Research Review

Physiologically aged potato tubers

(*chitting*)

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1. Abstract

This is a review detailing the current knowledge, practices and technologies employed in chitting or pre-sprouting of seed potato.

Chitting is a method of increasing the physiological age of seed tubers with many potential advantages including earlier emergence, better yield and marketable quality. Earlier emergence can shorten the time from planting to harvest, an advantage for late main crop varieties which might otherwise be harvested later in the year when conditions could be unfavourable. Another potential advantage is improved disease resistance as the rapid development and emergence of robust shoots will reduce the risk of disease. Despite these perceived advantages, chitting is now less commonly carried out than previously. The reasons are principally higher costs; increased labour requirements, increased infrastructure, logistic and organisational complexity compared to just-in-time delivery of seed for planting.

In this review the concept of physiological age of seed potatoes and the research to date on agronomic factors that can be influenced by chitting is discussed. Unfortunately, the available research is somewhat contradictory and incomplete and there are a number of knowledge and research gaps, particularly for current GB potato varieties.

The advent of LED lighting has introduced relatively cheap and flexible systems with the possibility of using different wavelengths of light at different stages of chitting to improve the physical and physiological robustness of sprouts. Studies on chitting to date have focused mainly on the yield generated from chitted tubers. However, the impact of chitting on the quality of tubers at harvest and their subsequent storage behaviour is under-reported. Therefore, there is a need for further study, on the storage potential of the tubers produced from chitted seed. A rapid and cheap diagnostic tool is required for assessing physiological age of tubers during seed tuber development and a degree-day model that adequately describes the growth and yield responses of seed to storage temperature would aid the industry. We describe currently available systems, with others in development, that considerably reduce the amount of manual labour because of their high modularity and the relative ease of mechanical handling.

Further research is required to enable a robust cost benefit analysis to provide growers with a reliable evidence-based information on the use of chitted seed. We also suggest collaborative grower trials as an approach to learning more, faster, on some of these research gaps.

2. Introduction

Seed tubers are used for potato production (van Loon, 2007) and consequently potato tuber yield is extremely dependent on the seed tuber quality (Caldiz, 2009). Potentially, seed tubers can be produced everywhere potatoes are cultivated, and even form part of the ware stored crop (although this leads to poorer quality seed). However, a good quality seed should be grown specifically for that purpose from certified initial seed, cultivated in land largely free from soil-borne diseases and special care taken to control potato diseases and pests during the growing season. Seed tubers are required to be inspected by a certification agency (van Loon, 2007) to ensure they meet strict phytosanitary requirements.

Chitting is a method of increasing the physiological age of seed tubers. This has the potential advantages of earlier emergence, higher early yield and also earlier senescence, bulking and skinset. Earlier emergence can shorten the time from planting to harvest, an advantage for very early crops and for late main crop varieties which might otherwise be harvested later in the year when conditions could be unfavourable. Another potential advantage is improved disease resistance as the rapid development and emergence of robust shoots will reduce the risk of disease, for example that by black scurf (*Rhizoctonia solani*). It can allow faster development of crops that are late planted because of heavy soil or the potential for adverse weather persists into late spring. The physiological age of seed tubers is influenced by many factors including the treatments of the seed after dormancy break.

This review will focus primarily on the effects of light and temperature on tuber seed development and will exclude the use of ethylene which is known to sometimes increase number of sprouts per seed tuber and the subsequent number of stems and stolons (Pruski *et al.*, 2006), however, this process is not strictly considered a chitting treatment.

3. The concept of physiological age

Storage of seed potatoes centres around delivering tubers that are non-dormant or are physiologically-aged (chitted) at the time of planting, whereas in contrast, in ware potato storage sprout inhibition is essential to prevent losses (Wustman and Struik, 2007).

Seed tubers can be described by chronological age and by physiological age. Chronological age is the actual age of the tuber (days) between emergence of the seed crop, ideally from tuber initiation but more practically from an event related to plant and tuber development such as 50% emergence, to the date of planting the following season. Older seed is characterized by a reduction or loss of apical dominance and so will typically produce more stems than younger seed.

Physiological age was defined by Struik (2007) as the developmental stage, or physiological state of potato seed tubers which determines the behaviour of each bud of the seed tuber, impacting on the sprout number per eye and vigour and subsequent yield. The importance of the physiological age of seed tubers is due to the fact that aging modifies the biochemical, physiological and agronomic traits of both plants and tubers resulting from them (Caldiz *et al.*, 1996). The physiological age of seed potatoes at planting is extremely important for storage quality of the subsequent crop as it can have an impact on harvest maturity (Groves *et al.*, 2005). Seed tubers that are too young or too old have slower, irregular and sometimes incomplete emergence (reviewed by Van der Zaag and Van Loon, 1987). Physiological age influences the vigour and physiological behaviour of stems (Struik, 2007), causing major impacts on potato yields and crop performance (Table 1) (Caldiz *et al.*, 2001; Caldiz, 2009).

There is a strong varietal (genetic) component for both chronological and physiological age with some varieties showing much more marked differences between younger and older ages.

For Burton *et al.* (1992) the storage potential of potatoes was determined before the beginning of storage, taking into account factors such as cultivar, growing techniques, soil type, weather conditions during growth, diseases before harvesting, maturity of potatoes at the time of harvesting, tuber damage during lifting, transport and the time taken to fill the store and the start of cooling process to bring tubers down to store temperature.

During storage, losses occur due either to physiological breakdown or development of bacterial or fungal disease. Moreover, during prolonged storage, potato metabolic activity changes with length of storage and storage temperature. Respiration rates rise with storage duration and sprouting resulting in increased water loss and a decline in fresh weight. The extent to which these processes are occur is dependent on storage temperature and the uniformity of air distribution within the store, and the physiological status of tubers entering the store and therefore the impact of chitting seed tubers will have an important bearing on tuber maturity entering store (Smith, 1987; Wustman and Struik, 2007).

Table 1 - Main characteristics of physiologically young and old seed potatoes (Source: Caldiz, 2009)

Characteristic	Young seed	Old seed
Emergence	Slow/later	Quick/earlier
Stem number	Lower	Higher
Tuber initiation	Later	Earlier
Tuber number per stem	High	Low
Secondary growth	Low	High
Haulm growth	Exuberant	Poor
Tuber yield in short growing seasons	Low	High
Tuber yield in long growing seasons	High	Low
Maturity	Late	Early

Understanding the physiological age of the potato tuber is not only useful for the processing industry but also for the seed potato industry, where excessive physiologically aged tubers tends to produce weaker plants than those derived from younger chitted-seed stock (Colgan *et al.*, 2012).

Physiological age of a tuber is affected by its chronological age and environmental conditions, since tuber formation is initiated from the mother plant (van Ittersum, 1992). However, tubers with the same chronological age at harvest may have different physiological ages due to variable environmental and management conditions during growth (Van der Zaag and Van Loon, 1987) and storage conditions of seed tubers (Hartmans and Van Loon, 1987). Physiological age of potato tubers is affected by both pre- and post-harvest conditions, markedly temperature (Jenkins *et al.*, 1993).

There have been many attempts to develop indicators for the physiological age of tubers in order to quantify cultivar differences in the rate of aging during storage, and the effect of seed age on crop growth and yield (Caldiz *et al.*, 2001; Caldiz, 2009). However, until the work of Caldiz *et al.* (2001) there was a lack of any quantitative and comparable indicators of the physiological age.

Caldiz *et al.* (2001) defined the Physiological Age Index (PAI) as a framework to determine the optimum physiological age for seed tubers, and to investigate how cultivar, environments and treatments affected the rate of aging of tubers. It is straightforward, although time consuming to measure, it requires little capital investment. This index ranges from 0 (very young seed tubers) to 1 (old seed tubers) and is calculated as PAI = T_1/T_2, where T_1 is the days from T_0 (haulm killing date) to possible planting date, and T_2 is the days from T_0 to the end of the incubation period, with this period defined as the time elapsed from sprouting until new tuber formation on the sprouts (Caldiz *et al.*, 2001).

The protocol for measuring PAI is illustrated in

Figure **1**. The fact that the measurement is time consuming limits predictive value for future planting and use (Caldiz *et al.*, 2001), meaning that further work on its development is required to allow growers to make decisions on seed purchases or management practices (Caldiz *et al.*, 2001). In later work (Delaplace *et al.*, 2008), the same disadvantage for PAI was reported as the additional time required to measure PAI values. However, the authors propose that PAI could be used as a valid reference frame for biochemical studies of potato tuber aging. These authors suggested that PAI could be used as a parameter to characterise age progression in storage, because PAI showed limited variation and can be measured at any point after the time of haulm killing.

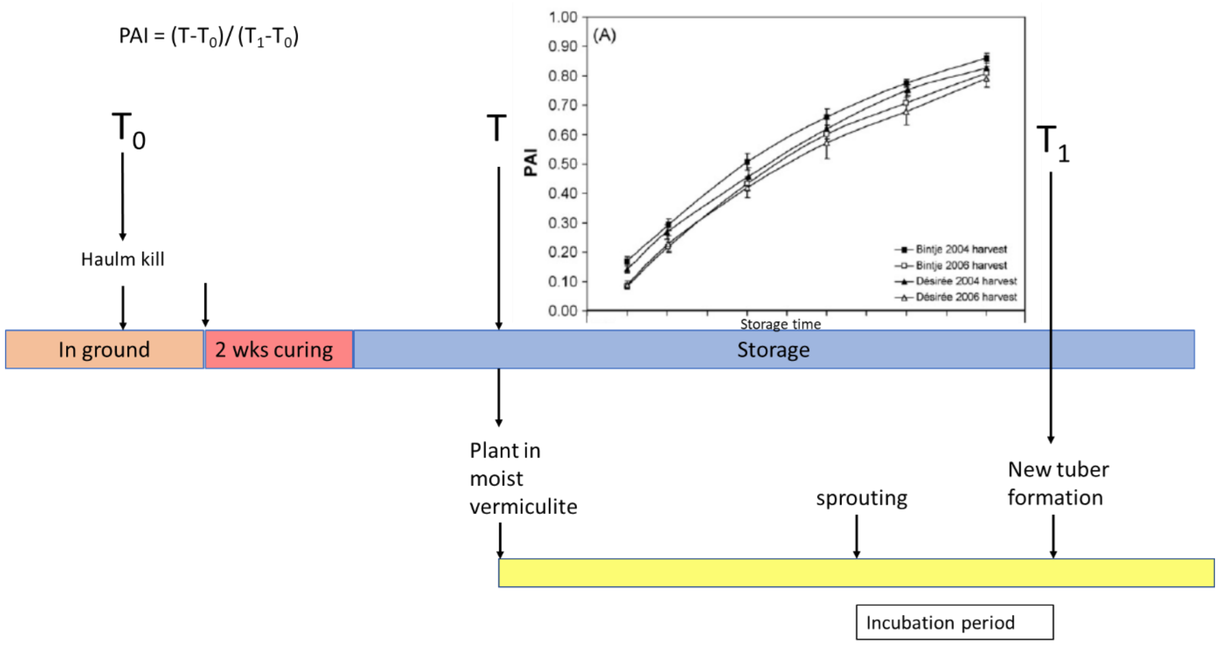


Figure 1 - Measurement of PAI, as described in Deleplace *et al.* 2008

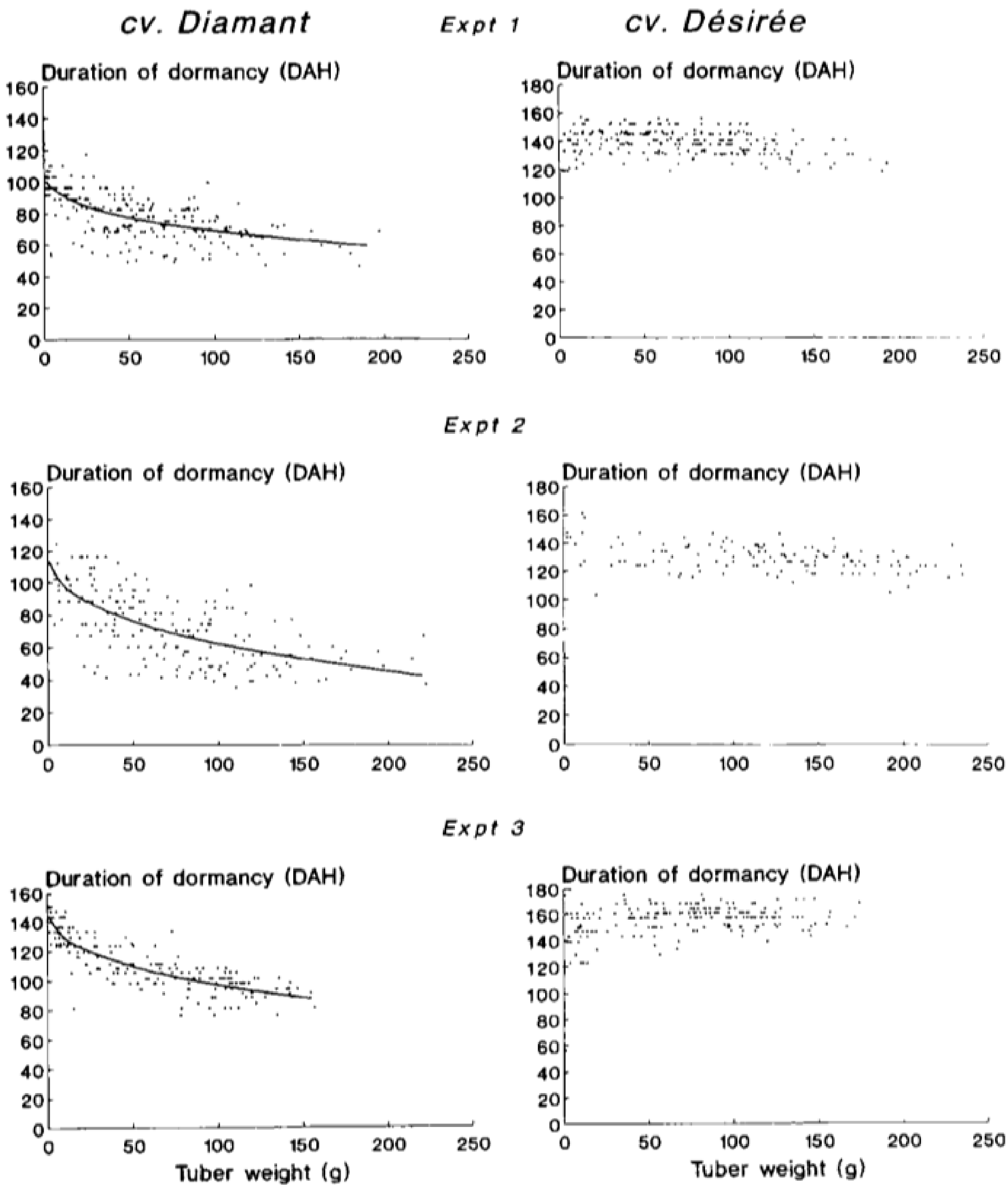
The physiological status of a seed tuber starts at tuber initiation with a dormant phase until new tuber formation (Struik, 2006; Caldiz, 2009). The rate of physiological aging in potato tubers appears to be cultivar specific, but also individual tuber specific and temperature dependent (Coleman, 2000). The higher the cumulative temperature during storage, the faster the tuber physiological age advances (Struik and Wiersema, 1999). Tuber size affects the number of tuber eyes, that are directly related with the physiological status of the tuber. In most cultivars, smaller tubers are physiologically younger (larger tubers are further advanced in growth and development), having higher dormancy (Struik and Wiersema, 1999). Van Ittersum (1992) using cvs. Diamant and Desiree observed that the heavier the tubers the shorter the dormancy.

This relationship was not linear for cv. Diamant; where small tubers dormancy release was more influenced by increasing tuber weight than it was for larger tubers, however for cv. Desiree this relationship was not clear (**Figure *2***).

Usually early varieties tend to have shorter natural dormancy period than maincrop varieties, during which tubers do not sprout except through chemical inducement or exposure to abnormally high light levels and raised temperatures (ADAS, 1982).

With seed tubers, physiological aging is most affected by the cumulative temperature experienced after the end of dormancy during storage, although its effect is moderated by light conditions (for example if diffuse light conditions are used during chitting) and by genotypic characteristics (Struik, 2007).

Figure 2- Relation between the duration of dormancy (DAH = days after haulm removal) and tuber weight, for cvs. Diamant and Desiree in three different experiments (From Van Ittersum, 1992).



4. The principles of chitting

Earlier crop emergence, establishment and advancement of tuber initiation can be achieved by pre-sprouting (chitting) of seed tubers under diffuse light (Caldiz, 2009). Chitting promotes the development of one or more sprouts on the seed tubers so that the new plant has started to develop before planting (ADAS, 1982).

The principles of chitting have been understood for many years. Chitting treatments are imposed by removing seed tubers from cold storage (<4°C) followed by exposure to light and increased temperatures (10°C) 4-6 weeks before the estimated planting date, ensuring that by the time of planting, seed has accumulated sufficient day-degrees (Groves *et al.*, 2005; Johansen and Molteberg, 2012).

Enhancement of seed age is measured in day-degrees, calculated according to Van der Zaag and Van Loon (1987) and corresponds to the sum of the daily mean store temperature above 4°C (for example 250°C days) from dormancy break (Asiedu *et al.*, 2003).

Temperature is the most important factor controlling dormancy (Krijthe, 1962). In general, higher storage temperatures lead to a shorter endo-dormant period after harvest (reviewed by Burton, 1989). However, it is not only the storage temperature that influences the physiological age of the seed tuber, the timing of introducing periods of warming in store can be used to manipulate the tuber physiological age (Struik and Wiersema, 1999).

According to Van Ittersum and Scholte (1992) cultivars with long dormancy require a longer period of warm temperatures to advance their growth vigour. However, the optimal storage conditions will always depend on the cultivar and thus each cultivar requires bespoke warming and storage protocols (Struik and Wiersema, 1999). Storage temperatures influence the number of sprouts developed from a seed tuber; tubers placed after dormancy break at suitable temperatures for sprout growth will produce few or even single sprouts as a result of apical dominance resulting in dominant, strong apical bud growth that supresses the growth of other buds. When tuber seed is stored at lower temperatures and later transferred to higher sprouting temperatures apical dominance is broken earlier resulting in more sprouts per tuber. Removing the apical bud is another strategy to achieve multiple buds. These types of tubers are referred to as multi-sprouted (Allen *et al.*, 1992).

Sprout growth rate is affected by light exposure after dormancy break (McGee *et al.*, 1987) and increases with temperature (Burton, 1989). However, different varieties have different responses to temperature stimulus, for example, in most early varieties sprout growth is quicker than in maincrop varieties, such as King Edward or Cara (ADAS, 1982). Therefore chitting is considered an important tool in regions with cooler and shorter growing seasons allowing growers to achieve acceptable tuber yields and quality in less favourable growing conditions (Furunes, 1990).

In addition, sprouts have their own physiological characteristics which may affect seed performance (sprouts perceive environmental signals, such as presence of light and photoperiod). Physiological age is influenced by processes at the level of the tuber, or tissues in the tuber, and by processes in the sprout. For example, during diffused-light storage, it is possible to generate young sprouts on old tubers. The inhibitory and/or delaying effects of diffuse light preserve the sprouts at relatively young and vigorous state, while the mother tubers age rapidly due to the prolonged storage under relatively high temperatures. The action of de-sprouting tubers leads to subsequent regeneration of younger sprouts on old tubers because the de-sprouting accelerates seed tuber ageing (Struik, 2018).

Chitting is undertaken in stores equipped to provide the temperature and lighting regimes appropriate for the type of sprouting and handling system adopted (Maunder *et al.*, 1984). It is important that they are free from residues of sprout suppressants such as CIPC.

Chitting involves several decisions and operations, but typically start with the filling of the chitting trays (traditionally 75cm x 45cm x 15cm trays) 4 to 6 weeks prior to the planned planting date. Tubers are spaced wide apart in the trays to minimise contact. Trays are stacked on pallets ensuring sufficient ventilation and exposure to natural or artificial light. As soon as the sprouts start to emerge, light may be provided by lamps with warm tones, >100 W per tonne of planting material, 8–10 hours per day, with humidity set to 70–80% (Speiser *et al.*, 2017). A thermal heat shock treatment can be used to break dormancy, depending on the tuber seed maturity, planting time, variety, storage conditions and desired stem number.

In order to prevent heat shock, seed tuber temperature is raised in graduated steps of 1 to 2°C a day to 18 to 20°C after which temperature is maintained, with good ventilation in the dark until formation of sprouts (Baarveld *et al.*, 2001; Speiser *et al.*, 2017). After 3-4 days, post-emergence, when the sprouts are judged to have reached an average of 1-2 mm, store temperatures are lowered to 8-12°C followed by exposure to light (natural or artificial), in the presence of good ventilation (Struik and Wiersema, 1999). Sprouts formed in the dark are etiolated forming long, weak sprouts that are vulnerable to damage when handled. Hence light exposure helps to produce short and robust sprouts suitable for mechanical planting (

Figure **3**) (Johansen and Mølmann, 2017). Light exposure inhibits sprout elongation and allows long term storage of potato seed in higher temperatures (Johansen and Mølmann, 2018; McGee *et al.*, 1987). Sprouts developed under lighting conditions are more physiologically active (Struik and Wiersema, 1999).

In terms of effort and resources, it has been estimated that six people filling and stacking trays are needed to generate up to 10 tonnes of seed potato a day ready for chitting treatments (Farmers Weekly, 06-04-2018).

Other developments have been introduced with the aim to reduce manual handling.

Chitting can be performed in chitting bags (mesh bags hanging from metal frames), for example the "Joppe Pre-sprouting (chitting) system" (Figure 5) (https://www.presprouting.com/, 05-04-2019) or in large boxes (flat wire crates with a second "cage" holding the inside up to a depth of 30 cm) (Speiser *et al.*, 2017).

Figure 3 - Sprout developmental status on potato seed tubers after various pre-sprouting treatments during 12 weeks. Rows (cultivars) from the top: Mandel, Gullauge, Folva and Asterix. Columns (treatments) from left: control (cold storage at 4 °C), dark-stored at 10 °C, and 8, 16 and 24 h daily light exposure at 10 °C (Johansen and Mølmann, 2017).

Figure 4 - Joppe Pre-sprouting (chitting) system (https://www.youtube.com/watch?v=GxjG0y75TB8&vl=de)

The Mega-Chit™ system has been developed by Staffordshire potato producer WB Daw & Son. (Farmers Weekly, 19-02-2019). It comprises four large wooden-slatted and galvanised steel-framed trays the size of a potato-box stack (Figure 5), with the bottom tray slightly taller with pallet tine channels and locking bars to keep the stack stable on uneven ground. A box tipper can empty the crate directly into the planter (Figure 6), by removing the end slat of each tray before engaging the box tipper above the hopper. The system has the option to build in LED lights into the underside of each tray.

30 tonnes of Pentland Dell seed could be loaded into trays using 2.5-man days and a mechanical loader. This was a big improvement compared with the traditional method that could take more than 6 people to fill and stack 10 tonnes of seed potatoes per day. Overall, this system makes it possible to handle larger quantities of seed reducing the damage to the seed while saving time and labour.

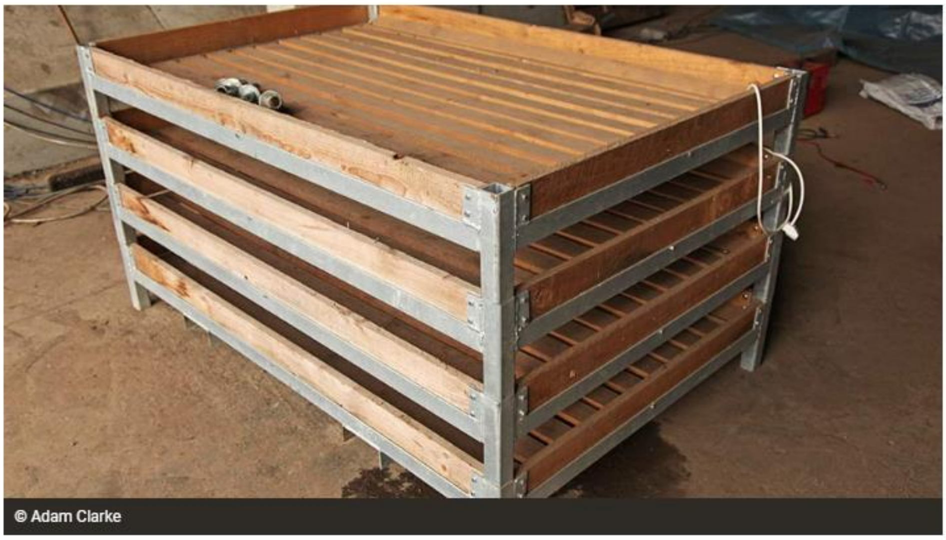


Figure 5 - Mega-Chit™ chitting system developed by Staffordshire potato producer WB Daw & Son.

Figure 6 - A box tipper emptying the Mega-Chit™ treated seed directly into the planter.

The Blackburn Potato Chitting Crate is also a box-based chitting system (Figure 7), The crates are capable of holding a half-tonne of seed, stackable to 5 high, and all phases of filling and emptying for planting can be mechanised. The mesh construction is designed such that no tuber surface is more than 100 mm a source of light.

Sprouts can become entangled in mesh or netting so trapping tubers and hindering the emptying into planters. Good control is necessary to ensure that sprouts do not become excessively long.

Figure 7 – Stacked Blackburn crates in store with artificial lighting.

4.1. Potential use of LED lighting to manipulate potato tuber seed potential

Supplementary lighting for cultivation under glass has progressed over the last century with the development of different lamp technologies such as incandescent, fluorescent, metal halide, and high-intensity discharge lamps (reviewed by Viršilė *et al.*, 2017). Conventional lamps are being replaced by light-emitting diodes (LEDs) in almost every indoor and outdoor lighting application. The rapid technological progress of LEDs are leading to gradual uptake by the horticultural industry (reviewed by Viršilė *et al.*, 2017).

The use of LEDs provides the opportunity to control plant growth, development and metabolism by tailoring light parameters, by selecting the specific wavelengths in the light spectrum that match the absorbance of plant photoreceptors, impacting on specific vital plant processes (reviewed by Viršilė *et al.*, 2017; Samuolienė *et al.*, 2017). Furthermore, LEDs can be used in close proximity to the seed tuber due to their low radiant heat output when properly cooled (Morrow, 2008; Nelson and Bugbee, 2014; Mills and Dunn, 2016). LEDs do not contain mercury, glass envelops or generate high surface temperatures that can potentially cause injury, or contaminate the seed, when broken. LEDs have a long operational life and can be turned on and off instantly. They are easily integrated into digital control systems, with the potential for significant cost savings when compared with other horticultural lamp types (Morrow, 2008). Mills and Dunn (2016) list the advantages and disadvantages of LEDs use for plant production as:

a) Advantages:
    - Energy efficient
    - Easy installation
    - More durable
    - Longer lifetime
    - Low heat emission

b) Disadvantages:
    - Higher initial costs
    - Heavier weight with some devices
    - Inappropriate design (most devices are designed and used in research settings)
    - Less coverage area
    - Different ratios of LED colours
    - High temperatures (of the environment) shorten lifespan and reduce efficiency

In horticulture, different LED lighting devices (top-lights, inter-lights, tubular LEDs and flowering lamps) and bulb types (bulged reflectors, tubular and miniature) are selected based on the specific needs of plants and grower requirements (Mills and Dunn, 2016). Top-lights are used for high wire and leafy vegetables, inter-lights allow horizontal and vertical distribution of light (used in vines and climbers, such cucumber and tomatoes), flowering lamps have identical features to incandescent lamps and are ideal for extending day length, the traditional fluorescent tubes can be replaced with tubular LEDs offering a more uniform lighting and producing less heat (Mills and Dunn, 2016).

Janda *et al.* (2015) observed that both LED light and fluorescent tubes light provided similar photon flux density (PFD), however, the light field from fluorescent tubes was more uniform. In the same study, the authors noted that fluorescent tubes had very strong temperature gradients, compared to LED lighting. The authors believe that the non-uniformity in heat generated by fluorescent lighting could be an important variable influencing plant growth and resource efficiency. Temperature gradients due to the different lighting types were visible in plants water requirements, trays under LED light needed around 40% less water. LED's are much more energy efficient than fluorescent tubes.

The effect of light on a tuber's dormancy depends on its maturity; light will lengthen the dormancy period of mature tubers but shorten the dormancy of immature tubers (Baarveld *et al.*, 2001). For potato plantlets grown *in vitro,* blue light stimulates larger cell size in the vascular bundles, pith and cortex tissues resulted in an increased width of growing shoots whereas red light has the opposite effect and produced slender shoots (Chen *et al.*, 2011). For potato tubers, a mix of red (90%) and blue (10%) LED lighting regime stimulated shoot proliferation under *in vitro conditions* (Edesi *et al.*, 2014).

Light quality is a key factor in physiological responses of the tuber sprout. Khalil and Abd El Aal (2017) tested the effect of different LED light qualities on potato sprout growth. They observed that red LED lighting was responsible for longer and thinner sprouts with lower dry weight than blue or white LED light, or where a combination of 75% red and 25% blue LED light was used.

Ma *et al.* (2015) noted that the soluble sugar, soluble protein and starch contents in potato plantlets *in vitro* were significantly higher when plantlets were grown under LED lighting compared to fluorescent light. In this study, green LED light promoted the accumulation of carbohydrates and proteins, which could influence tuber reserves at planting time and have a significant positive effect on the emergence after planting and on the final yield.

4.2. Research to date on chitting

Studies on chitting so far have mainly focused on the yields generated from chitted tubers with a paucity of information on the storage potential of tubers harvested from chitted seed. During this review of the literature, only four studies were found on the storage potential of the tubers harvest from chitted seed: Groves *et al.* (2005), Heltoft *et al.* (2016; 2017) and Carvalho (2017).

Groves *et al.* (2005) investigated the importance of tuber maturity at harvest on processing quality, by testing the effect of agronomic factors on the physiological age of the ware crop. The authors found that even though the results suggested that increased maturity at harvest compromised fry colours during storage, these effects were small relative to the seasonal differences in fry colour that were observed during the study.

Heltoft *et al.* (2016) investigated the effect of three different combinations of factors (chitting, planting date and level of nitrogen fertilization) on the tuber maturity at harvest. Three levels of maturity were considered. The maturity indicators used in this study were haulm greenness (haulm maturity), tuber skin set (physical maturity), tuber dry matter content (physiological maturity) and the sucrose, glucose and fructose content of tubers. Chitted seed tubers generated the most physiologically mature tubers at harvest compared to non-chitted, while delayed planting decreased maturity even further.

In addition, lower N fertilization resulted in more mature tubers. The authors observed that maturity at harvest influenced the crop storage potential significantly, with the least mature tubers (unchitted, planted later with higher N fertilization) having higher weight loss, higher respiration rate and lower dry matter content than the more mature tubers. Later work, by Heltoft *et al*. (2017) adopting the same three maturity levels, considered maturity indicators measured in the field or at harvest to predict the crop quality during and after storage in cvs. Asterix and Saturna. In these two studies, the authors observed that there was potential for using field measurement of maturity as indicators of storage potential.

Carvalho (2017) during her PhD (Senescent Sweetening), thesis at: https://gala.gre.ac.uk/id/eprint/23520/) studied the effect of chitted potato seed on the propensity to develop senescent sweetening during storage during one season (2015/16). It was concluded that tubers from chitted seed did not show any important physiological changes in reducing sugar accumulation, respiration rate and sprout growth compared to non chitted seed tubers however, tubers from chitted seed were lower in ascorbic acid (AsA) and with raised amounts of reactive oxygen species (ROS), suggesting that some aspects of tuber maturity and aging were affected by chitting.

Chitting studies undertaken by INAGRO in Belgium (https://leden.inagro.be/Artikel/guid/2757, 10-04-2019) found increasing the chitting period to 7 weeks, increased yields by 3 to 6 t/ ha. However, yield increases were dependent on pest pressure and the varieties used. Contrasting results have also been reported in 2015, where regardless of differences found in crop emergence and development at the start of the cultivation, chitted seed failed to generate higher yields, probably due to the dry weather during that growing season. Similar observations were made by McKeown (1994) in the growing season of 1988 in Southern Ontario (Canada). This author observed an increase of early plant emergence and higher early yields from chitted seed as well as varietal differences in response to chitting.

In Norway, Johansen and Molteberg (2012, 2017) observed in some cases, earlier emergence, higher yields and higher dry matter at harvest in chitted tubers; however, in some situations, chitting led to reduced tuber weights, reduced tuber grade sizes and lower marketable yield. It was observed that the duration of light exposure did not affect the field growth characteristics for any of the study cultivars and that late maturing cultivars, Gullauge and Mandel, benefitted more from chitting than the early maturing varieties Folva and Asterix (Johansen and Mølmann, 2017). Light exposure significantly inhibited the development of black scurf (*Rhizoctonia solani*) in the varieties Asterix and Gullauge, when compared with tubers stored in the dark (**Error! Reference source not found.**) (Johansen and Mølmann, 2018).

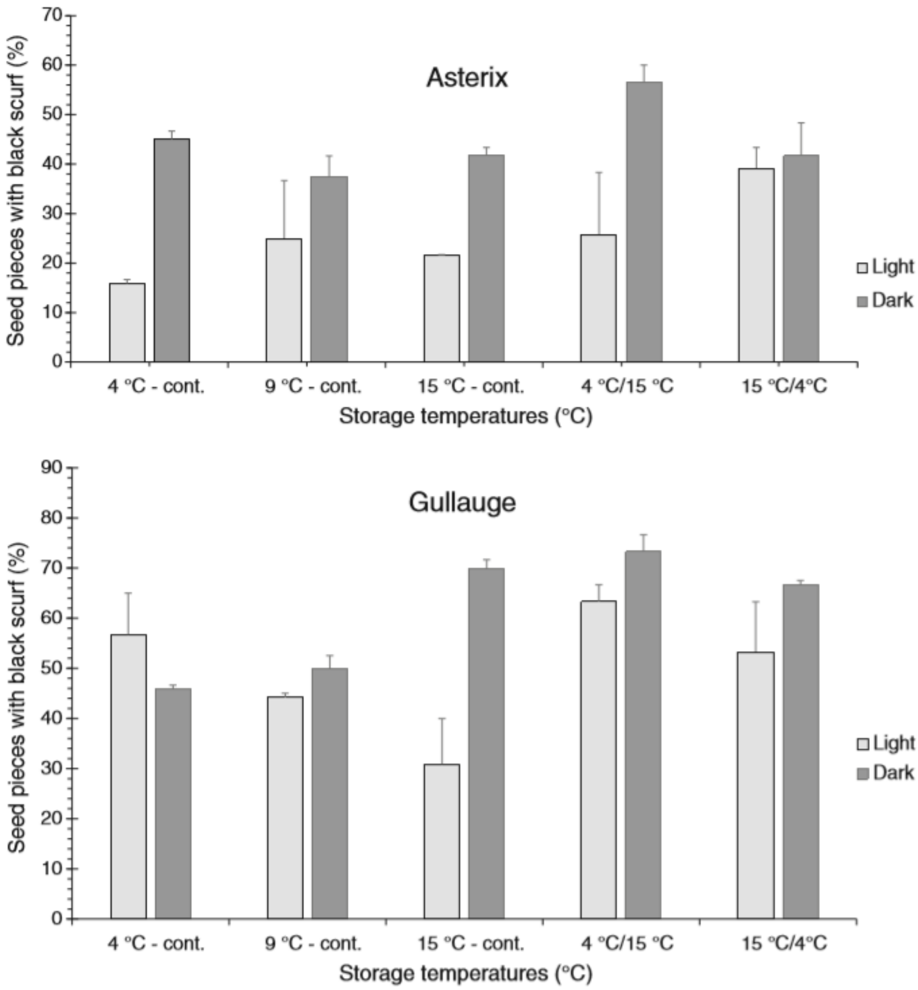


Figure 7 – Occurrence of black scurf (*Rhizictonia solani*) (with SE indicated, n=2) on potato seed tuber skin after 177 days storage in light and darkness from 1 October 2013. Light exposure continuously (cont.) or only at 15 °C for the last 87 days of storage (4 °C/15 °C) or at 15 °C for the first 90 days of storage (15 °C/4 °C). Occurrence was measured as percentage of 60 seed tuber pieces per sample with mycelium or sclerotia. Before treatments started, the percentages were 26 and 42 for Asterix and Gullauge, respectively (Source: Johansen and Mølmann, 2018)

Trials in the UK have shown higher yield when seed is chitted. An example was the 2016 AHDB Strategic Potato Farms comparative trial with the French fry varieties Markies and Pentland Dell. Chitted seed tubers (10-12°C in the store, LED lighting at 10W/m2, chitting period to provide an additional 200-250 day degrees) reduced the time to 50% emergence by 8 to 10 day compared to unchitted seed. Matt Smallwood, trial agronomist, commented that for Markies chitting combined with well-timed burn-off provided improved storage stability by delivering more consistent tuber maturity at harvest.

4.3. Advantages and disadvantages of chitting

Seed tuber chitting has the potential to stimulate significantly the growth and performance of potatoes enhancing potato production. This has particular advantage in areas experiencing short growing seasons (Johansen and Mølmann, 2017), where late maturing varieties are used (Maunder *et al.*, 1984) and in seasons when planting is delayed or growth is shortened by blight (ADAS, 1982). Unseasonal weather conditions may impact negatively on crop yield generated from chitted seed; for example early frost events that damage the earlier emerging shoots or through periods of drought that may induce earlier canopy senescence (ADAS, 1982). In parts of the country with heavier soils, where planting cannot start early in March, chitting provides a clear advantage by compensating for late planting with accelerated canopy establishment (ADAS, 1982).

Although chitting has in the past been considered a laborious and energy costly process (Johansen and Mølmann, 2017) chitted seed can mature up to two weeks earlier than non-chitted seed. Using chitted seed tubers in fields suffering from nematode infestation or *Rhizoctonia* will benefit from the reduction in time to emergence, allowing for earlier establishment of crop outside the most pest and disease susceptible growing periods. However, according to Hagman (2012) chitted tubers are more susceptible to potato late blight infection with the effects visible earlier than in non chitted tubers. This could be the result of the production of multi-sprouted seed increasing the number of stems per tuber, producing a denser canopy with increased periods of leaf wetness and high humidity, favouring disease spread (Hospers-Brands *et al.*, 2008). Nevertheless, due to the shortening of the growing season as a result of chitting, it is possible to harvest mature tubers before the incidence of late blight takes hold (Hospers-Brands *et al.*, 2008; Hagman, 2012). Karalus and Rauber (1997) noted that chitting has a positive effect on yield when foliage has been heavily damaged by late blight or Colorado beetles, proving to be an important method to maintain or improve yields in farming systems such as organic farming, where no chemical pesticides are used. Karalus and Rauber (1997) noted an improvement in tuber size and marketable yields, with a reduction in undersized tubers where chitted seed had been used. In later studies, it was observed that chitting could be used to alter tuber size distribution to meet market requirements with minimal impact on overall and marketable yields in some varieties (Knowles and Knowles, 2006; Oliveira *et al.*, 2014).

The Belgium organisation INAGRO trialled the Joppe pre-germination system and recommended keeping the bags in open air and full sun during the entire chitting period and which resulted in short but firm chits (buds/early sprouts). Consequently, shoot breakage was minimised during handling or planting of the potatoes. However, they advised that for certain varieties, such as Antonia and Allians, planting chitted seed would lead to earlier emergence and expose plants to greater pest pressure, thereby counteracting the advantage of chitting.

During the AHDB Strategic Potato Farm West results day, small groups of farmers discussed why chitting is not more commonly used (Anne Stone, personal communication, 9th April 2019). Although a trial was presented that demonstrated advantages for chitting potato seed, farmers see the need for investment to permit good quality chitting as a disadvantage and are resistant to introducing the complexity of another factor at planting time. During that meeting it was pointed out that in situations where chitted seed was ready to be planted and the weather turned unfavourably wet, there was the risk of damage when over-long chits were damaged through delayed planting. Another disadvantage is that the planters available on many farms are not suitable for filling with chitted seed. Cup planters are seen as gentler for the chits than belt planters (Stafford Proctor, Proctor Bros (Long Sutton) Ltd, personal communication, 13th June 2019). These planters use cups to lift tubers from the planter hopper and deposit them in the row, with extremely accurate spacing. While belt planters use a rubber belt to distribute seed from the planter hopper, they are not as precise as cup planters but have the advantage of being faster (Farmers Weekly, 13-06-2019).

Some growers prefer to use natural light for chitting because they have access to glasshouses (Stafford Proctor, Proctor Bros (Long Sutton) Ltd, personal communication, 13th June 2019). A comparison of the effects of natural versus artificial light on the outcome of chitting would be helpful.

5. Priority areas for future research on chitting

Given the many factors that must interact for chitting to be of benefit it is unrealistic for any research programme to provide insight into all possible scenarios. The principles have been well described and there is a good body of research that could be expanded. Much research has focused on yield, less on quality and storage potential of tubers produced from chitted seed.

The effect of physiological aging varies with many factors including variety, cultivation practices, geographical area and seasons etc. such that the optimum seed age for each market needs to be determined for each location. A reliable, rapid and cheap diagnostic tool for assessing physiological age at any stage of the seed tuber development, capable of predicting future trends of physiological ageing of the seed tuber and behaviour of the future crop would be invaluable (Struik, 2018) in this regard.

The advent of LED lighting brings the opportunity to readily modify the wavelengths of light during chitting with potential positive benefits in tuber and sprout physiology; to date there have been only limited scale trials.

There remains a need for a robust degree-day model that adequately describes the growth and yield responses of seed to storage temperature (Knowles and Knowles, 2006)..

The amount of labour required for chitting is one of the biggest disadvantages of traditional chitting systems so improving the mechanisation of the process to reduce labour inputs is essential. Mechanised methods can be destructive of sprouts so gentler systems are sought.

An economic evaluation, cost benefit analysis, is required to quantify the costs and advantages of chitting. To date much of the knowledge was gained using varieties that are very much less mainstream.

6. Conclusions

Even though chitting is a labour intensive and energy costly process, it can be very important in situations with short growing seasons or in situations due to pest and disease pressure where early emergence can allow earlier development and maturity before pest and disease pressures have increased to damaging levels. Chitting is a powerful technique where there is the need to alter tuber size distribution to meet market requirements.

There are many studies on the yield of chitted tubers, but research is required to better understand the complex interactions of light and heat on the propensity to break dormancy and how well chitted seed behaves under different environmental growing conditions. Tools capable of predicting changes in the physiological ageing of the seed tuber, behaviour of the future crop and storage potential of the tubers harvested from chitted seed are required.

There are increasing developments towards efficient chitting systems with improved mechanisation potential and decreased costs. Even though the use of LED lighting gives the opportunity to control plant growth, development and metabolism by tailoring light parameters, there is insufficient research to date on the effects of specific wavelengths in the light spectrum on potato sprout growth.

Crucially, there still a need for a detailed economic evaluation (cost benefit analysis) to quantify the costs and financial advantages of chitting. Based on experience and trials, many growers and companies have (long) established chitting protocols and systems for specific varieties for particular markets. Commercial considerations may restrict information sharing but there would be an overall industry benefit to collaborative efforts to trial different techniques.

7. References

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8. Appendix: Dormancy

Lang *et al.* (1987) defined dormancy as "temporary suspension of visible growth of any plant structure containing a meristem". Lang *et al.* (1987) divided dormancy into three states, paradormancy (regulated by physiological factors outside the affected structure, e.g. apical dominance), endodormancy regulated by physiological factors inside the affected structure, e.g. chilling responses) and ecodormancy (regulated by environmental factors, e.g. water stress, storage temperature.

Dormancy break is a complex process known to involve several physiological and biochemical changes (Liu *et al.*, 2017). Shoot elongation which is more commonly termed sprouting starts quickly after dormancy break (Suttle, 1996). Dormancy is considered to be a physiological adaptation of the tuber to prevent sprouting during intermittent periods of environmental limitations (Suttle, 2007). In most varieties, immediately after harvest, potato tubers cannot be induced to sprout even under optimum environmental conditions (Cutter, 1992). However, certain diploid Phureja species (*Solanum tuberosum var phureja*) dormancy break can occur in the field.

Tuber maturity at the point of harvest has an important bearing on dormancy, Krijthe (1962) studied the sprouting of seed potatoes and showed that immature tubers have a shorter dormant period and more rapid sprout growth than the mature tubers. Characterisation of tuber maturity is often clouded in confusion due to different types of maturity being referenced (chemical (sucrose content), chronological (days from planting) and physiological).

Others factors that affect the length of the dormant period are soil and weather conditions during growth, timing of foliage removal, if at all before harvesting, degree of tuber damage (bruising) and the storage regime (Burton *et al.*, 1992). Potato dormancy has been recently reviewed by Carvalho et al (2021).