Cultivar responses to long-cane fruit production in raspberry

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Introduction Currently the United Kingdom is a net importer of raspberries. Traditionally the main outdoor raspberry cropping season in the UK begins in June with summer fruiting cultivars and is extended through to late August early September by the use of primocane/autumn fruiting cultivars.

In recent years, consumer demand for fresh raspberries outwith the main production season has increased, with high premiums being paid for fresh market raspberries. This demand is being met by imports from countries such as Spain, Portugal and Chile, which have the advantage of more favourable weather conditions and a longer growing season. Production of raspberries for fresh market either side of the main season is achieved through protected cropping under polytunnels, or in some cases glass, using novel systems of production to manipulate flowering and fruiting. Protected cropping and out-of season production in European countries is expanding, so that in areas of southern Spain nearly 100% of fresh market dessert raspberries for early, main and late season are being grown under tunnels.

The economic advantage and current consumer demand for out-of-season raspberry production has led growers in the UK to try new production techniques for extending the cropping period. One production technique, termed 'long-cane production', is increasingly being adopted, especially in protected cropping situations.

Long-cane production This system involves the manipulation of summer fruiting cultivars by cold storage of the canes. Long-canes are produced in the field in spawn beds. In autumn, when the canes have matured and are dormant, they are lifted from the beds with roots and placed into cold store. When adequate chilling has been accumulated, the long-canes are brought out of the cold store and planted for cropping under the protection of either polytunnels or glass. Production can either precede the main season, by removing the canes from storage as soon as dormancy has been satisfied, or be delayed by leaving the canes in the cold store until later in the season. After fruiting the mature canes are cut back and new spawn is allowed to grow for fruiting in the following year. The new spawn can either be incorporated into an annual or biennial plantation system, or lifted from the fruiting bed and cold stored again.

In truth, the success of long-cane techniques under protected cropping in the UK has been mixed, particularly regarding bud break and cropping consistency. Greater understanding of the plant has been required to improve the reliability of these production systems.

Research at SCRI This article describes research being carried out at SCRI on the long-cane production system. The ultimate goal of the 'Year-round soft fruit production' project, funded by MAFF (Project Number HH1519TSF), is to develop a commercial blueprint for the production of out-of-season *Rubus* crops in the United Kingdom. Commercial trialling in the project is carried out in conjunction with ADAS and in close collaboration with local propagators.

To improve the competitiveness of the long-cane system, research has been aimed at examining various means of optimising every stage of production, through a better understanding of the physiological processes involved with the aim of maximising fruiting potential. The main areas of long-cane production being studied are:

- Cane production
- Cold storage
- Dormancy and flower initiation
- Crop production

Figure 1 Traditional spawn bed production of primocanes.

Cane production The growing of canes for protected cropping in the following year has several specialised aspects. Currently, in the commercial sector, long-cane primocanes are being produced in traditional spawn beds (Fig. 1). The density of the growth within traditional spawn beds has clear effects on the quality of the cane produced, in terms of morphology and development. For example, canes within the dense canopy tend to initiate flower primordia *ca*. 2 weeks later than canes at the outside of the bed[1]. The quality, quantity and temporal distribution of light are known to influence correlative inhibition (apical dominance) and therefore plant growth and morphology[2]. A trial to examine the effect of initial spawn bed planting density and subsequent light penetration on root size, bud break and flower production is in progress.

Figure 2 The effect of infection by *Botrytis cineria* in cold stored canes.

In addition, the time of lifting canes from the spawn bed is critical: canes lifted too early show poor survival in cold stores even if the storage temperatures are reduced slowly. However, delay in lifting can leave canes vulnerable to frost injury with impaired cropping in the following year[3].

Lifting date has been found to have a significant effect on cane survival post-storage. Survival of cultivars Glen Moy and Glen Clova lifted before October was found to range from 0-16 %, from October survival post-storage increased to 80%.

Cold storage The ability of raspberry canes to store in a viable condition is crucial to the success of the long-cane system, with regard to meeting the chilling requirement of the plant, preventing growth, desiccation and disease while in the store, and avoiding low-temperature injury.

Cold storage of raspberry canes is necessary to fulfil the chilling requirement of the canes after lifting from spawn beds in the autumn. Storage of canes at 4°C for 6 weeks is sufficient to meet the chilling requirement of upper buds in Glen Moy. The intensity dormancy attains can be influenced by environmental conditions, the age of the plant and cultivar differences[4]. Other factors, including the woodiness of the stem and the water content of both the bud and stem may also affect dormancy and chilling requirement. The deeper the dormancy attained, the more chilling is required for bud break, and therefore the minimum amount of chilling required to break dormancy cannot be regarded as constant for any one cultivar.

Fruiting potential and cane quality must be maintained through cold storage. Storage conditions must prevent bud desiccation and reduction in cane quality in storage. The major problems in storage to date have been desiccation of the cane and disease problems, predominately cane *Botrytis* infection. Comparison of bare root and covered root has established that bare root cane will desiccate in cold storage. Desiccation of buds is also an important consideration. Breathable fleece has been used to wrap around bundles of canes to maintain humidity and defoliation treatments have also been included in these storage trials. A higher incidence of *Botrytis* infection and cane death (Fig. 2) was observed when fleece was used and leaves were left intact on the canes.

For long-term storage (greater than 4 months) it is apparent from our present studies that temperatures lower than 4°C are necessary to prevent bud break and growth in storage. Canes of Glen Lyon that had been stored at 4°C with 24 hour dark began to break bud and etiolated laterals developed after 4 months in storage[5].

Canes of cv. Glen Ample have been successfully stored for up to 10 months post-lifting. For long-term storage, 1°C was found to be necessary to check bud break and growth. When grown on under protection, these canes produced a crop from late October through to mid November. Long-term storage was found to significantly decrease the time from bud break to flowering, from approximately 11 weeks (under normal field conditions) to just under 4 weeks. This response has also been observed in peach[6], where it appeared that further chilling caused compositional changes, particularly in the cell membranes, and produced a more concerted bud break.

Cane physiology In order to manipulate fruiting of raspberry outwith the main summer season, dormancy status within the over-wintering (resting) bud and the developmental stage of the apical meristem (i.e. vegetative or reproductive) must be accurately assessed. To obtain the maximum fruiting potential from cold stored canes, buds should have passed through endo-dormancy (true winter dormancy) and be in an eco-dormant (environmentally imposed) state, and flower primordia should be fully differentiated.

Flower initiation (Fig. 3 and Fig. 4) and development of dormancy in raspberry occur concurrently but independently in response to the lower temperatures and shortening daylengths of autumn. When buds become *endo*-dormant, their water content is reduced as free water becomes bound to hydrophilic proteins (macro molecules) in cell membranes[7]. A period of chilling is then required to break dormancy, leading to an increase in free water.

Work with S. Glidewell (CEP Dept.), using Nuclear Magnetic Resonance Imaging (NMR), and I. Roberts (Virology Dept.), using Confocal Laser Scanning Microscopy (CLSM) is being carried out to develop novel techniques for monitoring the water status and flower primordia development of raspberry buds.

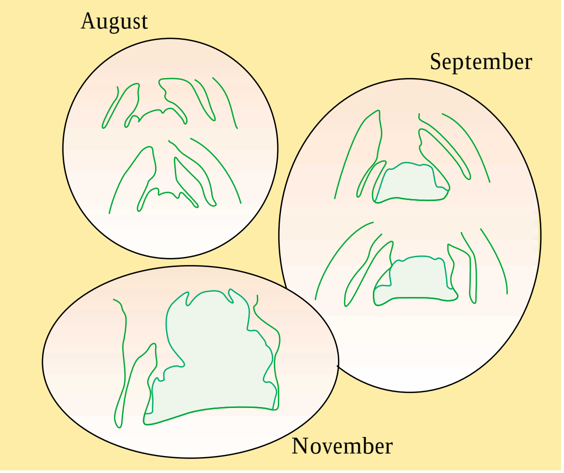

Figure 3 Schematic representation of floral development in raspberry (after Williams, 1950). The apical meristem changes from vegetative to reproductive in response to shortening days. The shape of the apex is modified and becomes domed and conical as the flower primordia develop.

NMR micro-imaging represents a non-invasive approach for evaluating changes in the behaviour of water in biological systems[8]. The basic principles of NMR spectroscopy and 3-dimensional imaging have been previously described[9,10].

Using NMR micro-imaging, we have been able to monitor changes in the water status of the same raspberry bud from the point at which it entered dormancy in the autumn through to bud break in the spring. NMR imaging is performed with a Brucker AM300/WBFT spectrometer (7.1 Tesla). A 20 mm coil has been modified to accept a woody plant speci-

Figure 4 Median longitudinal section of a bud taken with a Zeiss Tessovar macro camera. Terminal and axillary flowers can be seen developing at the centre of the bud.

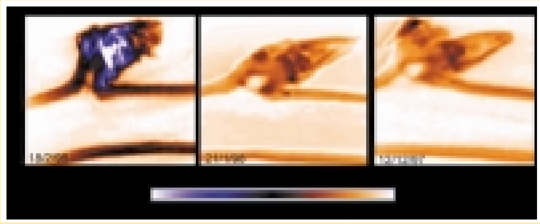

Figure 5 A longitudinal slice taken from each 3-d data set is shown. Data has been colour coded with an arbitrary scale to show the increase in signal intensity as bound water in the bud tissues is freed.

men by drilling out the base, so that the same stem can be imaged through the winter. At each imaging date, a series of 2D and unweighted 3D spin echo images are acquired using standard Bruker pulse sequences.

We have obtained 2D and 3D images showing the development of leaf primordia and flower initials with the bud (Fig. 5). From these images, T_1 (spin-lattice relaxation) and T_2 (spin-spin relaxation) times can be calculated to establish the concentrations of ^1H protons from the water within the bud. Dormancy in raspberries is a dynamic process, and the use of NMR micro-imaging of the water status in raspberry buds presents a powerful technique for direct, non-invasive observation of developmental and temporal changes of internal structures in raspberry buds.

To complement the NMR micro-imaging, optical imaging by CLSM is being used to observe the structural changes within buds as flower primordia initiate and differentiate. Excised raspberry buds are fixed using 5% glutaraldehyde in PIPES fixative. The buds are stained using Safranin-O (0.01%) and embedded in Araldite® resin[11]. A Bio-rad MRC 1000 CLSM is used to optically section the embedded raspberry buds.

CLSM optical sectioning is a simple and reliable method to visualise flower initiation and differentiation in raspberry buds. Clearly defined images at both the macro and micro level have been obtained (Fig. 6).

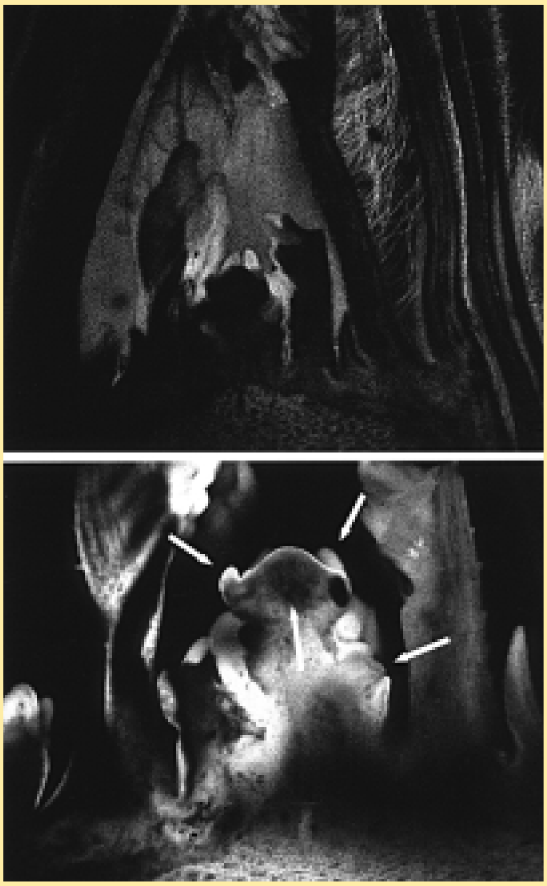

Figure 6 Text: CLSM optical section through a resin embedded bud stained with Safranin-O. a) x4 objective: the terminal flower primordia can be seen in the centre, with developing leaves and protective bud scales to the right and left. b) x10 objective: terminal flower with arrows pointing to the rounded torus and sepal rudiments, a secondary flower stem can be seen on the right of the terminal flower.

Crop productionThe removal of apical stem parts in the winter, or 'tipping', has been standard practice in the field cropping of raspberries in the UK for many years, for ease of management and improved yields[12]. Growing of protected raspberries using long-cane methods has also involved the use of tipping on canes entering the glasshouse from cold store (Raffle, Pers. Comm.), again for ease of management but also in an apparent attempt to reduce the effects of apical dominance as expressed in the uneven breaking of buds down the cane. Such unevenness is a major factor in reducing yields in protected raspberry cropping.

In a trial to examine the effect of tipping on long-canes under glasshouse production, canes of Glen Moy and Glen Clova were tipped at two heights, 1.5m and 1.8m, on entering the glasshouse. Bud development (assessed on a scale of 1-6, with 1 being unbroken and 6 fully opened), fruit yield and berry weight were compared to untipped controls.

The use of tipping is often thought to have a beneficial effect on the reduction of apical dominance and evenness of bud break, but our studies showed that there was generally little effect on the uniformity of bud break along the cane. Results of tipping on bud-

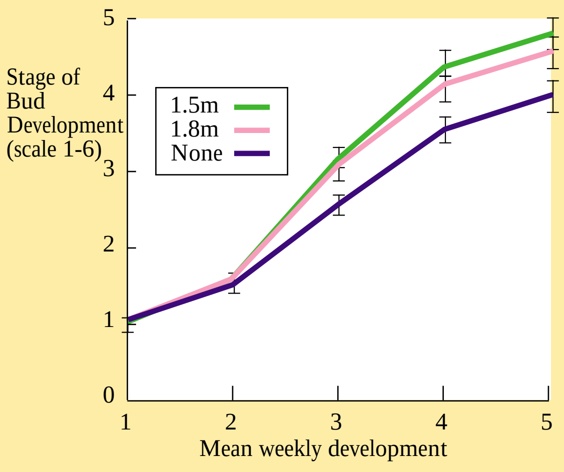

Figure 7 The effect of 'tipping' on the rate of bud development in Glen Moy.

break varied between varieties: there was an increase in the rate of bud development in Glen Moy (Fig. 7) together with larger fruit size. No comparable effects were observed in Glen Clova, with evenness of bud break assessed by the percentage of unbroken buds, similar in all three treatments (11.3%, 10.7% and 13.3 % for untipped, 1.5m and 1.8m respectively). Yields between the treatments were similar. The tipped canes with less buds per cane produced more fruit per lateral compared to the untipped canes in both cultivars.

One developing school of thought is that uniform bud break will occur in the cropping region of the cane if the cane has received adequate chilling. Uniformity of cane diameter and 'wood' maturity are thought to be important with regard to chilling requirement. If the cane is uniform in diameter, then the lower buds should require the same or only slightly more chilling than the upper buds. Taper at the base of the cane and woodiness of the lower stem may increase the chilling requirement of buds in the lower region of the cane.

Correct cold storage conditions are also vital for good bud break. If the cane is able to transpire during storage, the likelihood of bud dehydration is increased. Temperatures that reduce transpiration and respiration to a minimum are ideal. Infection of buds by fungal pathogens is also exacerbated if temperatures in the cold store are too high. Other workers have successfully stored canes at temperatures as low as -2°C, primarily to control infection by *Botrytis*[13]. Work at SCRI is currently in progress to examine these hypotheses and the interaction between cane maturity, chilling requirement and storage at sub-zero temperatures.

Future The ability to extend the fresh fruit season in the UK will confer benefits in terms of diversification, reduction of the considerable imports of fresh and processed fruit, and increase availability to consumers.

Through a greater understanding of the physiological processes involved, and quantification of the ideal conditions for long-cane production, maximum fruiting potential from this system can be achieved. At present, cultivars that were originally bred for field production are being used for out-of season production under protected cropping systems. Material from the extensive germplasm collection at SCRI is being trialled in the long-cane project to quantify the differing responses of cultivars to the long-cane system. New cultivars with useful traits that have been identified through the long-cane project, e.g. low chilling requirement, can then be selected specifically for protected cropping in the UK.

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