Institution: University of Reading

Unit of Assessment: Agriculture, Veterinary & Food Science

Title of case study: Development and evaluation of novel spectral modification films for horticulture

1. Summary of the impact

Polythene film manufacturers and the horticultural industry have benefitted since 2001 from research conducted at the University of Reading, which helped design and evaluate spectral (light wavelength) modification films for use in polytunnels and greenhouses. The research led to the development of several innovative products, including one launched in 2013, by leading polythene manufacturer BPI-visqueen. These new products established BPI-visqueen as an international leader in the market, which led to enhanced export sales for the company and a subsequent investment of £7 million in manufacturing facilities that created 40 new jobs in the Scottish community of Ardeer. Widespread adoption of these new film products, in the UK and internationally, has led to increased yields in crops such as UK strawberries.

2. Underpinning research

Key research leaders were Professor Paul Hadley (Centre for Horticulture and member of the Soft Fruit Technology Group (SFTG) 1994 to present), Dr Fred Davis (Senior Lecturer in Organic Chemistry, 1994 to present) and Professor Chris Payne (1999 to 2003), with inputs from Professor Nick Battey (also of SFTG, 1999-2008) and researchers Simon Pearson (1994 -1998), Mark Fletcher (2001 -2003), Matt Ordidge (2005 -present) and Evangelos Tsompatsidis (2000 -present). The research began in 1994 and continues today.

Reading's research in horticulture has looked at ways to help optimise plant growth and yield for growers. Horticultural crops, particularly soft fruit species, are grown increasingly in polytunnels and greenhouses since these allow the UK production season to be increased, whilst reducing pesticide use and harvest costs. At the time this research began in 1994, most crops were grown under clear standard polythene. Researchers at Reading began investigating the effects on plant growth and development of polythene films that modify the spectral characteristics of light passing through as published evidence suggested that certain modifications could significantly improve yield and quality of crops grown in polytunnels.

In 1995, Hadley and his colleagues found that additives could be incorporated into polyethylene films, which scattered a high proportion of light, allowing very little transmission of direct beam light and reducing transmission of infra-red compared to standard films [1]. The light scattering films transmitted the light wavelengths used for photosynthesis in diffuse form allowing light to hit the plant from all angles and giving better plant illumination. This increased rates of photosynthesis and improved growth compared to plants growth under direct beam light under standard films.

As a result of this initial work, Hadley began a relationship with BPI-visqueen, Europe's largest manufacturer of polythene film products, to develop a range of novel spectral modification films for the horticultural industry. In 1997, with the support of a LINK grant [7], the Reading team produced a range of additives and experimental plastics, which BPI-visqueen then produced in experimental amounts to use in a series of growing trials designed to evaluate the films for their effect on plant growth and disease. Films with light scattering, UV clear and UV blocking properties were identified and further research, funded by grants [8-9] and BPI-visqueen directly (4 PhD projects in total), evaluated the effect of these films on plant growth, pests and diseases, and further refined the stability of the films for commercial production.

Light scattering films control heat

Controlling temperatures in polytunnels and greenhouses is difficult and in hot summer months there is a serious risk of crops being damaged by scorching.The light scattering film that was developed [1] not only improves plant growth and yield, it reduces the amount of heat generated. As well as scattering the light wavelengths used by plants, the film scatters longer wavelengths – infra-red radiation - not used in photosynthesis. It is largely infra-red radiation that heats the polytunnel, but when these longer wavelengths are scattered, less radiation enters the tunnel,

significantly reducing the temperature compared to standard polythene films.

UV clear films increase nutrient content and fruit

Previous research had indicated that plants grown under high UV radiation contain increased levels of secondary products. Plant secondary compounds are beneficial to human health (increased nutritional value) and also form part of the plant's natural defences to pests and diseases. Therefore, growing plants under films that allow UV light through – UV clear films - could improve nutrient content as well as plant resistance to pests and disease. Standard horticultural films contain UV absorbing compounds that protect the film from UV breakdown, but collaborative work between Reading and BPI led to the development of a UV clear film. The Reading team showed that growing lettuce under UV clear films gave increased levels of plant secondary compounds including phenolics and anthocyanins [2, 3]. They also looked at the effect of UV radiation on fruit secondary compounds in one of the main commercial varieties of strawberry, Elsanta, and found that it hastened the rate of colour development and gave increased levels of anthocyanin, flavonoid and phenolic compounds at the time of harvesting [4]. Plants also produce greater numbers of firmer strawberries under UV clear films compared to UV opaque films [4].

UV blocking films control diseases and pests

While UV light has a number of benefits for the plants, it's also beneficial to the diseases and pests that affect the plants. Many fungi, such as *Botrytis cineria* (grey mould), need UV light to produce spores and insects use UV light to navigate and forage for food; films that block UV light could help control fungal diseases and pests. In 2000, Hadley and his colleagues at Reading reported that UV blocking films led to reduction in the production of *B. cineria* spores *in vitro* and that in field trials, the incidence of *B. cineria* in strawberries was reduced by 26% compared to standard films [5]. Field and behavioural experiments showed that fewer insect pests (aphids, thrips and beetles) were found under UV blocking films [6].

3. References to the research Research that led to the impact has been published in peer review journals and has been assessed as of at least 2* quality.

[1] Pearson S, Wheldon AE, Hadley P. (1995) 'Radiation transmission and fluorescence of 9 greenhouse cladding materials'. *Journal of Agricultural Engineering Research,* 62 (1) : 61-69. DOI: 10.1006/jaer.1995.1063 (Citations – 42)

[2] Tsormpatsidis E, Henbest RGC, Battey NH, Hadley P. (2010) 'The influence of ultraviolet radiation on growth, photosynthesis and phenolic levels of green and red lettuce: potential for exploiting effects of ultraviolet radiation in a production system'. *Annals of Applied Biology*, 156 (3): 357-366. DOI: 10.1111/j.1744-7348.2010.00393.x

[3] Tsormpatsidis E, Henbest RGC, Davis FJ, Battey NH, Hadley P, Wagstaffe A. (2008) 'UV irradiance as a major influence on growth, development and secondary products of commercial importance in Lollo Rosso lettuce 'Revolution' grown under polyethylene films'. *Environmental and Experimental Botany*, 63 (1-3):232-239. DOI: 10.1016/j.envexpbot.2007.12.002 (Citations – 30)

[4] Tsormpatsidis E, Ordidge M, Henbest RGC, Wagstaffe A, Battey NH, Hadley P. (2011) 'Harvesting fruit of equivalent chronological age and fruit position shows individual effects of UV radiation on aspects of the strawberry ripening process'. *Environmental and Experimental Botany*, 74:178-185. DOI: 10.1016/j.envexpbot.2011.05.017

[5] West JS, Pearson S, Hadley P, Wheldon AE, David FJ, Gilbert A, Henbest RGC. (2000) 'Spectral filters for the control of *Botrytis cinerea*'. *Annals of Applied Biology*, 136 (2):115-120. DOI: 10.1111/j.1744-7348.2000.tb00015.x

[6] Doukas D, Payne CC. (2007) 'The use of ultraviolet-blocking films in insect pest management in the UK; effects on naturally occurring arthropod pest and natural enemy populations in a protected cucumber crop'. *Annals of Applied Biology,* 151 (2): 221-231. DOI: 10.1111/j.1744-7348.2007.00169.x (Citations – 13)

Impact factors: *Environmental and Experimental Botany*: 2.578. *Annals of Applied Biology*: 2.147

Grants

[7] Awarded to Dr A.E. Wheldon, Dr S Pearson, Prof A. Gilbert, Prof P.Hadley and Dr F. Davis (1995-1997) The development of enhanced polyethylene cladding materials for greenhouses and horticultural tunnels, LINK grant funded by Department of Trade and Industry and the Engineering and Physical Sciences Research Council (EPSRC), £146,088.

[8] Awarded to Dr F. Davis, Prof A. Gilbert and Prof P. Hadley (2000-2003) Selected wavelength spectral filters for horticultural crop protection, EPSRC, £143,130

[9] Awarded to Prof P.Hadley (2001-2003) To evaluate methods and systems for using spectral modification films in horticulture; generation of data for the commercialisation of products which have been developed for the control of plant growth and quality. Knowledge Transfer Partnership with BPI-visqueen, £42,528.

4. Details of the impact

The research at Reading into the development and evaluation of spectral modification films has involved a long term partnership with BPI-visqueen, with Richard Henbest (former Technical Director at BPI-visqueen) co-authoring many of the papers listed above. The Reading team provided expertise in crop physiology and designed, implemented and analysed experiments at the research facilities at Reading, which examined crop responses to different film types. BPI-visqueen provided expertise in the development and production of the plastic films. The collaboration resulted in several commercial products that have been on sale during the impact period 2008-2013. These products offer tangible advantages to growers, which differentiated BPI-visqueen products in the market-place.

Development and sale of new commercial products

The first product developed from the work on light scattering film [1] was Luminance THB (Thermal Heat Barrier), launched in 2001 and marketed as a diffusing heat control film for polytunnels. The research undertaken by Reading into the effects of light scattering films provided BPI-visqueen with a credible, scientific basis for their key communication messages and marketing materials [a]. In 2013, Luminance continues to be a globally recognised brand of film that BPI-visqueen sells in over 50 countries worldwide [b]. Though specific sales figures for this product are commercially sensitive, in 2011 BPI-visqueen reported that more than one third of sales, valued at £508 million, were in the agricultural sector, including their value-added agricultural films [b, pg 18]. Luminance THB continues to be one of the leading wide film plastic products manufactured by BPI.Visqueen and was the first diffuse heat control film for polytunnels - since then other plastics companies have developed similar products (e.g SunMaster superthermic from XL/Plastika Kritis).

In February 2013 BPI-visqueen launched a new product, Lumisol, which is a greenhouse film designed to create an optimum growing environment by actively managing UV light [c]. The Lumisol film range includes both clear and diffused film formats and it was the Lumisol Diffused product that was developed using a formulation based on Luminance technology [c]. Therefore the original work undertaken by Reading [1] continues to provide effective temperature control in this next generation of diffused horticulture films. In Lumisol, all of the UV light is allowed through to the plant to increase the secondary compounds in the plant, increase nutrient quality, and improve fruit colour and firmness [2-4] as well as promote the plants own defence mechanisms against pests and diseases. This is a novel approach and has been built on work conducted by Reading [2-4] into the effects of UV clear films on the levels of plant secondary compounds [d].Lumisol is sold for greenhouse applications throughout BPIs domestic and overseas markets including Europe (France, Germany, Austria, Italy, Spain) Egypt, Turkey and some African countries.

Reading's research on UV blocking for pests and diseases [5, 6] has been used in products and marketing for BPI-visqueen, including Lumivar, a UV blocking film [d]. Films from manufacturers such as Plastika Kritis, Greece, now use UV blocking as a means of reducing pest and disease attack in greenhouses, in part influenced by the research done at Reading as a highly skilled individual from the Reading team became the exports manager for Plastika Kritis in 2007 (see below).

Industry invests in 'smart-film' technology and creates job opportunities

BPI-visqueen's success in horticultural film led to a £7 million investment in 2008 in new manufacturing technology at their site in Ardeer, North Ayrshire to produce these next generation films with "optimum quality and efficiency levels" and with "increased throughput and quicker turnaround times" [e]. This investment provided 40 additional jobs in the Scottish community of Ardeer [e].

Advanced films enhance export sales

The benefits provided by Luminance have enabled BPI-visqueen to export successfully into a

variety of overseas markets thanks to its unique advantages over standard, locally available films.

The Sales Director at BPI-Visqueen said that ”w*orking with Reading has allowed BPI-visqueen to advance films from being merely covers that protect crops from the elements to a range of spectral filters that add significant value to the grower. Reading helped us to develop our range in a methodical, scientific manner that gave us a head-start in the marketplace with temperature control films. This allowed us to compete at an international level which in turn has enhanced our export sales*” [f].’

New films increase strawberry production in the UK

The strawberry industry has seen a steady increase in production and market value since the widespread use of light diffusing, heat retaining and other spectrally specific films [g]. Between 1991 and 2001, the average production of strawberries in the UK was 66.3 thousand tonnes [h, table 10]. In 2002, after the introduction of Luminance THB, total strawberry yield increased to 77.9 thousand tonnes and has steadily increased ever since [h, table 10]. Total production in 2012 (provisional) was 145.1 thousand tonnes, nearly a 5% increase over production in 2008 [h, table 10]. In 2011, the National Horticultural Forum acknowledged the contribution of the collaborative research conducted by the University of Reading and BPI-visqueen to these improved yields[g, pg 3]. The development and commercialisation of novel films has helped extend the British strawberry growing season from eight weeks to one that now stretches from Spring to Autumn. Although there are many factors responsible for increased strawberry yields in the UK, Reading’s research into spectral films has been one of the contributing factors.

Highly skilled people trained at Reading take expertise to other companies

Postdoctoral researchers and PhD students who worked on research into spectral modification films at Reading are now working at horticultural film/polythene companies and are using their knowledge on spectral films to improve their company’s performance. Dr. Dimitris Doukas, who worked with Payne on UV blocking and pests became Exports Manager, Agricultural Films Division at Plastika Kritis SA in 2007 [i]. Doukas has “re-directed the company into this specialised area” [g, pg 3] of horticultural films, making the company a major player in horticultural films, including UV blocking films for pest and disease control [f].

5. Sources to corroborate the impact

[a] ‘Luminance’, *VISQUEEN* [website] http://tinyurl.com/p8872d5 accessed 26 Sept 2013. Marketing material on Luminance, which refers to the research conducted at Reading [1, 4].

[b] *Resilience: A defining feature of our business,* British Polythene Industries PLC, Annual Report and Accounts 2011 http://tinyurl.com/nmt7hx2 Evidence of global distribution of visqueen products and context for overall sales in agricultural products.

[c] ‘Getting light right’, *VISQUEEN,* Lumisol brochure http://tinyurl.com/q9mnvto. Refers directly to collaboration with University of Reading in the development of the Lumisol product.

[d] ‘Lumisol and Lumivar’, VISQUEEN, brochure http://www.bpivisqueenhort.com/media/FE_26_LUMISOLLUMIVAR.PDF. Refers directly to research conducted by the University of Reading as evidence of the efficacy of the product.

[e] ‘BPI announces major investment in Ardeer facility’, *BPI* [website] http://www.bpipoly.com/news.aspx?id=255 accessed 26 Sept 2013. Links success in specialty film production with significant investment in Ardeer manufacturing facility.

[f] Sales Director, BPI-visqueen - Corroborative emails indicating impact of research on British Ploythene Industries (BPI), on the horticulture industry in general and the soft fruit sector in particular. Available upon request.

[g] *Research into Use: The Strawberry and Brassica crops*, The National Horticulture Forum (April 2011) http://www.hortforum.net/uploads/7/2/9/5/7295387/nhf_research_into_use_april_2011.pdf. Links Reading’s research contributions to advances in film technology that are in part responsible for improved crop performance in strawberries

[h] ‘Basic horticulture statistics – dataset’, *Department of Environment, Food & Rural* Affairs, Horticultural statistics series (Updated 31 July 2013) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/141609/hort-dataset-31jul13.xls. Provides annual strawberry production statistics.

[i] ‘Dr Dimitris Doukas’, *LinkedIn profile* [website] http://www.linkedin.com/pub/dr-dimitris-doukas/2a/5a2/341 accessed 26 Sept 2013.