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Research Review

Control Measures for Potato Skin Spot (Owen & Wakef.) Ellis Synonym: *Oospora* pustulans (Owen & Wakef.)

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Preface

This review was commissioned by the British Potato Council to improve our understanding of the biology of skin spot in order that control measures can be effectively and practically integrated.

The Main objectives were to:

- Comprehensively review refereed and conference publications and internet sources on skin spot,
- Contact research groups around the world to identify research in progress (if any) that would contribute to understanding of control of skin spot,
- Objectively assess the information available and interpret for the GB situation,
- Provide a summary literature review and bibliography for reference by agronomists,
- Write a best practice guidelines leaflet for growers.

The review considers published and grey literature and makes recommendations for control under the following headings:

- Skin Spot Control at Planting
  - Variety selection
  - Healthy seed
  - Fungicide treatment of seed tubers
  - Control by field selection
  - Control in the growing crop

- Control at Harvest
  - Timing of harvest
  - Post-harvest fungicide treatment
  - Harvesting methods

- Control During Storage
  - Control during the initial stages of storage
  - Sprout suppression
  - Heat treatment
  - Holding temperature
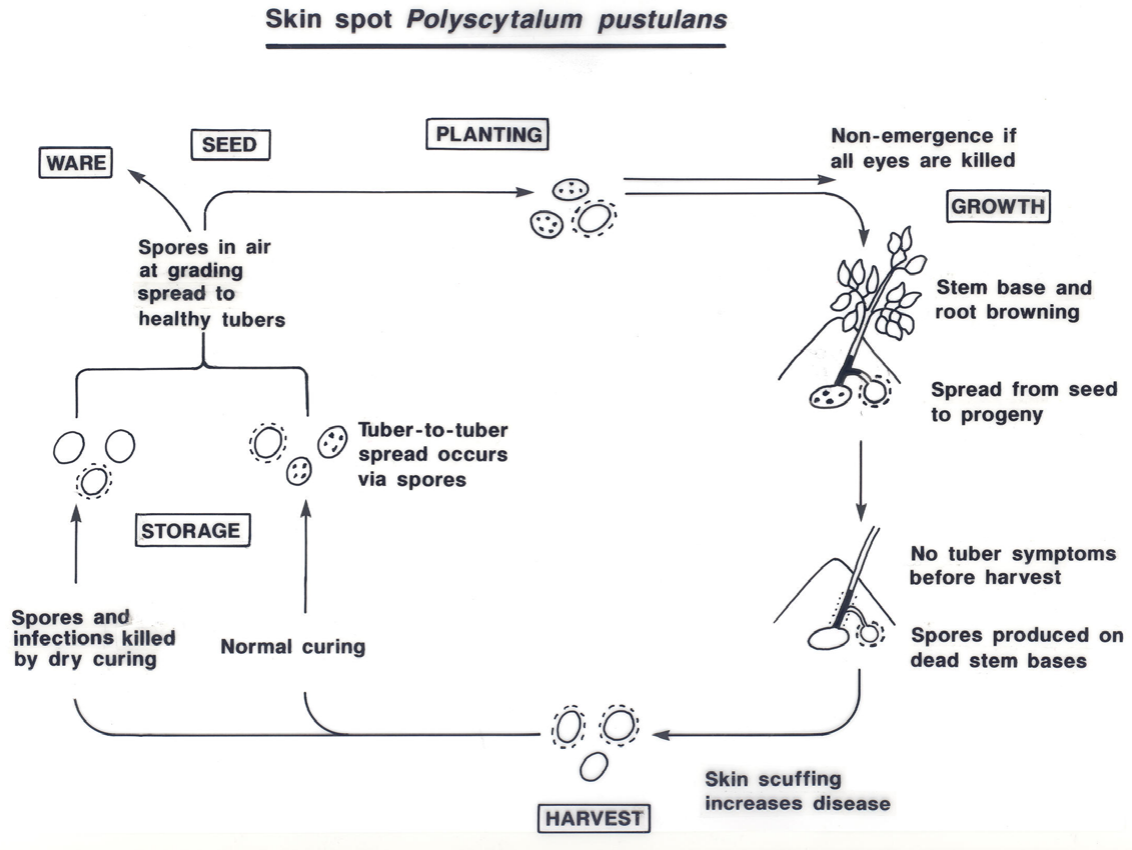 - Store maintenance and hygiene

Background

Skin spot is a disease of Solanaceae but is a major disease of the potato (*Solanum tuberosum*). It is restricted to cool temperate countries of northern Europe and states of the former USSR but has also been recorded in North America, South Africa, Australia and New Zealand. Whilst the disease has a wide distribution, it has only been intensively studied in the UK as demonstrated by the bibliography. In the UK, the disease is only of major concern in susceptible varieties such as Cara, King Edward, Lady Balfour, Lady Christl and Pentland Squire.

Skin spot is primarily seed borne (Franc, 2001). However, inoculum can survive in soil as sclerotia that can persist for 7 years or more (Carnegie & Cameron, 1990; Hide & Ibrahim, 1994). *Polyscytalum pustulans* inoculum (conidia or sclerotia) infects stem bases, roots and stolons of potato plants, often causing brown lesions (Hirst & Salt, 1959; Franc, 2001). The disease, skin spot, is expressed on tubers following a storage period of at least 6 weeks (Allen, 1957). A survey of potato diseases in England and Wales (Bradshaw et al., 2000) showed that, at harvest, 0.2% of tubers developed symptoms of the disease. However, after a (non-specified) storage period, the level of skin spot had risen to 3.2% of tubers affected. During the survey period, 9.1% of seed tubers had symptoms of skin spot. Allen & Scott (2001) argue that the disease has been on the decline over the past 20 years. This is mainly attributed to the use of micro-propagated seed and drying prior to storage. However, the introduction of 2-aminobutane as a fungicide in high grade seed production has also had a major effect. Despite being present at low mean frequency within GB potato crops, the disease can develop rapidly and have a large economic cost on those stocks that have been badly affected by reducing or delaying emergence and thereby affecting yield and tuber size distribution or by reducing the quality and thus marketability of ware tubers.

Life Cycle

Skin spot life cycle (reproduced courtesy of the British Potato Council Crop Protection Group – formerly the British Crop Protection Council Potato Treater Group)

Skin spot *Polyscytalum pustulans*

WARE   SEED   PLANTING   Non-emergence if all eyes are killed

GROWTH

Spores in air at grading spread to healthy tubers

Stem base and root browning

Spread from seed to progeny

Tuber-to-tuber spread occurs via spores

STORAGE

No tuber symptoms before harvest

Spores and infections killed by dry curing

Normal curing

Spores produced on dead stem bases

HARVEST

Skin scuffing increases disease

Skin Spot Control at Planting

Variety selection

Potato varieties differ appreciably in their susceptibility to skin spot (Anon., 2004a – Appendix 1). However, assessment of varietal susceptibility by research workers has sometimes produced inconsistent results depending on the method used. For example, Nagdy and Boyd (1965) inoculated tubers with skin spot after lifting and incubated them before planting, whereas Bannon (1975a) inoculated tubers the day before planting. Differing results were obtained for varieties which tend to produce tubers on very short or very long stolons. Bannon (1975a) found varieties Up-to-Date and King Edward to be relatively less susceptible to skin spot than Nagdy and Boyd (1965) and suggested that the relatively long stolons, together with relative resistance to stem base infection of these varieties reduced spread to progeny tubers. The variety Record, which produces tubers on short stolons and appears susceptible to stem base infection, was rated more susceptible by Bannon (1975a) than other varieties by Nagdy and Boyd (1965). Carnegie and Cameron (1983) found greater differences between the two methods than earlier workers: but attributed them to similar causes.

- UK varieties differ widely in their susceptibility to skin spot
- Ranking of susceptibility appears to differ depending on the method of testing used
- Tuber susceptibility may be linked with susceptibility to stem base infection and shortness of stolons

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Healthy Seed

Factors affecting the relationships between disease incidences on planted and harvested progeny tubers appear complex. Adams and Hide (1980) working with crops on a single site and in a single season, demonstrated a positive correlation between amounts of skin spot inoculum on harvested tubers and disease incidence on seed tubers. Therefore, they concluded that, in these circumstances, seed tubers were an important inoculum source. However, when studying crops on different farms and in different years the same authors (Hide & Adams, 1980) seldom found a relationship between seed tuber infection and infection of progeny tubers at harvest. This leads to the conclusion that seasonal influences and soil conditions have greater affects on infection of progeny than the amount of disease on seed. Carnegie and Cameron (1991) found that, although skin spot incidence tended to increase in commercial stocks on some farms, on others it did not. Previously, Hirst and Hide (1967) had shown that potato plants free of skin spot can be produced by rooting stem cuttings using mist propagation. Carnegie and Cameron (1991) found that infection of stocks produced from stem cuttings (i.e. healthy stocks) was more consistent than infection of commercial stocks and suggested soil and environment factors affect transmission of skin spot inoculum from infected seed to daughter tubers and infection of healthy stocks in different ways.

Maintaining the healthy status of seed tubers produced by stem cuttings or micropropagation (Jefferies, 1986) when stocks become large and are treated commercially has proven difficult. Hide and Hirst (1972) and Hide (1978) reported that stocks untreated with fungicides became severely infected with skin spot but that tubers generally remained healthy when treated with organo-mercury or benzimidazole fungicides. Alternative methods of producing healthy stocks such as

minitubers (Coombes, 1992) or aerial tubers (Percival *et al.,* 1999) may improve the chances of maintaining healthy stocks.

> - The relationship between seed inoculum and disease on progeny tubers is complex
> - Seasonal influences and soil conditions can have a greater impact on progeny infection than the level of inoculum on seed
> - As seed stocks increase in quantity maintaining freedom from skin spot becomes increasingly difficult

Fungicide treatment of seed tubers

Fungicide treatment of infected seed tubers prevents skin spot lesions sporulating, thereby preventing escape of inoculum into the soil and sometimes allowing the production of healthy crops from diseased seed (Hide, 1992). Many writers have demonstrated the effectiveness of different fungicides in decreasing skin spot when applied before sprouting or planting. These include thiabendazole (Hide *et al.,* 1980; Carnegie & Cameron, 1987; Oxley *et al.,* 1990), imazalil (Hall & Hide, 1992; Hide *et al.,* 1994a; James & Higginbotham, 1994), a mixture of imazalil and thiabendazole (Hide *et al.,* 1994b; Ogilvy. 1992; Oxley *et al.,* 1990), iprodione and imazalil (Oxley *et al.,* 1990), fenpiclonil (Leadbeater & Kirk, 1992) and prochloraz (Hide & Read, 1991; Drummond *et al.,* 1990). Carnegie and Cameron (1987) demonstrated that Tego 51B (an amphoteric surface active biocide) had some effect, but sodium hypochlorite was less effective. They suggested the efficacy of these treatments demonstrated that skin spot infection was superficial on tubers. Carnegie *et al.* (1990) found that 2-aminobutane and a mixture of 2-aminobutane and thiabendazole gave more effective control of skin spot than thiabendazole alone, although application late in storage had reduced efficacy.

However, fungicide treatments, have limitations. Carnegie and Cameron (1991) showed that although fungicide treatments reduce contamination of progeny tubers by *P. pustulans*, they do not eliminate it. Isolates of skin spot resistant to thiabendazole were found on all classes of seed potato in Scotland by Carnegie and Cameron (1992). When stocks infected with thiabendazole sensitive isolates of skin spot were treated annually with thiabendazole for 4 years the proportion of isolates resistant to thiabendazole increased, but at different rates on the three farms tested (Carnegie *et al.,* 1994). Thiabendazole resistant isolates were found on stocks never treated with thiabendazole. Using a mixture of thiabendazole and imazalil gave lower incidence of thiabendazole resistant isolates, but did not eliminate them.

Whilst there are no published reports on the use of dithiocarbamates for the control of skin spot, an uncompleted project funded by the Potato Marketing Board in 1990-1992 evaluated a range of seed treatments including a mixture of maneb plus zinc oxide for the control of tuber diseases. Two trials in England in each of two years demonstrated reductions of 67, 77, 96 and 99% in stems exhibiting skin spot lesions over untreated controls. The reductions were equivalent to that achieved by a mixture of thiabendazole and imazalil at one site and substantially better than the mixture at the second site.

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- A variety of tuber treatments have proved effective in reducing seed-borne inoculum
- These include thiabendazole, imazalil, imazalil + thiabendazole, imazalil + iprodione, fenpiclonil prochloraz and thiabendazole + 2-aminobutane.
- Resistance to some fungicides has been detected
- The use of dithiocarbamates for control of skin spot requires investigation

Control by Field Selection

Soils where potatoes are grown on a wide rotation are unlikely to contain significant amounts of skin spot inoculum: "The best commercial seed stocks now carry much more potential inoculum of the pathogens that cause such diseases as skin spot …. than are ever likely to be encountered in the soils of fields where potatoes are grown only once in 4 to 7 years" (Hide *et al.,* 1969). Hide and Read (1991) found previous cropping did not affect stem base infection by *P. pustulans* or skin spot symptoms on stored tubers. Carnegie and Cameron (1990) showed that the pathogen can survive in soil for longer than the statutory minimum interval of 5 – 7 years between seed potato crops. However, the degree of contamination is such that skin spot symptoms are unlikely to result in a first year crop but could occur in subsequent generations if environmental conditions were conducive.

The physical characteristics of soil will affect the spread of *P. pustulans* from seed tuber to daughter tuber. Bannon (1975b) investigated whether tuber infection was related to position of tubers in the ridge relative to parent tubers and stems. He suggested the pathogen spreads progressively outwards from infected parent tubers and first symptoms are seen on stems where they are attached to the parent tubers. Tubers formed beside the parent tuber or in close proximity to infected stems become infected early in the season. By September/October most tubers are infected and at the end of the season, very few are free of infection. Skin spot tends to be worse in moist heavier soils than lighter ones (McGee *et al*., 1972; Hide & Adams, 1980). Brenchley and Wilcox (1979) claim light or freely drained soils reduce skin spot transmission to the minimum but on heavy or clay loam soils even lightly infected seed will give crops severely damaged by skin spot.

- A rotation of at least 5 years reduces the significance of soil contamination by *P. pustulans* but survival occurs at low levels even with a 7 year rotation.
- Varieties forming daughter tubers close to the mother tuber are more at risk from skin spot
- Skin spot is worse in moist heavier soils than light or freely drained soils

Control in the Growing Crop

Irrigation increases the severity of skin spot (Hide 1987). There was no attempt to determine the reason for the effect of irrigation on disease. However, the author suggested that irrigation encouraged early senescence. This might have influenced disease development but the direct link between senescence and skin spot development has never been tested. Dashwood *et al* (1993) examined the fungal communities of potato roots in the field. They found relatively little infection of roots by *P. pustulans,* the disease being mainly tuber borne, but found evidence of negative associations with some other soil fungi including *Trichoderma viride, Penicillium sp., Chrysosporium pannorum, Aureobasidium pullulans* and *Phoma leveillei.*

- Irrigation increases the risk of skin spot

Control at Harvest

Timing of harvest

Skin spot tends to increase with later harvest (Adams & Hide, 1980; Hide *et al.,* 1969; Hide & Cayley, 1987). Hide *et al* (1994a) demonstrated that early lifting reduced skin spot in 1988 but not 1987. Boyd (1981) recommended early haulm destruction and early harvest for reduction of skin spot, but cautioned this may decrease yield. The effect of lifting time on skin spot may result not from the biological maturity of the crop but simply the warmer, drier conditions usually associated with early lifting. Lennard (1967) found that dry conditions after lifting and a temperature of at least $10^{o}C$ gave good control of skin spot at late lifting dates, although eye infection still tended to increase as lifting was delayed. Transfer of tubers from conditions of high humidity and low temperature to dry conditions and $10^{o}C$ in November still gave some control of skin spot, but transfer in January had no effect; presumably, because infection was too advanced.

- Skin spot tends to be less with early harvesting
- This is related to the generally warmer and drier conditions with early harvests

Post-harvest fungicide treatment

Thiabendazole and 2-aminobutane treatments after harvest have been widely reported to reduce skin spot (Boyd, 1981; Cayley *et al.,* 1979; Graham *et al.,* 1981; Hide & Bell, 1980). Older literature also refers to the effects of organo-mercury products, particularly Agallol, in reducing skin spot (Boyd, 1981; Hide *et al.,* 1969). Other treatments where beneficial effects after harvest have been reported include chlorinated phenols (Aardisol and Aretanol) (Hide *et al.* 1969), imazalil (Cayley *et al.* 1983), imazalil + thiabendazole (Ogilvy 1992) and propargyl bromide, chloropicrin (phytotoxic, operator hazard), gaseous ammonia and dibromotetrachloroethane (difficult to use) (Graham *et al.* 1981)

Fungicides applied to tubers immediately or shortly after harvest have a fungicidal or fungistatic effect on inoculum and recent infections and prevent infection developing during storage (Carnegie

et al., 1986; Hide, 1992). Delaying treatment until skin spot has penetrated the tuber may compromise control (Hide, 1986). Manufacturer's labels for fungicides applied by spraying tubers recommend application within 48 and preferably 24 hours of harvest. Efficient application to completely cover the tuber surface is also vitally important (Hide, 1992) although target residue levels are rarely achieved by spray application (e.g. see Carnegie *et al.*, 1994b; Carnegie *et al.*, 1998). 2-aminobutane is applied only after wound healing to avoid damage to wounds. Consequently, fumigation is normally carried out 10 days to 1 month after harvest.

Comparatively, the use of 2-aminobutane during storage gave the greatest reduction (83%) of skin spot compared with thiabendazole (70% reduction) and a mixture of thiabendazole and imazalil (65% reduction) (Carnegie *et al.*, 1998). In earlier studies on three stocks, the ranking of control of skin spot by 2-aminobutane fumigation and a number of spray applied fungicides was thiabendazole/imazalil mixture (66 to 86% control), 2-aminobutane (66 to 79% control), imazalil (48 to 66% control), prochloras manganese complex plus tolclofos methyl (23 to 48% control) and fenpiclonil (18 to 43% control) (Carnegie *et al.*, 1994b). However, Carnegie *et al* (1994) found that the proportion of thiabendazole-resistant isolates of *P. pustulans* increased with the number of successive applications of thiabendazole. The effectiveness of thiabendazole in reducing disease levels varied. At two sites, there was 96 - 100% control. But, at another site, following 4-years of fungicide treatment, control declined from around 88% in year 1 to no control in year 4. The use of thiabendazole is no longer recommended on seed crops.

Hide *et al.* (1969) showed that although a range of materials applied after lifting including an organomercurial product (Agallol) and thiabendazole reduced infection of tubers by skin spot in store, only thiabendazole and benomyl applied in spring reduced skin spot on harvested tubers. Disinfection of seed tubers was, therefore, considered inadequate leaving significant seed-borne infection to develop on the growing crop. Even systemic fungicides were only partially effective and resistance to some of these materials, notably thiabendazole, is now widespread.

Carnegie and Cameron (1991) believe that annual fungicide treatment of seed during multiplication can check the build-up of *P. pustulans* on high grade seed stocks provided they are correctly and timeously applied. They consider that fungicide residues do not indicate relative efficacy of treatments. The effect of a fungicide depends on the extent of latent infection, the amount of soil on the tuber and the interval between harvest and application.

- Post-harvest fungicide treatments can reduce skin spot development in store
- Spray applied fungicides must be applied within 48 hours of harvest to be effective and coverage must be as complete as possible.
- In comparative tests, fumigation using 2-aminobutane was more effective than spray applied fungicides
- Resistance has been widely detected to thiabendazole

Harvesting methods

Windrowing, where tubers are harvested in a two-stage process, was developed in the mid-eighties to increase the harvesting rate by allowing the harvester to work at full capacity (F. Milne, SAC, pers. comm.). In addition, mechanical damage to tubers might be reduced because the harvester can operate at lower speeds. Two-stage harvesting might also offer benefits for disease control because tubers have an opportunity to dry prior to going into store. Windrowing for two hours after lifting

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improved the control of skin spot where tubers were subsequently dry stored (Hide *et al.,* 1994b). However, these authors acknowledged that the effectiveness of windrowing as a method for drying potatoes prior to storage would be influenced by environmental conditions.

> • Provided conditions for drying tubers are present, the practice of windrowing may reduce skin spot

Control During Storage

Control during the initial stages of storage

During the early stages of storage, it is important to remove surface moisture from tubers, heal (or cure) wounds occurring during harvesting and to cool the crop to holding temperature (Pringle & Cunnington, 2001). Maintaining tubers in a dry, warm environment is required for wound healing. This ensures that an adequate barrier is formed preventing moisture loss and infection by wound pathogens such as *P. pustulans*. The length of time required for adequate curing is temperature dependent (Burton, 1989). Therefore, the rate of pull-down to the holding temperature has implications for the extent of curing the tuber can achieve and, thus, on disease development. The concept of 'dry curing', where air with relatively low RH (i.e. below 90%) is used to ventilate the crop, has been shown by various workers to be an effective method for reducing the development of skin blemish diseases including skin spot (Bjor, 1974; Hide & Adams, 1980; Hide *et al*., 1994a, 1994b; Mawson & Cunnington, 1995). Lennard (1967) showed that a temperature of 15°C alone was insufficient to control skin spot: the treatment is only effective if the atmosphere is dry. Hide and Boorer (1991) suggested that dry conditions kill conidia or superficial infections because few spots developed when tubers were later stored in cool and damp conditions that would encourage skin spot. Hide and Cayley (1987) inoculated tubers with *P. pustulans* and stored them at 5°C, 10°C or 15°C in dry or damp conditions for up to three weeks. Disease was progressively decreased on tubers untreated with fungicide by increasing the holding time and temperature in dry, but not damp, conditions. Curing at 15°C for 14 days in dry conditions reduced the proportion of prick wounds infected from 70% to 4%.

Skin spot development was reduced by storing the tubers under dry conditions for the two-week period immediately following harvest (Hide & Boorer, 1991). Hide and Boorer also found in the same study that disease decreased as the storage humidity decreased during the same two week period. Also, Mawson and Cunnington (1995) showed that the development of skin spot in a susceptible variety (Cara) was inversely proportional to the amount of accumulated day degrees above holding temperature. Expressed another way, an immediate pull-down of 0.5°C/day to the holding temperature resulted in significantly more skin spot than tubers that had been cured for 1- and 2-weeks at 12°C. Therefore, a combination of curing and ventilating with dry air offers the best option for control of ware crops that are susceptible to skin spot and are being stored for long periods.

> • Dry curing is an effective method to control skin spot

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Sprout suppression

The sprout suppressant, isopropyl-N-chlorophenol carbamate (chlorpropham or CIPC), increased the severity of skin spot when applied soon after inoculating tubers with *P. pustulans* conidia (Hide & Cayley 1987). However, the use of CIPC 10 weeks after inoculation had no effect on skin spot development. Therefore, these authors advise that CIPC application should be delayed for several weeks after store loading. Ives (1955) found that an abnormal form of skin spot was associated (either directly or indirectly) with the use of the sprout suppressant, isopropyl-N-phenol carbamate (propham or ICP). It was suggested that because IPC interferes with the formation of cork (or phellum) during wound healing, this allows the pathogen to penetrate deeper into tuber tissue. French (1976) reported that skin spot lesions were deeper in the presence of CIPC. French suggested that because existing lesions were influenced, the effect of enhancing skin spot development could be due to CIPC altering the pathogen's ability to penetrate the cork barrier.

> - Application of CIPC soon after harvest can increase the severity of skin spot
> - This is probably associated with a delay in wound healing caused by the chemical

Heat treatment

Hide (1975) demonstrated that infections of skin spot are killed by heat and that heat treated seed tubers produced crops with much less disease than untreated seed. Early treatment gave better disease control but the tuber eyes were often damaged. Treatment in water (45-50°C, 20-30 mins) was more effective than treatment in air (45°C 1-4 hours) but more likely to cause damage.

Dashwood *et al* (1991) reported tuber borne skin spot was virtually eliminated by hot water treatment at 55°C for 5 minutes.

> - Heat treatment has the potential to kill established skin spot lesions and spores but care is needed to avoid damage to the tuber eyes.

Holding temperature

Ware and seed crops are normally stored cool (typically 2.5 to 4.5°C), using circulating refrigerated air (Pringle & Cunnington, 2001). Storage at those low temperatures is necessary to minimise weight loss, sprouting and blemish diseases such as silver scurf and black dot. However, various studies have shown that skin spot development is greater at lower storage temperatures than at warmer temperatures (Hide & Adams, 1980; Hide, 1992; Mawson & Cunnington, 1994). For example, Hide and Adams (1980) demonstrated that skin spot was more prevalent on tubers stored at 3°C than 10°C. Also, Ogilvy (1992) showed that storage below 4°C gave greater development of skin spot than ambient storage at 5-8°C. In addition, Mawson & Cunnington (1994) found that on variety Cara, more skin spot developed at 3°C than at 5.5°C. Anecdotal evidence suggests that skin spot is more severe at store temperatures of 2°C than 4°C.

Hilton *et al* (2002) found that temperature was more important for the development of skin spot than tuber wetness in tubers that had been wounded and artificially inoculated with *P. pustulans* conidia. Whereby, more infection occurred on inoculated tubers at 5°C than at 10 or 15°C

irrespective of condensation duration. The authors conclude that if skin spot is to be controlled in a susceptible ware crop, adequate wound healing must be achieved prior to long-term cold storage.

- Low store temperatures (at or below 4°C) increase the development of skin spot compared to higher storage temperatures

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Store maintenance and hygiene

Most skin spot infection on plant stems and tubers originates from inoculum on seed tubers. However, re-infection of stem cutting derived tubers under conditions where fungicide seed treatments are not used (Hide & Hirst, 1972) suggests other sources of inoculum can be important. Hide and Stedman (1968) showed that tubers produced by stem cuttings became infected with skin spot when stored with a bulk of infected tubers. Moreover, skin spot spores were detected in air sampled from within the bulk.

Carnegie *et al.* (1978) found *P. pustulans* at many places within potato stores where dry soil had collected and spores remained air-borne for a considerable time after sweeping floors. Carnegie and Cameron (1987) demonstrated differences in contamination of seed tubers by skin spot between stores and that the differences related to air-borne contamination by *P. pustulans* recorded in the previous winter. Contamination of seed and progeny tubers was positively correlated and progeny tuber contamination was unaffected by use of 2-aminobutane fumigation at harvest – suggesting that 2-aminobutane on the tubers gave no protection against subsequent contamination.

Thus, store hygiene of potato stores is important to minimise the build up and spread of spores of *P. pustulans*. This includes, separating storage areas from areas where dust is disturbed, removing dirt and debris from where it gathers by vacuuming, minimising dust disturbance by regularly vacuuming areas where fork lift traffic occurs and cleaning grading lines regularly (Clayton *et al.*, 2001)

- Dust and debris can harbour spores of *P. pustulans*
- Store hygiene procedures can minimise the spread of spores to healthy tubers

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An Integrated Approach

The use of resistant varieties offers growers the "cheapest and most convenient" method of disease control (Hide, 1992). However, the author acknowledges that growers are rarely able to choose varieties solely on the basis of resistance to a particular disease. Therefore, for a control strategy to be generally useful, disease management should be effective when growing susceptible varieties. Hide *et al* (1994b) demonstrated that good control of skin spot in a susceptible variety, King Edward, could be achieved when seed tubers were treated with fungicide (an imazalil/thiabendazole mixture) and progeny tubers dry cured for two weeks. Control was better the earlier tubers were harvested.

Overview

The mechanisms by which *P. pustulans* infects and develops in potato crops appear well understood. The importance of seed-borne inoculum in the endurance of skin spot makes this an obvious target for control. However, the difficulty in completely eliminating infection in a seed stock by grading, or even preventing the contamination of uninfected tubers in a commercial situation, together with the potential for a rapid increase in inoculum in the field and, in consequence, contamination of daughter tubers means that complete control can rarely be achieved. Currently, control will rely on a combination of high health status stock, seed tuber fungicide treatment, agronomic and storage controls to contain skin spot at a low level. However, we still do not have a full understanding of how these practices can be integrated to provide the most effective skin spot control.

The most effective fungicide treatment for skin spot control, 2-aminobutane, has approved essential use until 31 December 2007 (Anon., 2004b). Approval for the continued use of this product after this date may not be given. Therefore, finding and developing new, chemical-free methods of control should be a priority. There has been little work on novel ways of freeing seed tubers of skin spot inoculum. Limited investigations of hot water treatment have been conducted (Dashwood *et al.,* 1991), biological controls using mycoparasites or fungal antagonists have been suggested (Hide 1992) but no experimental work on these lines has been identified, although the studies of Dashwood *et al* (1993) may form a first step in this direction.

Summary of control measures
- Grow a resistant variety
- Employ wide rotations to minimise soil contamination
- Crops grown in lighter soils have less skin spot than those grown in moist heavy soils
- Plant healthy seed
- Use an effective fungicide seed tuber treatment and apply evenly over the tuber surface
- Harvest early
- Windrow under drying conditions
- Dry cure tubers into store
- Apply an effective fungicide seed tuber treatment at or immediately after harvest. Ensure a uniform coverage of the tuber surface
- Avoid use of CIPC soon after harvest
- Avoid reducing the holding temperature below 4°C where possible
- Maintain good store hygiene

Options for future research

1. Quantification of skin spot on tubers has relied on visual assessment of disease. There have been no attempts to quantify inoculum by serological or PCR methodology. Thus the potential development of skin spot from seed with different levels of inoculum under a standard set of conditions has not been determined adequately. This is important as it is suspected that very low levels of skin spot (i.e. levels hardly detected on a washed sample and certainly easily missed by an un-trained eye) may result in substantial development of disease under conditions highly conducive to the pathogen. The potential rate of disease development needs to be established and more sensitive methods for detection of the pathogen (in lesions or as contamination) established. This would be important if (very) early warning of skin spot risk is to be made during seed multiplication.

Recommendations:
- Develop a diagnostic test for skin spot on tubers and in soil to enable early and quantifiable disease detection.
- Carry out field and laboratory experiments to evaluate the potential development of skin spot. This will assist growers in understanding the minimum levels of disease that require detection in order to judge the need for seed tuber treatment.

2. Alternative fungicide options require to be explored especially if 2-aminobutane is withdrawn in 2007. Because of highly publicised claims against fungicide seed tuber treatments and the cost of claims relative to the income from seed tuber treatments, there is a general reluctance by agrochemical companies to introduce new products. The process of independent institutes obtaining off-label approvals for a new product provides one way that new seed tuber treatments can be developed. A range of potential fungicide seed tuber treatments require to be identified and evaluated. These should include synthetic fungicides and biocides. With the biocides, it is accepted that they usually have short persistence and are unlikely to penetrate established lesions but they may effectively kill spores on the tuber surface. Thus they may be effective against spores that have settled on the surface of seed tubers in store via air currents or contaminated dust. In addition to identifying alternative fungicide options, there is an urgent need to improve methods of application of tuber treatments. Spray application technology to tubers passing over a roller table has not proved particularly effective. By contrast, dipping seed in a fungicide solution guarantees effective coverage. However, there is a general reluctance by seed producers to dip tubers because of the increased risk of blackleg, the need to dry tubers after dipping and the practical considerations at the busy grading period. Nonetheless, drying using positive ventilation can be readily achieved and this should eliminate both the drying problems and the increased blackleg risk. The timing of dipping might also be changed to avoid the busiest period. Thus, alternative treatments methods should be evaluated on a small and commercial scale.

Recommendations:
- Evaluate dithiocarbamate fungicides for use as seed tuber treatments for the control of skin spot. In addition, evaluate new fungicide treatments being considered for release in the UK by agrochemical companies for their effectiveness against skin spot. These are primarily targeted at control of other tuber diseases (e.g. silver scurf, black dot, Rhizoctonia) and skin spot is not usually evaluated. Currently, there two potential products undergoing trials are known to the authors.
- Evaluate the use of biocides and their potential role in control of skin spot.
- Evaluate tuber dipping as a potential method to effectively treat seed tubers with fungicides and biocides.

3. The integration of control measures is important for effective control. Some of the control measures, such as dry curing, are generic in that they are appropriate for a range of fungal diseases. However, apart from the work of Hide *et al* (1994b) there has been little attempt to quantify the control achieved by integration of control measures.

Recommendation:

- Determine the relative importance of components of integrated control and the degree to which skin spot can be reduced by their integration.

4. Alternative control measures using heat treatment or biological control have been attempted on a limited scale. Whilst the development of these alternative approaches would form a useful topic of a research studentship, from historic experience it is unlikely that they would form a major practical control option in the short to medium term.

Recommendation:

- Consider funding a research studentship to investigate and evaluate novel measures for the control of skin spot.

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APPENDIX 1

Varieties listed in the Pocket guide to potato varieties 2004 (Anon. 2004a) and their resistance ratings to skin spot. 1 = susceptible, 9 = resistant. Most varieties do not have a resistance rating established.

Variety	Skin Spot
Agata	1
Asterix	4
Cabaret	5
Cara	4
Estima	6
Eve Balfour	5
Fianna	8
Isle of Jura	4
King Edward	3
Konsul	2
Lady Balfour	3
Lady Christl	2
Lady Felica	4
Lynx	5
Marfona	5
Maris Piper	4
Melody	5
Nadine	8
Pentland Squire	2
Romano	7
Sante	3
Saxon	6
Virgo	4
Wilja	4