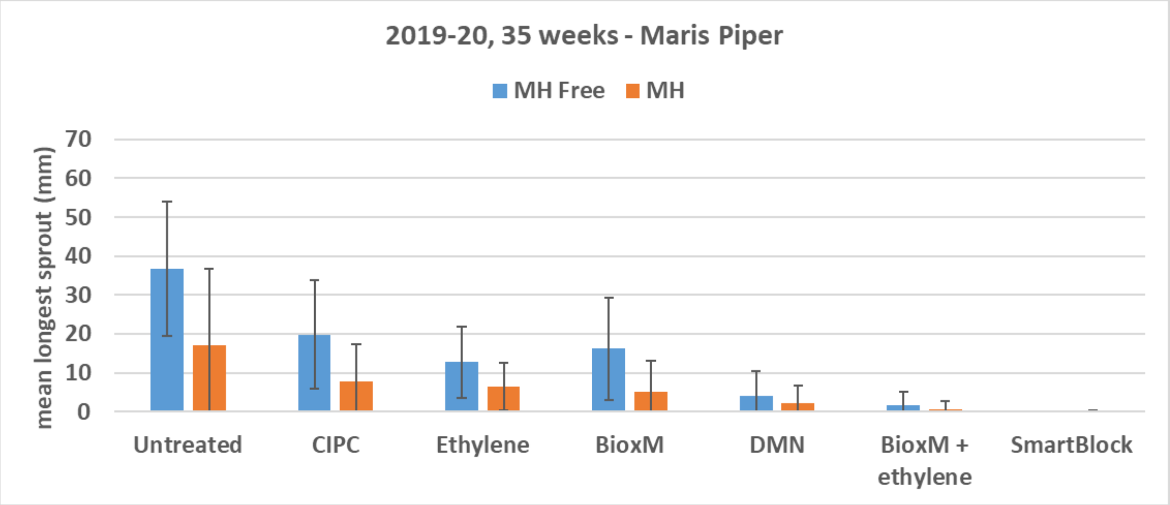

Fig 4. Mean maximum sprout length (+/- standard deviation) of cv Maris Piper.

Treatment of cv. Performer with maleic hydrazide resulted in effective control of sprouting with sprout length less than 10mm in untreated and ethylene treated samples and much less than 10mm in samples also treated with CIPC, Biox-M, DMN and SmartBlock. Without MH, only DMN and Biox-M/ethylene treatments resulted in mean sprouting levels less than 10mm.

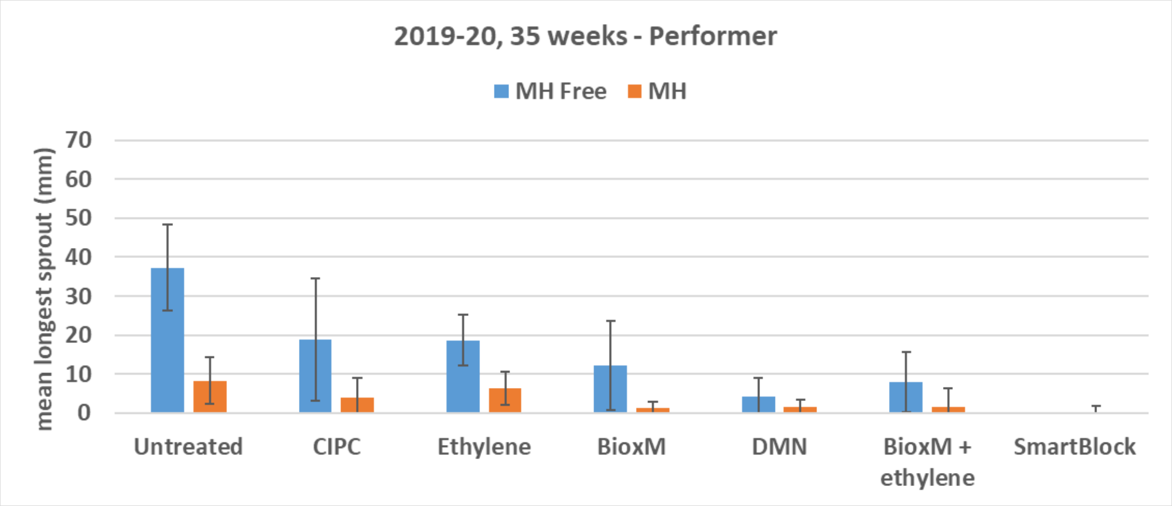

Fig 5. Mean maximum sprout length (+/- standard deviation) of cv Performer.

In combination with MH, all post-harvest treatments applied to cv. Royal resulted in mean sprout length equal to or less than 10mm and, in the case of DMN and SmartBlock® less than 5mm. Only the post-harvest treatments CIPC and DMN maintained sprouts at less than 10mm without MH.

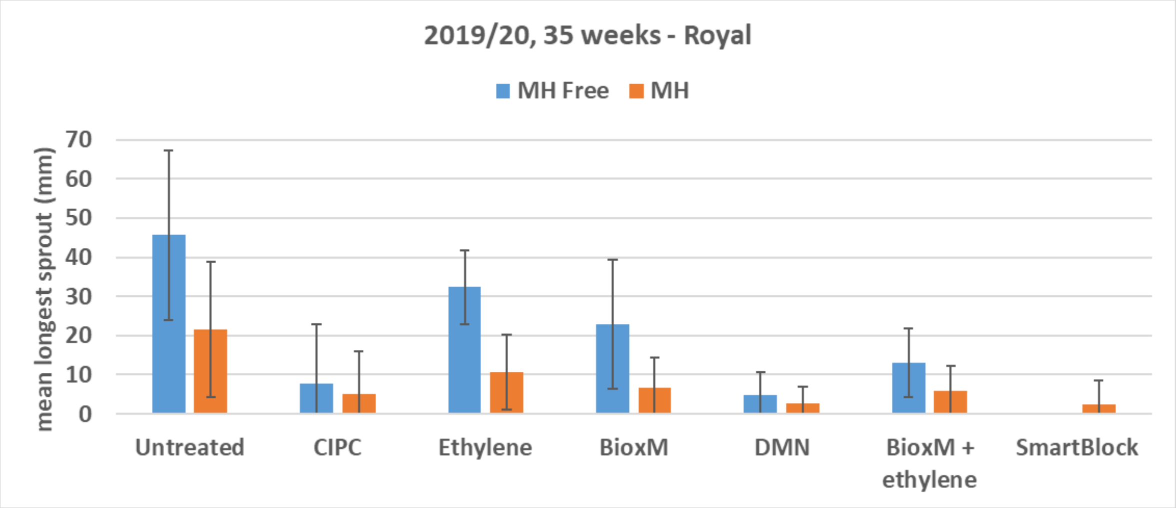

Fig. 6. Mean maximum sprout length (+/- standard deviation) of cv Royal.

MH treated and untreated samples of cv. VR808 are not from the same crop and therefore direct comparison is not possible. All post-harvest treatments resulted in mean sprout lengths equal to or less than 10mm in MH treated and MH untreated samples of cv. VR808. In combination with MH, Biox-M, DMN and SmartBlock® resulted in very low (c. 1mm) sprouting levels in cv. VR808.

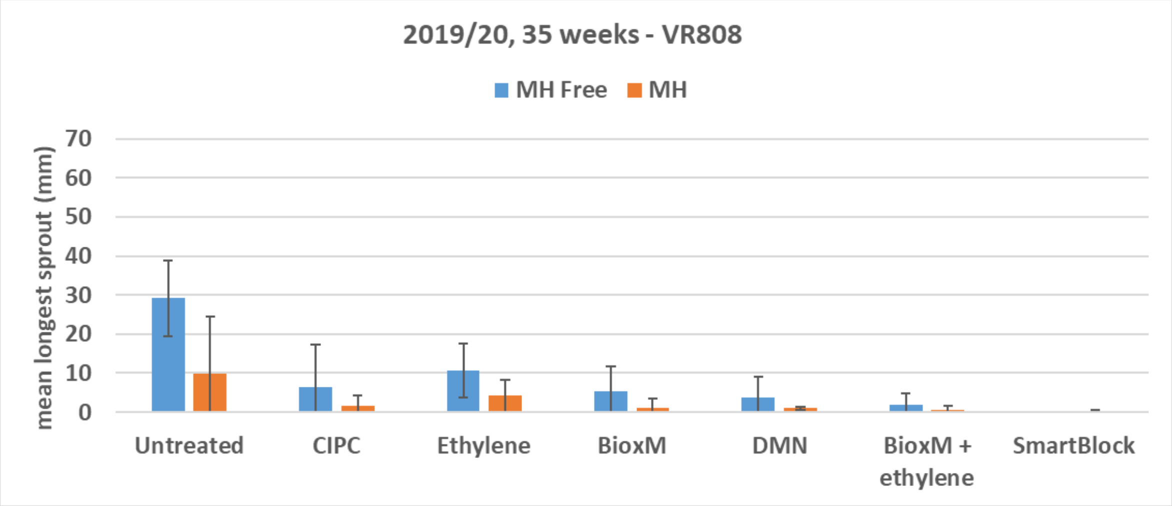

Fig. 7. Mean maximum sprout length (+/- standard deviation) of cv VR808.

Processing quality

The cultivars Innovator, Maris Piper, Performer and Royal were processed as chips (French fries) and VR808 as crisps. With the exception of cv. VR808, MH treated and MH untreated samples were from the same crop, with untreated samples obtained by sheeting over plots at the time of MH application. With cv. VR808 this was not possible and treated & untreated samples were different crops albeit both being from Norfolk. Comparison of these crops is therefore not possible.

Chips (French fries)

Fry colour of MH treated Innovator was darker than MH untreated material with colour in the range 4.4 to 5.1 equivalent to average fry colour close to USDA 2. MH free samples of Innovator had lighter fry colour, between USDA 0 and USDA 1, except for DMN treated samples where mean colour was significantly darker (t-test, *p*= 0.0223 for the difference between DMN and Biox-M).

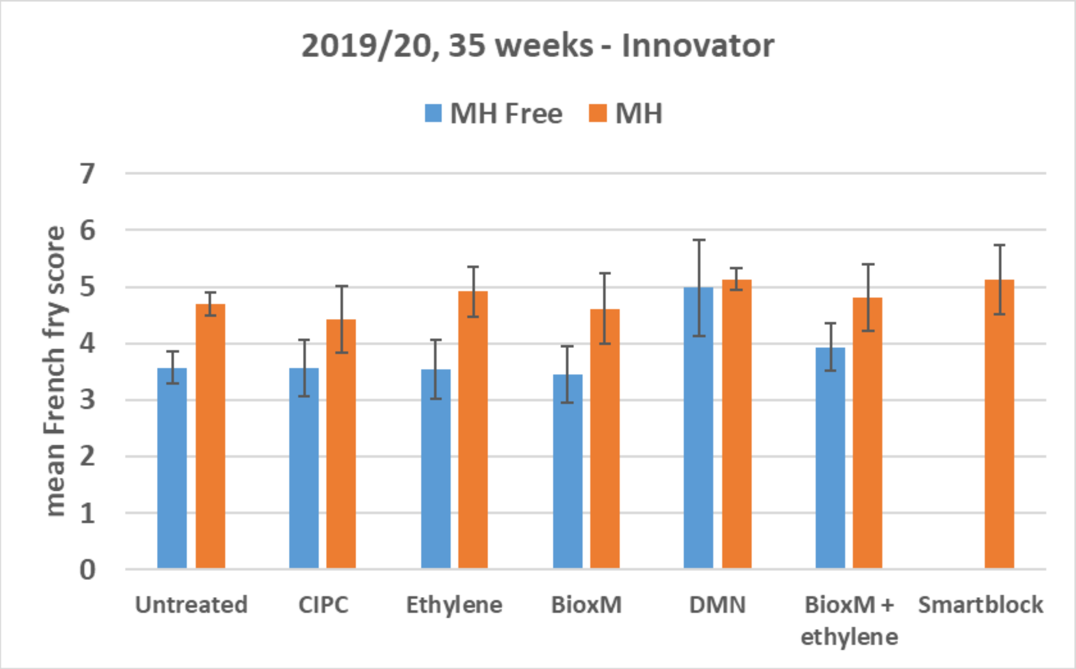

Fig. 8. Fry colour (mean score, +/- standard deviation) of cv Innovator.

The fry colour of all cv. Maris Piper samples (Fig. 9) was very light at store unloading. Mean values were all within the range 2 to 3, equivalent to USDA classes 00 and 0.

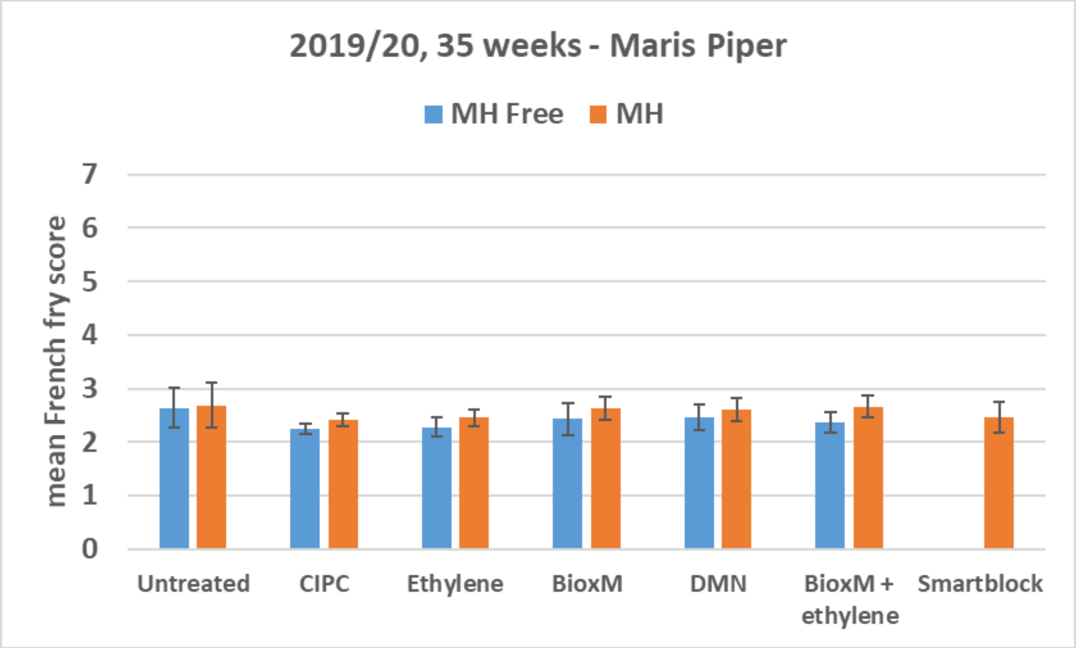

Fig. 9. Fry colour (mean score, +/- standard deviation) of cv Maris Piper.

Mean fry colour scores of cv. Performer were close to a score of 3 units (equivalent to USDA 0). Although differences were slight, MH free samples of cv.Performer treated with ethylene were significantly darker (t-test, *p*=0.0249) than samples from the Biox-M treatment.

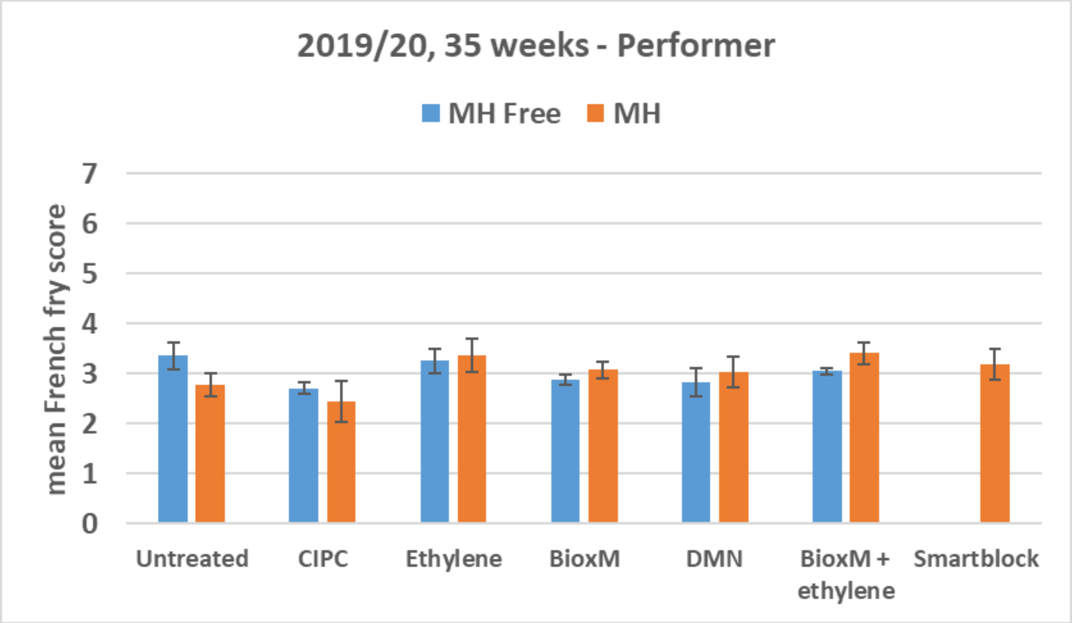

Fig. 10. Fry colour (mean score, +/- standard deviation) of cv Performer.

Fry colour of cv Royal was generally light with mean colour scores between 3 and 4 (USDA 0 and 1). The darkest colour was in samples treated with MH and CIPC but this was not significantly different to MH free samples.

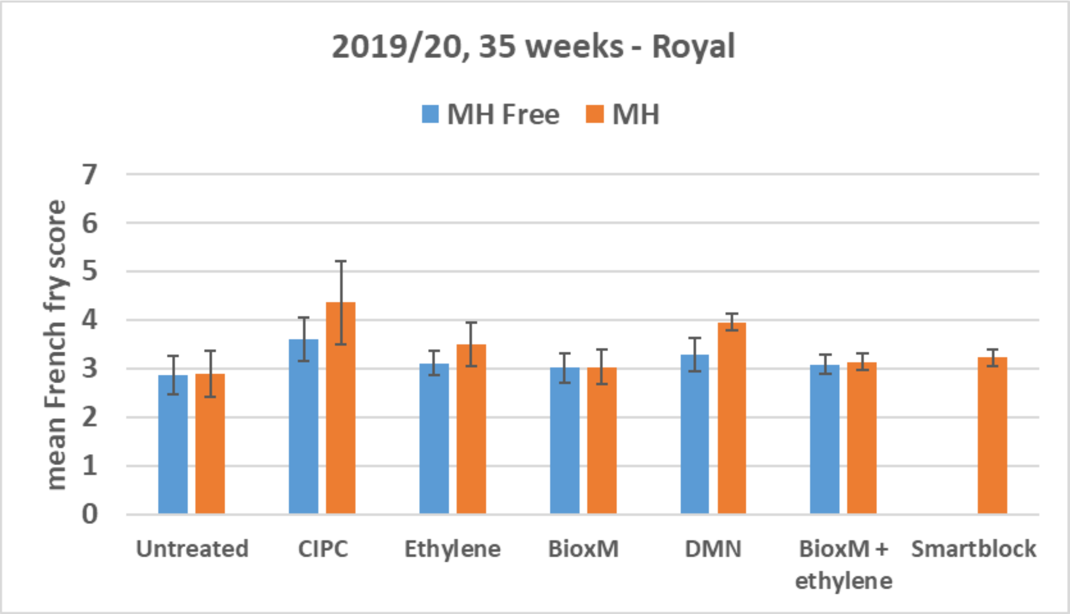

Fig. 11. Fry colour (mean score, +/- standard deviation) of cv Royal.

Crisps

VR808 MH free and MH treated samples are from different crops and differences should not be considered to be as a result of the MH treatment.

The fry quality of MH treated VR808 was poor with high (>10%) fry defect levels (Fig. 12) and relatively dark fry colour (Fig. 13). Fry defects were highest (50% or higher) in treatments that included ethylene. Fry defect levels in MH free samples of VR808 were very low (≤5%) irrespective of sprout suppressant.

Fry colour of MH free VR808 was light and of a commercially acceptable standard (L value >58) except in the combined ethylene & Biox-M treatment where colour was significantly darker (one way ANOVA *p*=0.011)

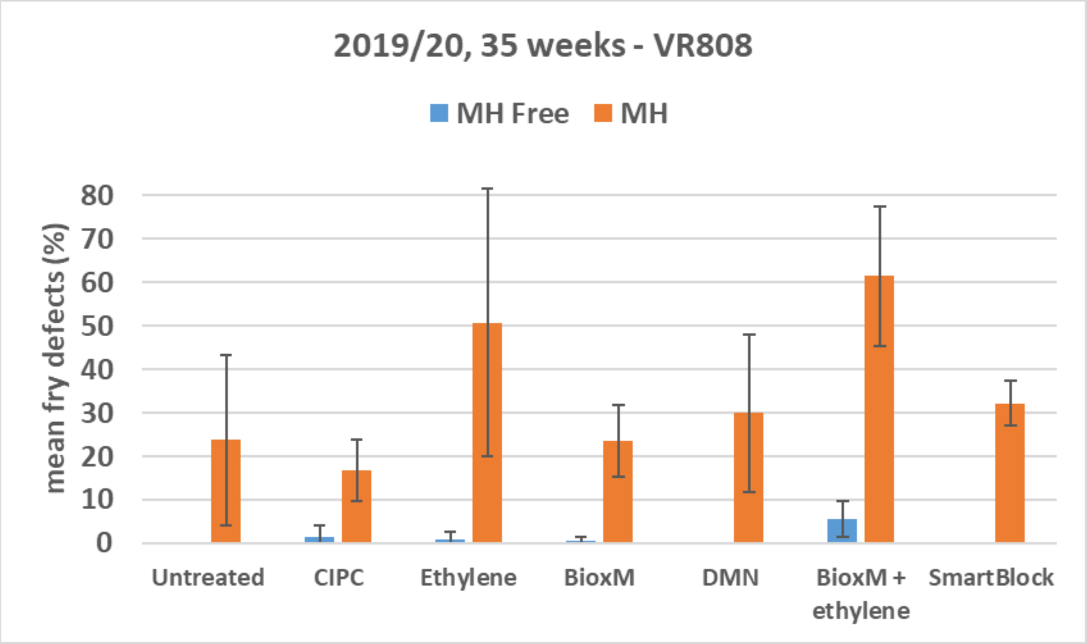

Fig. 12. Crisp fry defects cv VR808.

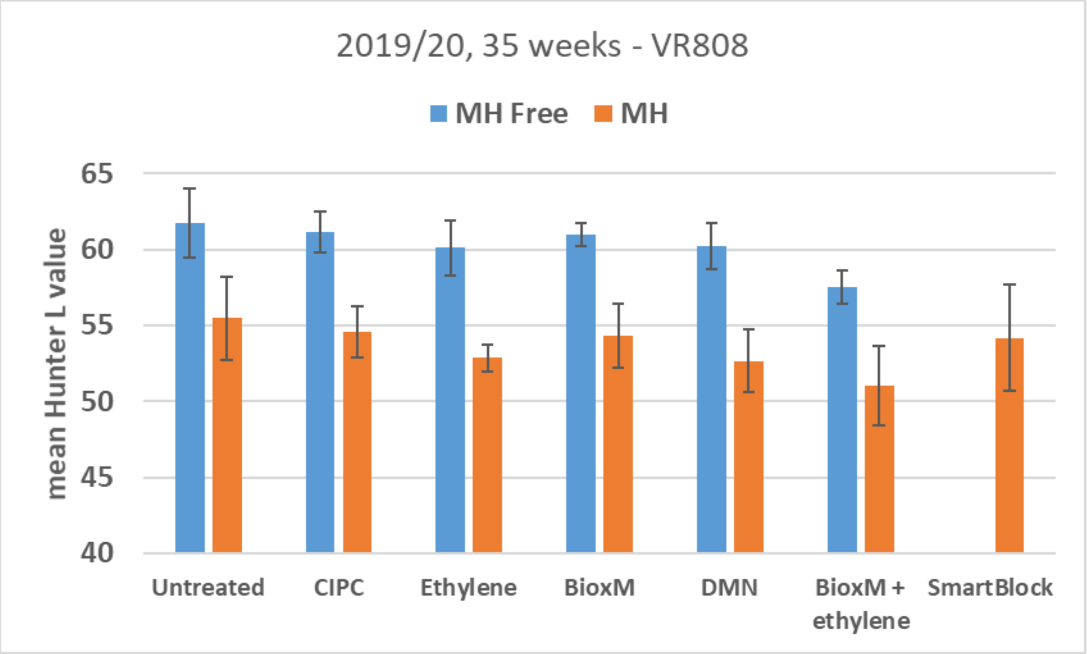

Fig. 13. Fry colour (Hunter L value) cv VR808.

Store carbon dioxide concentration

In addition to the standard stores where carbon dioxide concentration was controlled not to exceed c.0.3% (3000ppm), with Biox-M and DMN treatments, additional stores were operated with carbon dioxide concentration not exceeding c.1% (10,000ppm), in combination with a longer store closure period (72 hours). Chemical applications in Biox-M 1% and DMN

1% treatments were made at the same time as respective applications in the standard (0.3%) treatments.

The carbon dioxide concentration of stores, to which samples were exposed, is shown in Appendix C.

Chips (French fries)

The fry colour of cv. Innovator, under contrasting carbon dioxide regimes with Biox-M and DMN sprout suppressants is shown in Fig. 14. There was no significant effect of store carbon dioxide concentration using Biox-M sprout suppressant, but with MH treated samples, the higher carbon dioxide concentration resulted in a significantly darker fry colour using DMN (t-test, *p*=0.0476). Fry colour of MH treated Innovator was relatively poor; however, carbon dioxide did not have an impact on quality.

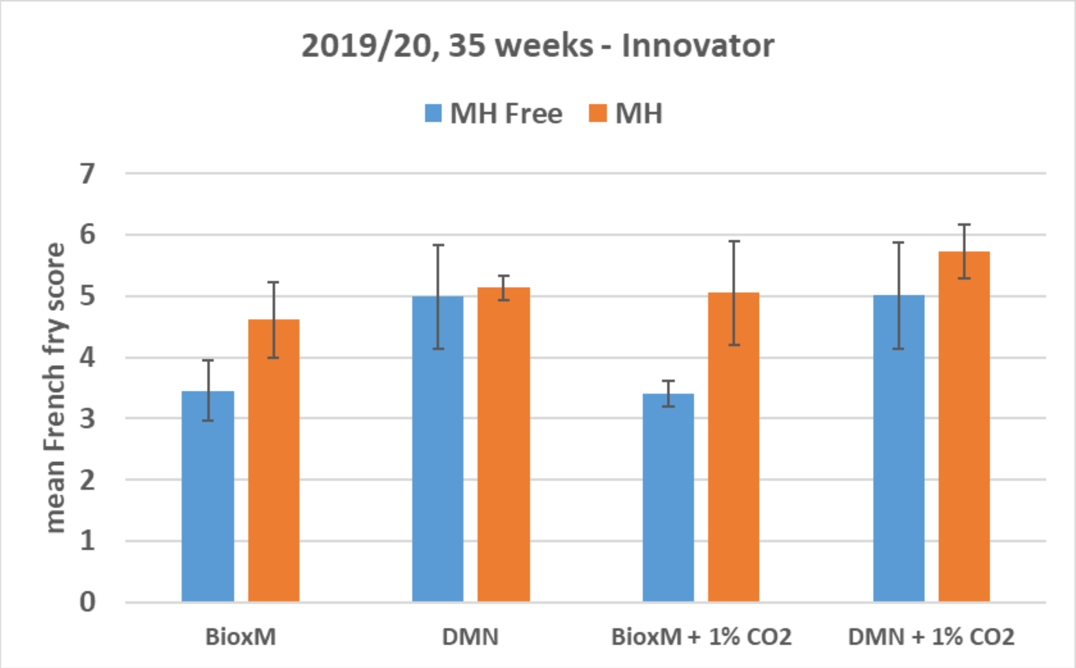

Fig. 14. Fry colour of cv. Innovator under standard (0.3%) and elevated (1%) carbon dioxide regimes.

Fry colour of cvs. Maris Piper, Perfomer and Royal was very light with values in the range 2.4 to 2.6 (cv. Maris Piper, Fig. 15), 2.8 to 3.3 (cv. Performer, Fig. 16) and 2.9 to 4.0 (cv. Royal,

Fig. 17), approximately equivalent to USDA 00 to 1. Store carbon dioxide concentrations of 0.3% or 1.0% did not give rise to differences in fry colour.

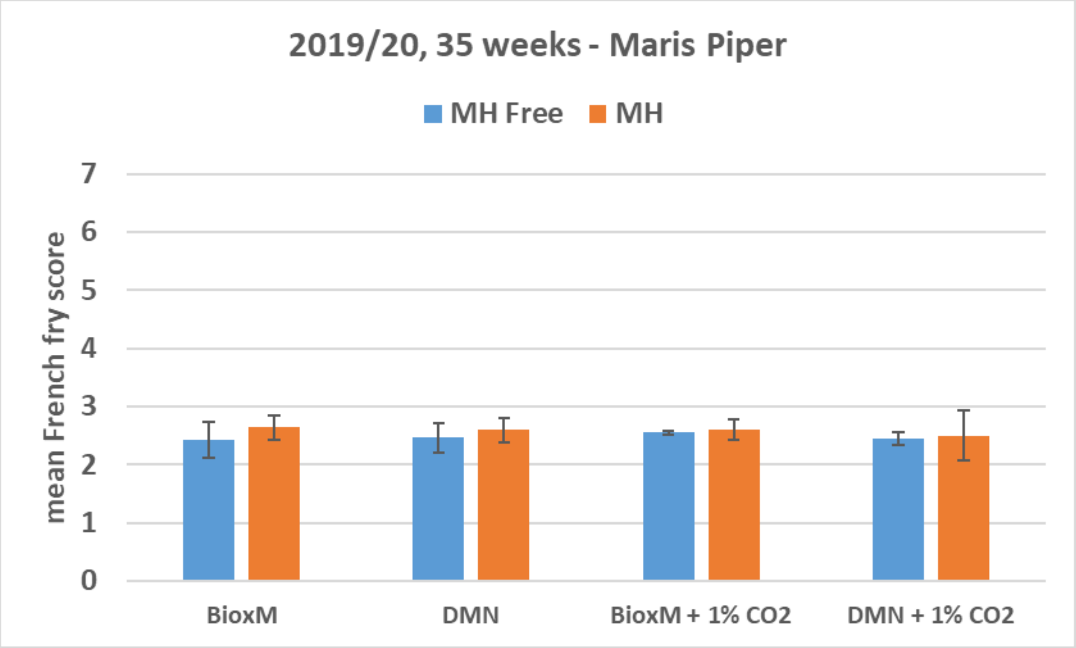

Fig. 15. Fry colour of cv. Maris Piper under standard (0.3%) and elevated (1%) carbon dioxide regimes.

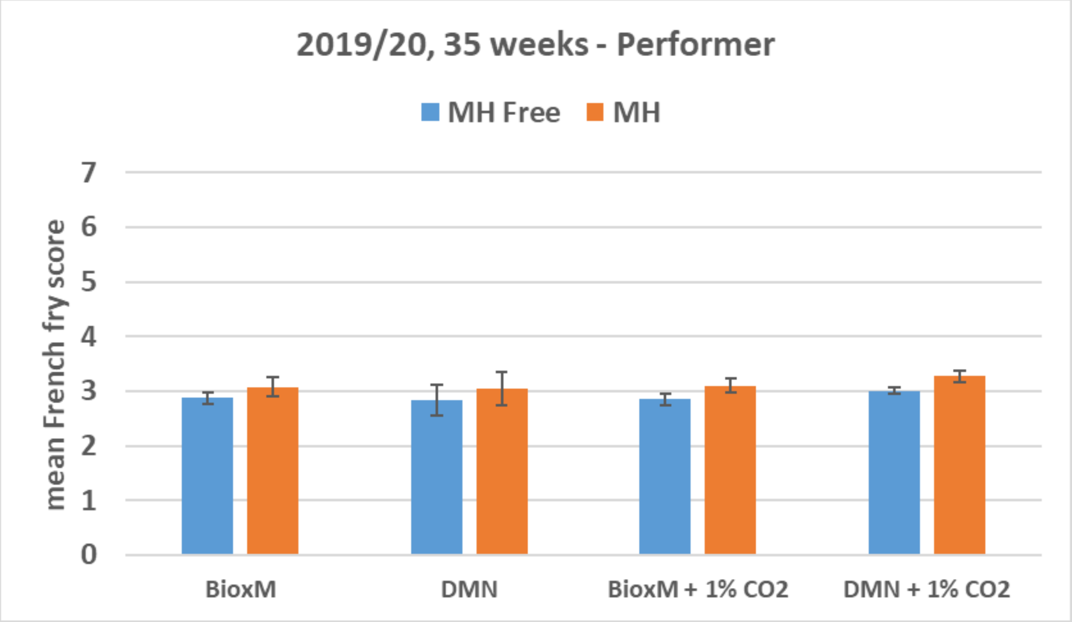

Fig. 16. Fry colour of cv. Performer under standard (0.3%) and elevated (1%) carbon dioxide regimes.

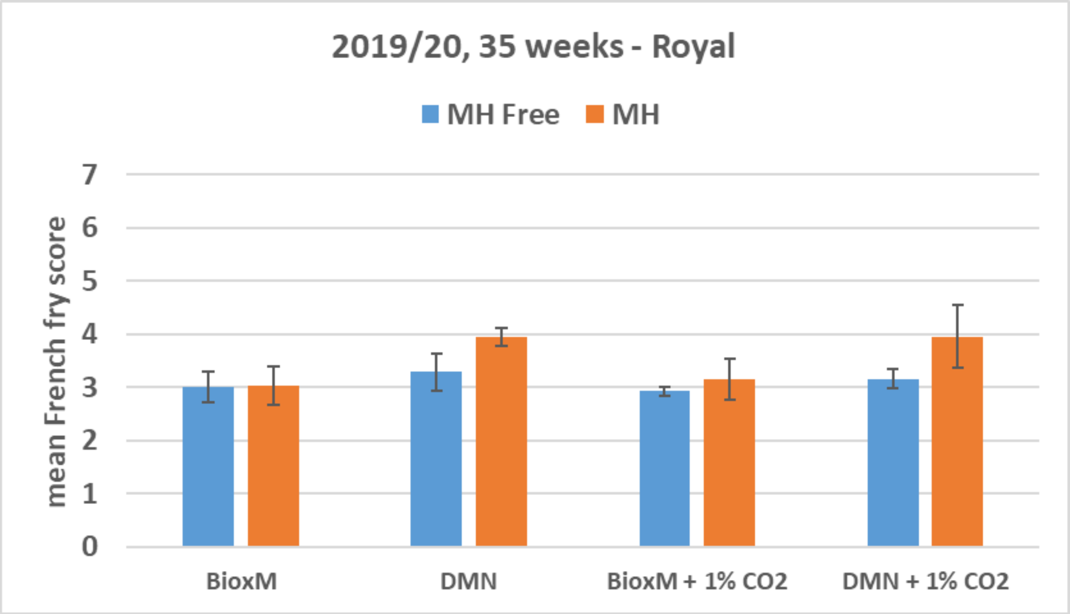

Fig. 17. Fry colour of cv. Royal under the elevated carbon dioxide regime.

Crisps

The fry defect levels and fry colour of cv VR808 is shown in Figures 18 and 19 respectively. The quality of MH treated VR808 was poor, with high defect levels (20-30%) and dark colour (50-55 L units). Store carbon dioxide concentration did not influence fry quality of this crop.

The quality of the MH untreated crop was good with low fry defect levels (<5%) and light colour (60-61 Hunter L units). The fry quality of MH free VR808 was not affected by store carbon dioxide concentration.

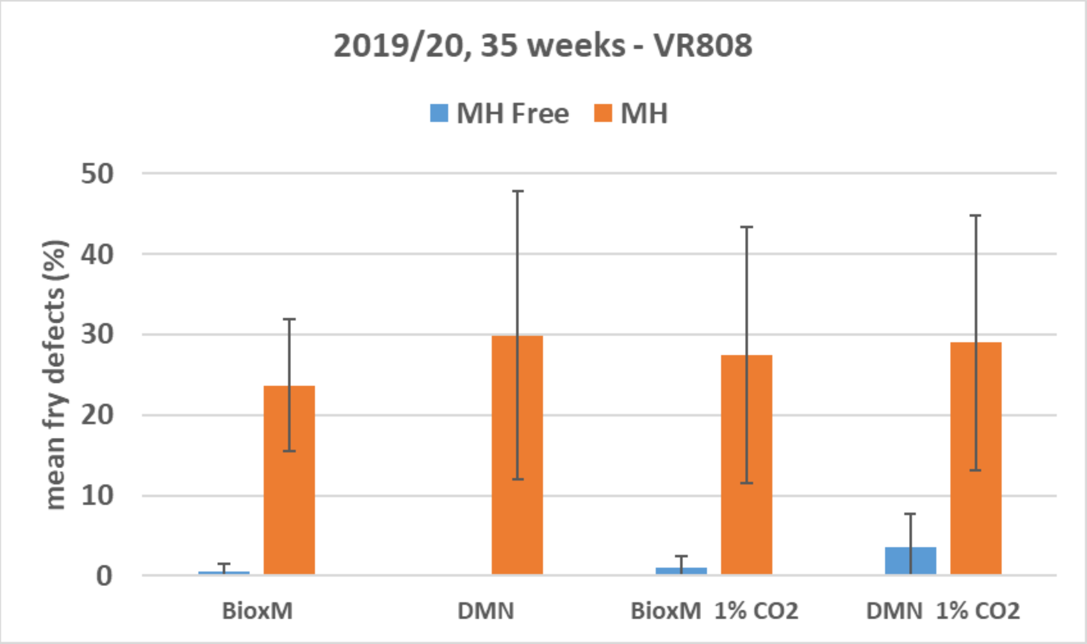

Fig. 18. Fry defects of cv VR808 under elevated carbon dioxide regime.

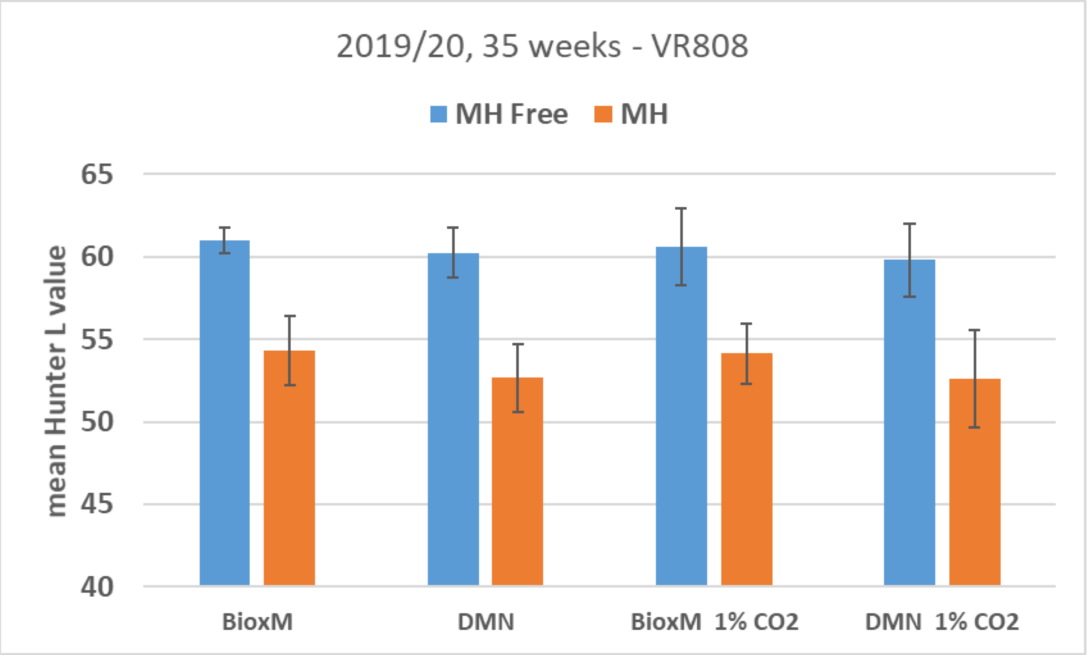

Fig. 19. Fry colour (Hunter L value) of cv VR808 under elevated carbon dioxide regime.

Sprouting

There was a tendency for sprouting in the Biox-M 1% and DMN 1% carbon dioxide stores to be greater than that in the respective control (0.3% carbon dioxide) stores. However, differences were generally not significant.

Internal sprouting

The incidence of internal sprouting is shown in Table 3 and includes slight and severe levels of the defect. Low to moderate incidences of the defect were recorded in MH free samples of the cultivars Royal and Performer, and a high incidence in MH free Innovator – this cultivar is especially susceptible to internal sprouting. In all cases, MH treatment resulted in effective control of internal sprouting.

Table 3. Incidence of internal sprouting (%) of samples at store unloading.

treatment	Innovator		Maris Piper		Performer		Royal		VR808		**means**	
	MH-	MH+	MH-	MH+	MH-	MH+	MH-	MH+	MH-	MH+	**MH-**	**MH+**
Untreated	28	1	0	1	9	0	3	0	0	0	**8**	**0**
CIPC	24	0	2	0	11	0	0	1	0	0	**7**	**0**
Ethylene	32	0	1	0	6	0	3	1	0	0	**8**	**0**
BioxM	23	0	2	0	8	0	3	1	0	0	**7**	**0**
BioxM 1% CO_2	28	0	5	0	7	0	12	1	2	0	**11**	**0**
BioxM/eth	34	0	1	0	11	0	8	1	0	0	**11**	**0**
DMN	23	0	0	0	2	0	0	0	1	0	**5**	**0**
DMN1% CO_2	30	0	5	0	1	0	0	0	2	0	**8**	**0**
SmartBlock®	-	0	-	0	-	0	-	0	-	0	**n/a**	**0**
mean	**28**	**0**	**2**	**0**	**7**	**0**	**3**	**1**	**1**	**0**		

4. Discussion

Sprout control

As in the 2018-19 storage season, maleic hydrazide had an important effect on sprout control when applied alone, but also when applied in combination with other products. In crops with higher MH residue concentrations (cvs Innovator and Performer), all post-harvest treatments maintained sprouting at levels less than 10mm at store unloading. SmartBlock® and DMN (1,4-SIGHT) products, effectively controlled sprouting in all MH treated crops[6]. SmartBlock®, applied on four occasions at 100 ml tonne^{-1}, was particularly effective with a mean sprout length of <1mm across all five varieties.

Without MH treatment, there was greater variation in sprouting responses. As in the previous season, application of DMN was particularly effective. Sprout length of DMN treated MH free cv Innovator though was greater than 10mm at store unloading. This suggests that, under the conditions used, applications with a total dose of 80 ml (67% of the proposed product label total dose of 120 ml tonne^{-1}) were insufficient for this cultivar. In commercial use, DMN (and other post-harvest treatments) are not generally applied at the full label rate[7] and in successive seasons in this work the application rate early in storage has been reduced more quickly from the initial rate (20 ml tonne^{-1}) to a 'holding' rate of 10 ml tonne^{-1}. Sprout control of the other cultivars at this DMN rate was good with mean maximum sprout length much less than 10mm.

Biox-M and ethylene treatments, without MH, resulted in mean sprouting levels of 20-35 mm in cvs Innovator and Royal, 10-20 mm in cvs Maris Piper and Performer and ≤10 mm in VR808. The combination of Biox-M and ethylene was effective and maintained very low sprouting levels in some cultivars. This treatment combination may be useful on crops where maleic hydrazide application is not possible. The processing quality of this treatment combination was similar to ethylene.

---

[6] Insufficient MH free crops were available, SmartBlock® was only applied to MH treated samples.

[7] Briddon, A., A C Cunnington and G Harper (2019) Study visit report, Non-CIPC potato storage in the Netherlands & Germany. AHDB, Stoneleigh Park, Kenilworth, Warwickshire, CV8 2TL

There was a tendency for high carbon dioxide levels (1%) to result in more sprouting early in storage, compared with levels up to 0.3%, but these differences were not significant at store unloading.

The cultivar VR808 was included in these trials because of its long dormancy. This season, dormancy of the cultivar was the shortest of all (44 days) compared with 71 days in the 2018-19 season. In spite of this, sprout control of this cultivar was again better than other cultivars, suggesting other factors (e.g. sprout vigour) also play a part.

Processing quality

The processing quality of crops was typically good or very good. Two crops, maleic hydrazide treated cv. Innovator and maleic hydrazide treated cv. VR808, was poor at store unloading. The cause of this is not known, but the quality of these crops had been good on previous sampling occasions. Deterioration in both was general, across all post-harvest treatments, suggesting the cause may be related to agronomy, rather than storage treatments.

Application of ethylene has been associated with deterioration in fry colour, see Prange et al. for example[8]. However, deterioration in fry colour has not been a feature of data from this trial, or indeed from this trial in the 2018/19 season. Although effects have been seen, they are occasional, slight and temporary. Careful initial management of ethylene when the compound is first introduced into the store (the 'ramp') serves to limit impact on crops. Data indicate that ethylene could be more widely used especially in the chipping sector, where careful ethylene management has effectively mitigated effects on processing quality.

Results for SmartBlock® are reported for the first time. The results indicate that processing quality was not affected by application of this product.

Application of most post-harvest treatments is followed by a store closure period when no active ambient air exchange is carried out. The purpose of the closure period is to ensure effective uptake/adsorption of the active substance. For Biox-M and DMN products long store closure periods are required (Biox-M, MAPP 16021 requires not less than 48 hours) compared with chlorpropham, where 6-8 hour closure periods were usual for processing crops.

---

[8] Prange, R.K., B.J. Daniels-Lake, J.-C. Jeong, M. Binns (2005). Effects of ethylene and 1-methylcyclopropene on potato tuber sprout control and fry color. Am. J. Potato Res., 82 (2005), pp. 123-128

Extending the period when ambient ventilation is restricted may result in the accumulation of carbon dioxide (from crop respiration) to a greater concentration in store. In this work, the combination of a longer store closure period (72 hours) and store management limiting carbon dioxide to 1%, did not have an important effect on processing quality, which was, with one exception, similar to samples from more conventionally managed stores (48 hour store closure and carbon dioxide controlled to no more than 0.3%).

In this work, care was taken to exclude exogenous ethylene from stores by carrying out applications using electric foggers. Results support observations[9] that carbon dioxide alone does not have an important effect on fry colour. If confirmed, results indicate applications should be carried out using electric or heat-exchange technology and, for processing crops, foggers using hydrocarbon fuels as the propellant should be avoided. There is no suggestion that store carbon dioxide management can be relaxed when ethylene is used. Store managers are reminded that carbon dioxide has implications for human health and that workplace exposure levels exist for it [10].

5. Conclusions

- **Pre-treatment with MH resulted in satisfactory (≤10mm) control of sprouting in samples by all post-harvest applied sprout suppressants after long-term storage at 9C.**
- **In MH treated samples, sprout control was very good following use of DMN and SmartBlock®.**
- **Post-harvest treatment with ethylene or Biox-M & ethylene was not associated with deterioration in processing quality.**
- **Long store closure periods, following chemical applications, in combination with high store carbon dioxide levels (1%) did not give rise to darker fry colour compared with a standard 48 hour closure period and control at 0.3% carbon dioxide.**

---

[9] Daniels-Lake, B. J., & Prange, R. K. (2009). The Interaction Effect of Carbon Dioxide and Ethylene in the Storage Atmosphere on Potato Fry Color Is Dose-related, HortScience horts, 44(6), 1641-1644.

[10] https://www.hse.gov.uk/pubns/books/eh40.htm

6. Appendices

A. Study diary

Table A. Diary of study events 2019-20

Date	Activity
13/09/2019	Maris Piper lifted
20/09/2019	Performer lifted
08/10/2019	Innovator lifted
09/10/2019	VR808 lifted
29/10/2019	All stores loaded
06/11/2019	DMN 1st applications (20 ml/t)
08/11/2019	CIPC 1st application (12g/t)
25/11/2019	All ethylene ramps started (final target concentration 10 ppm)
26/11/2019	*Biox-M* 1st applications to *Biox-M* only treatments (60 ml/t)
18/12/2019	*Biox-M* 1st application to *Biox-M*/ethylene treatment (60 ml/t)
16/12/2019	SmartBlock 1st application (100 ml)
17/12/2019	DMN 2nd application (15 ml/t)
08/01/2020	Sampling occasion 1
10/01/2020	*Biox-M* 2nd applications to *Biox-M* only treatments (60 ml/t)
28/01/2020	*Biox-M* 2nd application to *Biox-M*/ethylene treatment (60 ml/t)
29/01/2020	CIPC 2nd application (12g/t)
29/01/2020	DMN 3rd application (15 ml/t)
12/02/2020	SmartBlock 2nd application (100 ml)
19/02/2020	*Biox-M* 3rd application to *Biox-M* only treatments (90 ml/t)
10/03/2020	DMN 4th application (10 ml/t)
17/03/2020	Biox-M 3rd application to Biox-M/ethylene treatment (60 ml/t)
01/04/2020	*Biox-M* 4th applications to *Biox-M* only treatment (60 ml/t)
06/04/2020	SmartBlock 3rd application (100 ml)
14/04/2020	CIPC 3rd application (12g/t)
27/04/2020	Sampling occasion 2
28/04/2020	DMN 5th application (10 ml/t)
12/05/2020	*Biox-M* 5th application to *Biox-M* all treatments (90 ml/t)
04/06/2020	SmartBlock 4th application (100 ml)
11/06/2020	DMN 6th application (10 ml/t)
24/06/2020	*Biox-M* 6th application to *Biox-M*/ethylene treatment (60 ml/t)
29/06/2020	Sampling occasion 3

B. Maleic hydrazide residue concentration

Table B. Mean maleic hydrazide residue concentration (mg Kg^{-1}) of samples at intake and after storage.

cultivar	intake	SD	SO 1	SD	SO2	SD	SO3	SD
Innovator	**16.0**	3.37	**21.5**	8.43	**21.5**	4.51	**30.0**	11.46
Maris Piper	**6.6**	1.87	**7.2**	3.17	**6.8**	3.22	**5.3**	0.94
Performer	**14.0**	4.24	**12.8**	2.22	**15.0**	0.00	**14.0**	2.16
Royal	**4.7**	1.52	**4.9**	2.13	**5.3**	1.40	**5.4**	0.75
VR808	**7.5**	1.24	**7.4**	1.69	**10.2**	1.29	**9.5**	1.91

C. Store carbon dioxide concentration

Table C. Store carbon dioxide concentration (ppm) following chemical applications and prior to automatic store control resuming.

treatment date	CIPC 8 hrs	Smartblock 24 hrs	Biox-M 48hrs	Biox-M/eth 48hrs	DMN 48hrs	Biox-M 1% 72hrs	DMN 1% 72hrs
06/11/2019					**NR**		**NR**
08/11/2019	**NR**						
28/11/2019			**10566**				
29/11/2019						**19000**	
17/12/2019		**6750**					
19/12/2019					**11112**		
20/12/2019				**13000**			**20560**
12/01/2020			**13020**				
13/01/2020						**19880**	
29/01/2020	**NR**						
30/01/2020				**15370**			
31/01/2020					**12330**		
01/02/2020							**22980**
13/02/2020		**8730**					
21/02/2020			**12800**				
22/02/2020						**19500**	
12/03/2020					**13950**		
13/03/2020							**20720**
19/03/2020				**15010**			
03/04/2020			**14430**				
04/04/2020						**23900**	
07/04/2020		**10360**					
14/04/2020	**NR**						
30/04/2020					**12610**		
01/05/2020							**23420**
14/05/2020			**16400**	**17350**			
15/05/2020						**27500**	
05/06/2020		**10000**					
13/06/2020					**16490**		
14/06/2020							**33080**
26/06/2020				**19220**			
mean		**8960**	**13443**	**15990**	**13298**	**21956**	**24152**

Store carbon dioxide concentration (%).

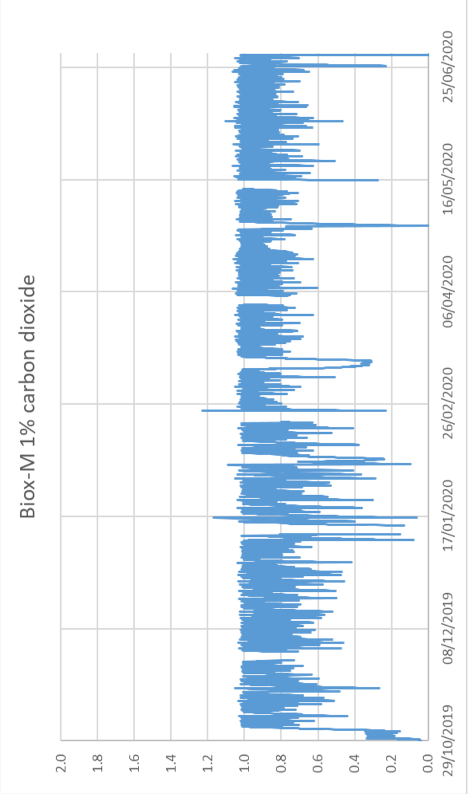

Fig. C3. Store headspace carbon dioxide concentration in elevated carbon dioxide Biox-M store.

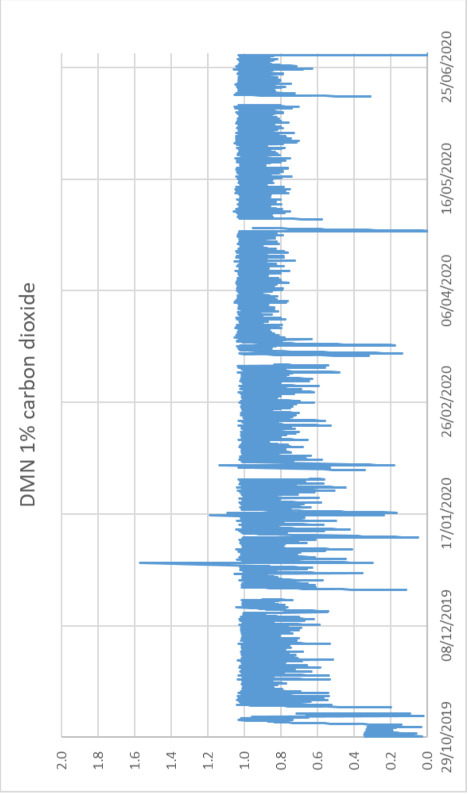

Fig. C4. Store headspace carbon dioxide concentration in elevated carbon dioxide DMN store.

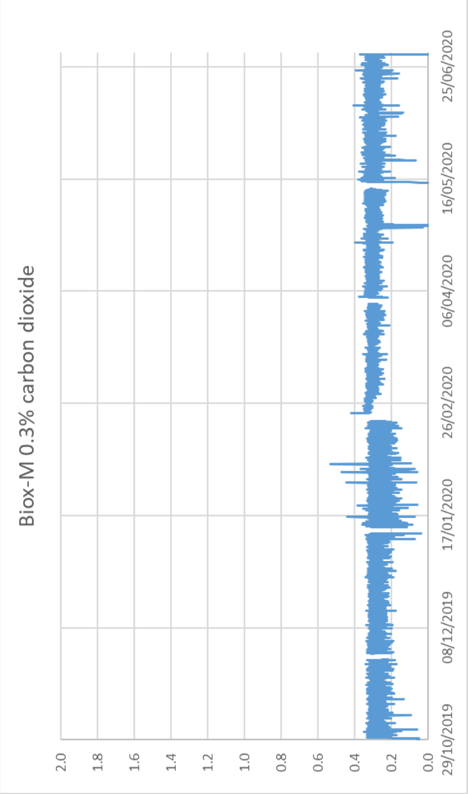

Fig. C1. Store headspace carbon dioxide concentration in standard Biox-M store.

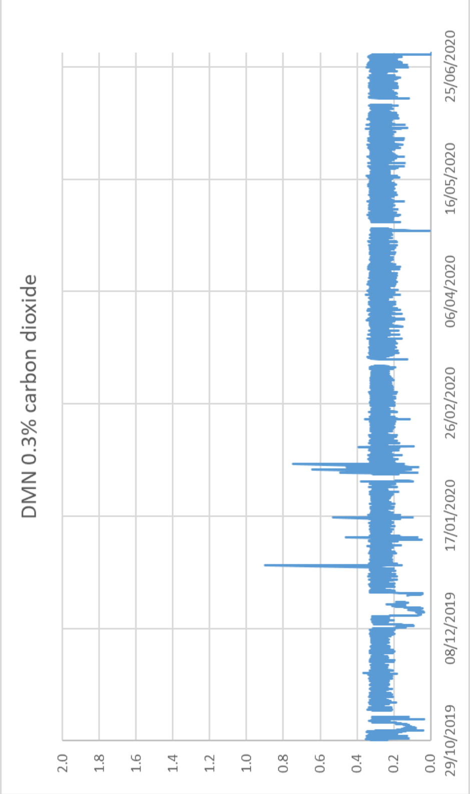

Fig. C2. Store headspace carbon dioxide concentration in standard DMN store.