Blackheart - an emerging problem for the GB potato packing industry

Literature Review

R456

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Published December 2015

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Executive Summary

- Since the late 1960s there has been a paucity of research centred on establishing the causal factor(s) of blackheart disorder in potatoes.
- Even though gaseous exchange is believed to be critical in defining blackheart susceptibility, there has been no work in the last 40 years which has investigated how gaseous permeability of potato tissue changes during storage and whether and to what extent it might be related to blackheart
- No modern research has been carried out on the relationship between respiration rate, gas exchange and incidence of blackheart
- No publically available research has been conducted on elucidating the role of packaging in determining the incidence and severity of blackheart disorder
- Despite evidence to suggest that some individual phenolics are associated with blackheart there is, as yet, no reliable and predictive genetic or biochemical biomarker(s) for the disorder.

Introduction

It is believed that losses during potato storage in the UK are around 3 – 5%, the main causes of which are detailed in Figure 1 (Terry *et al*., 2011). Blackheart has been identified as a significant cause of waste in the GB potato industry; however, its impact is probably under-estimated since it tends to only manifest itself during shelf-life and home-life. There is no reliable data on the incidence of blackheart in the GB potato industry, yet there is consensus amongst industry leaders that the disorder is a growing problem and one that should and is being addressed (in this R456 project) in order to safeguard against possible product displacement by imports.

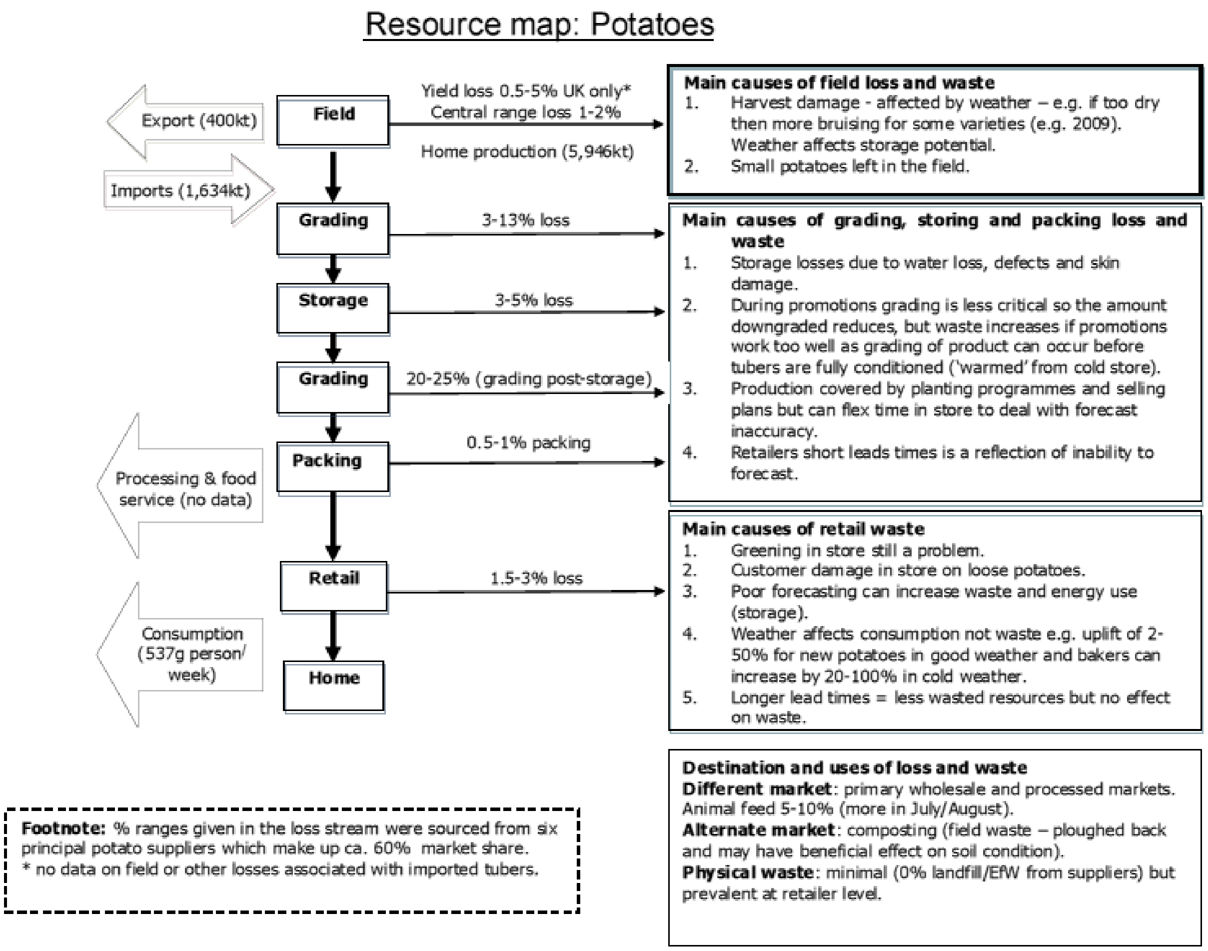

Figure 1. Resource map of UK potato yield losses (Terry *et al*., 2011 – more information available on http://www.wrap.org.uk/retail_supply_chain/research_tools/research/report_resource.html).

The disorder

Blackheart is a common physiological disorder resulting in necrosis and sometimes cavitation (associated hollow heart) of central tissues (pith) of potatoes (Figure 2). Tubers with the disorder show no external symptoms (Stewart and Mix, 1917). No plant pathogens or agents have been isolated or associated with blackheart (Bartholomew, 1916; Davis, 1928). The disorder is sometimes and mistakenly referred to as incipient hollow heart, brown centre, brown heart or sugar heart (Bussan, 2007), and this diversity in nomenclature has led to some confusion over identifying any underlying causal factors which may promote the specific disorder (Wolcott and Ellis, 1956; Wolcott and Ellis, 1959; Reeve, 1968; Sowokinos, 2007). Blackheart and other physiological internal necrosis may therefore overlap (Reeve, 1968).

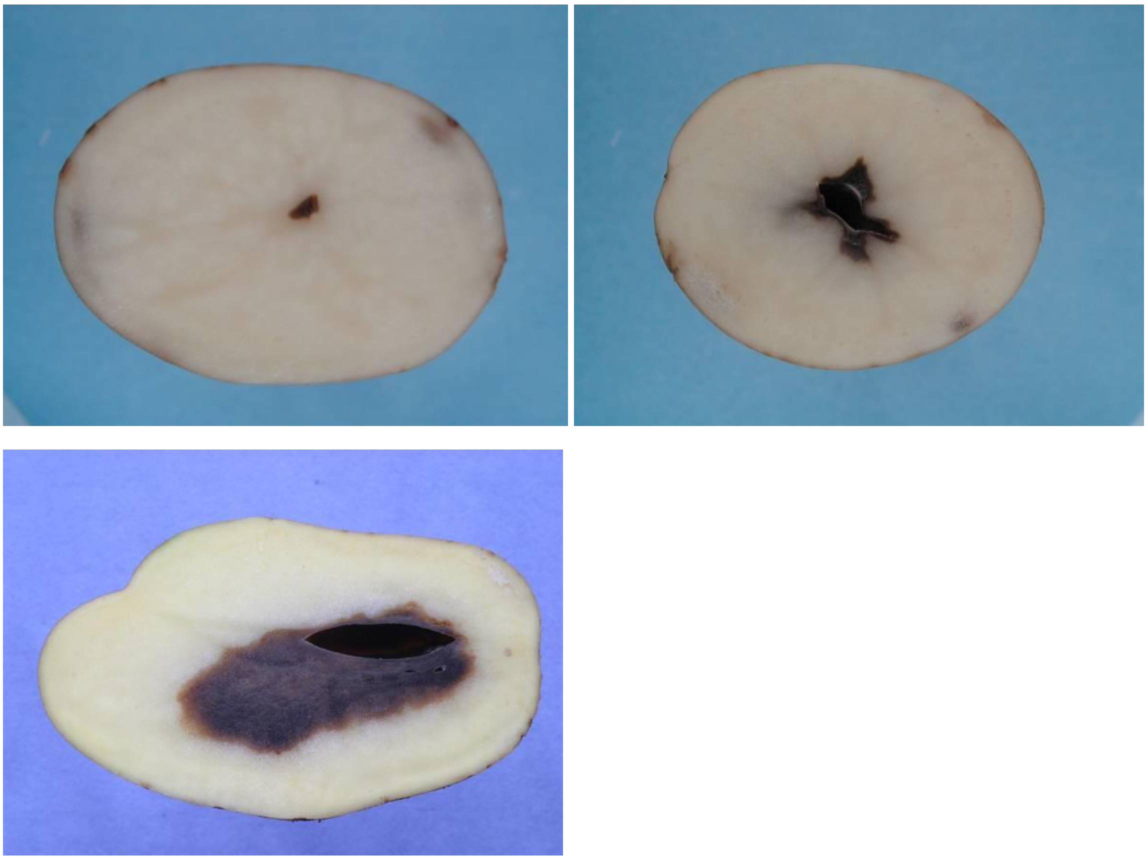

Figure 2. Tubers with symptoms of blackheart, showing discolouration and cavitation in central tissues (source A. Briddon)

Although the onset of the disorder is poorly understood, it is has been associated with oxygen depletion and/or carbon dioxide accumulation within the tuber (Davis, 1928; Olsen *et al*., 2003; Bussan, 2007). Blackheart does not tend to occur in crops from the field and is therefore a particular problem for the GB potato industry where a large proportion of the crop is marketed from store. Symptoms may also be absent in crops throughout storage and only become apparent after washing, conditioning and packing, and thus only during the subsequent shelf-life and home-life period. Blackheart is a particular problem for the fresh potato industry because quality control (QC) procedures cannot adequately check for the defect. That is, they cannot adequately predict which consignment will be at risk. This failure is undermining consumer confidence. It is believed that blackheart does not cause any nutritional losses to potato tubers (Bussan, 2007), but it is estimated to account for 25-30% of consumer complaints (David Walker, Chairman FPSA, personal communication) due to it being aesthetically unappealing.

The Fresh Potato Suppliers Association (FPSA) members have associated blackheart with soil type (silts), water logging, cultivar (Maris Piper, Marfona, Estima and Vale Sovereign being considered especially susceptible), large tuber size and the use of some plastic packaging films. Other factors have been highlighted as being potentially linked to blackheart and other internal browning disorders- these include tuber maturity, drought stress, high temperatures (Larson and Albert, 1945; Walcott and Ellis, 1959), but none of these causal factors reliably affect blackheart incidence.

There is still no true consensus on the causal factors which makes one particular tuber consignment more or less susceptible than another. Although seasonal variations are observed, the incidence of blackheart is reported to have increased in the last five years (David Walker, Chairman FPSA, personal communication). It is believed that the increased efficacy in logging consumer complaints does not fully account for this apparent increase, such that a change or combination of changes has occurred in the last five years that may be responsible for increased incidence of the disorder. Some candidates persist, for example, the increased usage of plastic packaging. Yet, it is likely that a combination of factors is responsible.

To reiterate, blackheart is a particular problem for the fresh, packaged potato industry. Because typically only central tissues become necrotic and tubers appear otherwise healthy, crops may pass QC checks and be marketed with defects only become apparent to the consumer after preparation during cooking (e.g. baked potatoes). Customer complaints from blackheart have increased in recent years. FPSA estimate that currently there are approximately 2,500 consumer complaints annually (D. Walker, personal communication) and it is likely that this level of dissatisfaction is much higher, but not reported. Customer complaints can start in January and peak in May, June and July. Some supermarkets have indicated that crops of critical cultivars (i.e. Maris Piper) will be sourced from abroad if the incidence of blackheart cannot be substantially reduced.

Biochemical basis of blackheart

Blackheart manifests itself as a darkening of central tissues in the tuber (Figure 2). However, the colour change can be progressive from light reddish or brown with areas mainly confined to the central pith. Indeed, these smaller areas are not always evident immediately after cutting (Reeve, 1968). The brown to black coloration indicates a phenolic-based reaction. Phenolics are any compound which contain an aromatic carbon ring and associated hydroxyl group and thus include phenolics acids and flavonols within the phenylpropanoid pathway.

Reeve (1968) first demonstrated that cells surrounding affected tissue could be highly stained with Sudan IV in histological studies, indicating the presence of suberin and other phenolics. In addition, histochemical tests for both chlorogenic acid and tyrosine showed more intensive positive colour reaction in blackheart affected tissue than did normal healthy parenchyma tissue from the central region in unaffected tubers. Chlorogenic acid was first implicated by Dinkel (1963) to be associated with blackheart. Unfortunately, there is no information which is publically available which has attempted to show there to be a correlation between other phenolics found in potato (*viz*. caffeic acid, p-coumaric acid, ferulic acid and trans-cinnamic acid; Yao *et al*., 1995; Mattila and Hellstrom, 2007; Im *et al*., 2008; Andre *et al*., 2009) and blackheart (Figure 3).

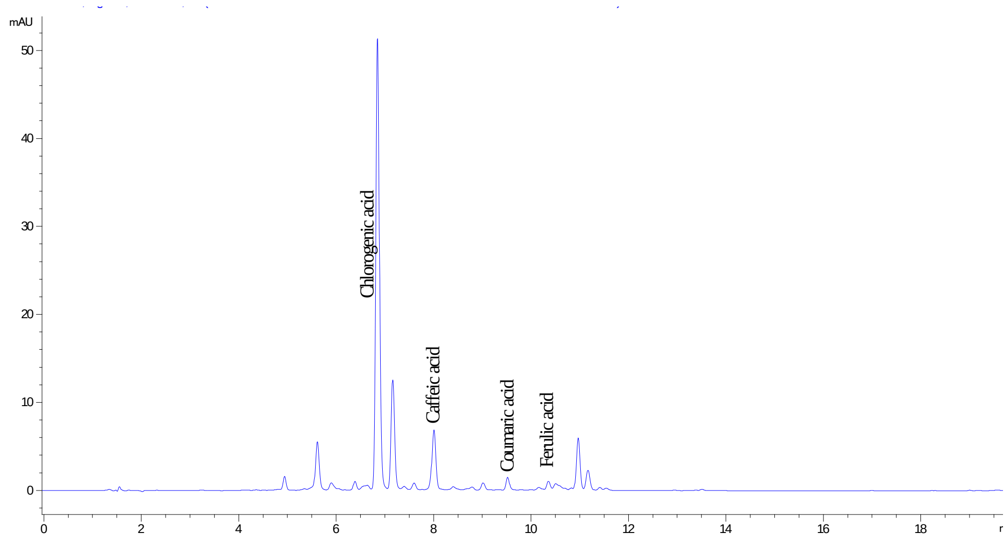

Figure 3. Example of HPLC chromatogram showing specific phenolics in potato at 340 nm (N.B. unknown peaks)

It is not clear whether chlorogenic acid, other phenolics (known and unknown) and/or tryptophan are indicators of blackheart or are produced as a result of blackheart. It is though that tryptophan may affect phenolics accumulation (Yao *et al*., 1995), but whether this is significant is unclear. That is, it is still not known whether tryptophan or phenolics are the cause or effect of the disorder. It is possible that phenylalanine ammonia lyase (the gateway enzyme to the phenylpropanoid pathway) may be upregulated following gaseous induced stress. Even though chlorogenic acid is the dominant phenolic found in potato this does not translate into it having a mechanistic role in blackheart. It is likely that other compounds (e.g. plant growth regulators) are involved, since these are up or down regulated according to storage stress and physiological age (storage life).

Blackheart tends to only manifest itself at certain times of the year, especially after longer term storage and conditioning, and can be exacerbated by inappropriate packaging. Thus, distinct chemical changes must be taking place during postharvest life, which make some tubers more susceptible to the disorder. Given that blackheart tends to only manifest itself from January onwards, it is probably that the transition from endodormancy (true dormancy) to ecodormancy (sprout suppression phase) may be significant, and this might point to a role for plant growth regulators and their metabolites as these are known to flux during storage. Targeted and non-targeted metabolomics will provide an insight and ultimately a greater mechanistic understanding of blackheart and may allow for presymptomatic risk assessment by establishing predictive biomarkers. To date, no detailed metabolomics have been conducted and it is unknown what role, if any, the temporal flux in hormones may be having on defining the disorder.

Gaseous diffusion and role of packaging

It has long been recognised that insufficient gas exchange between tubers and the external atmosphere is associated with blackheart. Gas exchange is caused by differences in gas composition between the applied external atmosphere and the internal atmosphere due to O_2 consumption and CO_2 production during respiration. The latter phenomenon is caused by overall gradients which may develop due to the large difference in CO_2 and O_2 diffusivity during, for example, inappropriate modified atmosphere packaging (MAP). In contrast to other crops which suffer from internal storage disorders (e.g. core breakdown in controlled atmosphere stored conference pears, Ho *et al*., 2006) no modern research has been conducted on understanding gaseous diffusion in potato tissue.

It has been proposed that where gaseous exchange cannot keep pace with increased respiration rate (e.g. during conditioning) then blackheart incidence will increase (Davis, 1928). High respiration is associated with high temperature. Bartholomew (1916) believed that high temperatures resulted in an accumulation of carbon dioxide (CO_2) and a lack of oxygen (O_2) in the central tissues. He believed that higher temperatures would act upon the enzyme tyrosine, and that greater enzyme activity would produce black melanic substances. He showed that he could induce the disorder by holding tubers between 38-44^{o}C for 15-24 hours. However, high temperature is not a necessary precondition for blackheart to occur. Indeed, Stewart and Mix (1917) where able to induce blackheart by storing tubers in hermetically sealed jars for about 20 days at 12-15^{o}C. Later, Davis (1926) showed that blackheart could be induced by holding tubers at 45^{o}C in a carbon dioxide free atmosphere with abundant oxygen available. He showed that during the time preceding the appearance of the disorder, the internal level of CO_2 rose to 50% whilst O_2 was reduced to 4%. What can be noted is that the work by Bartholomew, Stewart and Mix, and Davis is nearly 100 years old. This does not mean it is any less valid, but was conducted on older varieties grown predominantly in the USA, and clearly did not benefit from the recent advances in genomics and metabolomics. It was only with the pioneering work of Kidd (1919) and Barker (1936) and then subsequently by Burton and colleagues between 1950 and 1970 (Burton, 1958; 1962) that research focussed once more on elucidating the effects of gaseous composition on tuber physiology. However, in the main, this more recent work was centred on extending storage life (i.e. sprout suppression) without increasing sugar accumulation in processing varieties. For instance, Khanbari and Thompson (1994) ‘cured’ potato tubers cv. Record for three weeks at 10°C before being transferred to ‘controlled atmosphere’ storage at 4°C for six months. Concentrations of 0.7 – 1.8% CO_2 in combination with low O_2 (2.1 – 3.9%) gave the best results with light crisp colour, low sprout growth and few rotted tubers compared with 0.9% CO_2 and 21% O_2. Burton (1959) found that increasing CO_2 concentration was negatively correlated with sprout growth where levels as high as 20% CO_2 completely eliminated sprout growth after 4 months at 10°C. This was confirmed many years later by Khanbari and Thompson, (1994) who found higher CO_2 resulted in better sprout inhibition, however fry colour became darker. Only, Lipton (1967) has provided evidence on the effects of gaseous composition on blackheart. He showed that cv. White Rose tubers developed blackheart if they were held at 1 and 1.5% O_2. No more information was available on defining gaseous compositions which encourage blackheart.

Early work by Burton (1965) investigated the amount of dissolved gases in the cell sap of tubers and found that the optimum CO_2 concentration for growth to be 2-4 % or 0.04-0.05 ml CO_2 ml^{-1} sap whereas inhibition of growth was achieved at much higher CO_2 concentrations. The author also found that low O_2 stimulated growth especially around 5% which equates to 0.0006 ml O_2 ml^{-1} sap. It was concluded that since temperature affects the solubility of gases, increasing the storage temperature above 10°C in an air atmosphere would increase the amount of dissolved gases in the cell sap and the resulting sprout growth may be no more than would be expected as a result of the increased CO_2 in solution. Even though this work was not done in the context of blackheart, it remains the only piece of work that has systematically detailed gas exchange in potatoes.

Despite indications that packaging may influence the incidence and severity of blackheart, there is no literature in the public domain which has evaluated the effect and mechanisms involved. Only one piece of work has researched the effect of packaging on tuber composition (Gosselin and Mondy, 1989) and this was not focussed on blackheart. However, they did report that cvs. Russet Burbank and Chieftain packaged in polyethylene and held at 20ºC were lowest in weight loss, ascorbic acid and nitrate-nitrogen but highest in discoloration, phenols and glycoalkaloids than those packaged in mesh or paper. Potatoes packaged in paper were lowest in discoloration and phenols and highest in ascorbic acid. Anecdotally, it is believed that loose tubers suffer less risk of blackheart than tubers packaged in MAP. Ironically, it may be that inappropriate MAP may inhibit sprouting but encourage blackheart.

Conclusion

It is clear that there is a complete dearth of research which has investigated blackheart in potato; much of the literature is between 40 and 90 years old. Although some of the information is still relevant there is still no true understanding of the causal factors that govern blackheart susceptibility. More importantly, there is no understanding of the physiological, biochemical and indeed genetic mechanisms underlying resistance/susceptibility. Identification of predictive biomarkers of blackheart and elucidation of the role and effect that respiration and gaseous exchange have will ultimately enable storage practitioners and packers to reduce incidence and severity. If the mechanisms behind blackheart can be better understood, then specific consignments which are believed to be at risk (e.g. by higher levels of predictive presymptomatic biomarkers) may be released in advance of blackheart becoming a problem later in storage.

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