Quality Assurance and Safety of Crops & Foods, 2018; 10 (1): 17-24

Wageningen Academic Publishers

Use of CIPC as a potato sprout suppressant: health and environmental concerns and future options

P. Vijay[1,2*], R. Ezekiel[3,4] and R. Pandey[2]

[1]ICAR-Central Potato Research Institute-Campus (CPRI-Campus), Modipuram, Meerut, UP 250 110, India; [2]Division of Plant Physiology, ICAR-Indian Agricultural Research Institute (IARI), New Delhi 110 012, India; [3]Crop Physiology and Post-Harvest Technology, ICAR-Central Potato Research Institute (CPRI), Shimla, Himachal Pradesh 171 001, India; [4]National Agricultural Innovation Project (NAIP), Krishi Anusandhan Bhawan - II, Pusa Campus, New Delhi 110 012, India; vijay_paul_iari@yahoo.com

Received: 1 February 2017 / Accepted: 11 September 2017

REVIEW ARTICLE

Abstract

World over, isopropyl *N*-(3-chlorophenyl) carbamate (CIPC) is used as a potato sprout suppressant during storage. Residue of CIPC is therefore noticed not only in the stored potatoes but also in the processed potato products. It is about three decades ago that it was proposed that the use of CIPC may become restricted in several countries due to various environmental concerns. During the last 20 years, declining trend in values for the levels of maximum residue limit of CIPC, as recommended from time to time by regulatory agencies, is an indication of potential harmful effects of CIPC. However, at present, larger concerns are being associated with breakdown products (metabolites) of CIPC. Issues like built-up levels of CIPC and its cross-contamination have also started receiving the due attention. This article points out the health and environmental safety concerns that have emerged due to continuous use of CIPC in the last 55 years, since its commercialisation in the year 1962 and in view of advancements in our understanding about this chemical. This article highlights issues that need the attention of the regulatory agencies and presents workable approaches and options along with advisories to reduce the overall use and intake of CIPC so that the risks associated with CIPC can be minimised.

Keywords: ADIL, chlorpropham, health hazards, pollutants, safety concerns

---

1. Introduction

Isopropyl *N*-(3-chlorophenyl) carbamate (CIPC) or chlorpropham is a selective herbicide with systemic action, its first use is known to have begun in 1951. Presently, it is used world over as an effective potato sprout suppressant during long-term (6-9 months) and short-term (3-4 months) storage of potatoes at temperatures ranging from 8-12 °C (Costa *et al.*, 2007; Ezekiel *et al.*, 2003; Kumar *et al.*, 2005; Paul and Ezekiel 2013; Smith and Bucher, 2012; Van Es and Hartmans, 1987a; Wustman *et al.*, 2011;). Large-scale use of CIPC as a potato sprout suppressant started in 1962. Initially, its use picked up in many developed nations and later spreading to the developing nations (Ezekiel *et al.*, 2005a; Sawyer and Malagamba, 1987). There are different forms and formulations in which CIPC is available today in the open market which include dustable powder, granules, emulsifying concentrate and fogging concentrate. Among these, the most commonly used form is the postharvest fogging application to potato tubers during storage at a temperature of 8-12 °C, besides being used as an herbicide. According to Farawela (2009), about 11% of total herbicide sale (world over) is contributed by CIPC, and it is one among the three pesticides that has been reported to be present in substantial amount in food items and diet of USA. Out of total synthetic chemicals present as residue in potatoes, CIPC contributes to about 90% in the USA (Daniels-Lake *et al.*, 2011). CIPC residue is reported to be present not only in table potatoes but also in French fries, potato chips, extruded and other cooked and processed potato products (Camire *et al.*, 1995; Ezekiel and Singh, 2007; Park *et al.*, 2009). The presence of CIPC is also noticed in oil that has been used for the frying French fries and chips (Ritchie *et al.*, 1983). This article discusses the merits as well as various health and environmental concerns that have now emerged due to the prolonged and continuous use of CIPC; and as revealed by advancements in our knowledge about the properties of this chemical. The article also highlights various issues for regulatory agencies and brings out the different scientific approaches and options along with important researchable issues that will not only prove beneficial in optimisation and more judicious use of CIPC, but also help in minimising the risks associated with CIPC.

2. CIPC as a potato sprout suppressant during storage

It is a proven fact that CIPC suppresses sprout growth on potato tubers effectively, especially at of 15 °C or below. Sprout suppression by CIPC declines at temperatures more than 15 °C (Sanli *et al.*, 2010). During storage, CIPC is most commonly applied as fog treatment, once for 3-4 months duration and at least twice for 6-9 months duration at 8-12 °C. A single application of CIPC of 18 g per metric ton of potatoes is considered as the recommended dose. For the potatoes meant for table purpose, two such applications of CIPC are applied and this becomes equivalent to about 36 g per metric ton of potatoes (Ezekiel *et al.*, 2005a,b).

As per Mohammed (2012), for potatoes meant for table purpose – a dose of 36 g of CIPC (a.i.) is the maximum limit that can be applied to per metric ton of harvested potatoes in UK. While, for the potatoes meant for processing, the limit is 64 g. In sub-tropical and tropical countries, short-term (3-4 months) storage of potatoes is also done by non-refrigerated or traditional methods. Due to relatively higher storage temperatures, which prevail under these methods, stored potatoes remain suitable for table as well as processing purposes (as they accumulate little or no sugars). Experimentations with CIPC on the potatoes stored under non-refrigerated traditional or on-farm potato storage methods in India (a sub-tropical country) have indicated that CIPC can also be an effective sprout suppressant even at higher storage temperatures of about 21 to 32 °C (Ezekiel *et al.*, 2002; Kumar *et al.*, 2005; Mehta *et al.*, 2010). In such cases, the lower efficacy of CIPC (due to higher storage temperatures) is usually compensated by applying it in higher doses. About 40 g CIPC (a.i.) per metric ton of potatoes (if applied as fog) and 25 g of CIPC (a.i.) per metric ton (if applied as dustable powder) are used (Paul *et al.*, 2014). As a safety precaution, it has been suggested that if the total dose of CIPC applied (in any combination or number of times) is greater than 36 g and maximum up to 64 g per metric ton of potatoes, then the treated potatoes must only be used for commercial processing purpose and not for table purpose (http://tinyurl.com/y9s5n239).

3. Economics of potato storage with the use of CIPC

In India, economics of storing potatoes at 10-12 °C with CIPC treatment was worked out by collecting information from different cold stores located in six different cities (Ezekiel *et al.*, 2005b). The cost of cold storage was about INR 1000 to 1,200 (15.465 to 18.559 USD) per metric ton of potatoes and the cost of CIPC treatment ranged from INR 110 to 330 (1.701 to 5.104 USD) per metric ton of potatoes. So, the total cost was about INR 1,110 to 1,530 (17.167 to 23.662 USD) per metric ton of potatoes. Farmers and traders who stored their potatoes at 10-12 °C with CIPC treatment were able to increase their profit by 37 to 58% in some places but in other places they incurred losses because there was a fall in potato prices at the time of selling. Only those farmers were able to make a profit whose potatoes were of acceptable quality to the processors. But in many cases, the quality of stored potatoes was not acceptable to processors thereby potatoes were sold as table potatoes resulting in either marginal profit or loss depending upon the given market situation. In yet another study from India (Mehta and Singh, 2016), economics was worked out when one CIPC treatment (20 g of CIPC per metric ton of potatoes) was given to on-farm stored potatoes by heap method for 90 days (19-31 °C, 55-90% RH). The CIPC treated tubers recorded only 4.79% weight loss (due to suppression of sprouting) and could be sold at prices comparable to the tubers from the cold store. The farmers could market 6.5% more weight due to CIPC treatment and fetch 21.6% higher price than the control (untreated) tubers. Besides, the CIPC treatment also saved the de-sprouting cost of labour by about INR 300 (4.64 USD) per metric ton. Basically, low-cost of treatment and effectiveness are the two key reasons for widespread popularity and continuous use of CIPC, not only in the developing countries but also in the developed nations.

4. Mode of action of CIPC and possible health concerns

CIPC interferes with the process of spindle formation and as a result of this cellular division is inhibited (Ashton and Crafts, 1981). Since, the process of sprouting and sprout growth involve vigorous cell division, presence of CIPC curtails the cellular division and thereby the sprouting and sprout growth on the stored potato tubers. CIPC targets the process of cell division, which is common to both plant and animal systems and in this way CIPC is basically interfering with a very basic and an indispensable cellular process. In plants, CIPC has also been found to inhibit RNA synthesis, protein synthesis, transpiration, respiration, activity of β-amylase, photosynthesis and phosphorylation (Vaughn and Lehnen, 1991). In view of above it becomes apparent that CIPC can be a potential health concern.

5. Historical trend in the maximum residue limit of CIPC as indicator of health risks

As per Federal Re-registration Eligibility Decision by the United States Environmental Protection Agency (US EPA), CIPC was continued (on 1st August 1996) for its use as a sprout suppressant on potato tubers during storage (US EPA, 1996). As per this decision, the maximum residue limit (MRL, also referred as residue tolerance) was fixed at 50 mg/kg. This limit was reduced to 30 mg/kg for fresh potatoes (meant for table purpose) during 2002 (US EPA, 2002). Later, during 2009, MRL value for CIPC was further reduced to 10 mg/kg in potato tubers meant for consumption in Europe (McGowan *et al.*, 2009). The European Union member countries introduced MRL of 5 to 10 mg/kg (Kleinkopf *et al.*, 2003). Whereas, European Commission and Health and Safety Executive (HSE) had decided to keep the MRL at 10 mg/kg (HSE, 2009). Among the North American Plant Protection Organization (NAPPO) countries, USA (with potato consumption of 152 g potato/head/day) and Canada (215 g/head/day) fixed the MRL of CIPC (in any form of application) at 30 and 15 mg/kg, respectively (NAPPO, 2013). On the other hand, another NAPPO member country, i.e. Mexico (with only 37 g of potato consumption/head/day), has registered neither the CIPC nor any other sprout suppressant for the use on potato tubers (NAPPO, 2013).

The above decisions to reduce the limits of CIPC over the period are basically to put limits on the number of applications/over use of CIPC so that desirable acceptable daily intake limit (ADIL) is maintained or achieved. But, at the same time it is also true that in real and practical terms, at least two fogging treatments with CIPC are essential for 6-9 months of storage of potatoes. CIPC residue was usually found to be in the range of 8 to 15 mg/kg in potato tubers treated with CIPC (Singh and Ezekiel, 2010). While, for the human body the ADIL of CIPC is 0.05 mg/kg/day (EFSA, 2012). Survey based studies conducted by the Working Party on Pesticide Residues/Pesticide Residues Committee since 1994 indicated clearly that the problem of higher residue of CIPC is the most frequent in potatoes (Bradshaw and Ogilvy, 2006; Noel *et al.*, 2004*)*. Report by El-Awady Aml *et al.* (2014) also pointed out very clearly that the presence of CIPC in potato tubers is really harmful. According to Cools *et al.* (2014), new legal restrictions may further limit the dose or frequency of CIPC application. This is in fact going to be true because recently CRD (Chemicals Regulation Directorate) of UK has approved new statutory label limit of CIPC for 2015-16 season and onward. According to this recommendation (Allison, 2015), the total permissible dose of CIPC is now reduced to 30 g (a.i.) per metric ton of potatoes meant for table purpose (earlier it was 36 g) and 50 g per metric ton of potato tubers meant for processing (earlier it was 64 g).

6. Bigger concerns and safety issues are associated with breakdown products of CIPC

Prolonged and preferred commercial use of CIPC for more than 55 years has definitely contributed to some issues which are directly associated with human health and safety of animals, water and environment (Gomez-Castillo *et al.*, 2013; Paul *et al.*, 2014). It is now quite clear that besides the CIPC, one of its breakdown product, i.e. 3-chloroaniline (3-CA), is formed due to thermal degradation (during fogging), microbial activity (in potato tubers during prolonged storage or metabolic degradation of CIPC) and digestive activity (in humans during consumption of potatoes treated with CIPC) (Balaji *et al.*, 2006; Carrera *et al.*, 1998; Park *et al.*, 2009; Sihtmaee *et al.*, 2010). As per various scientific studies, 3-CA is more polluting and toxic agent than the CIPC itself (Park, 2004; Sihtmaee *et al.*, 2010). More recent reports also indicate that 3-CA, being an aromatic amine, is toxic to human and environment (Mohammed *et al.*, 2014, 2015). This concern is primarily based on the fact that two similar derivatives 2-chloroaniline (2-CA) and 4-chloroaniline (4-CA) are known for their harmful nature and also as the cancer causing agents to humans, especially the 4-CA (Smith and Bucher, 2012). Growing concerns on 3-CA are because of the fact that structurally 3-CA is similar to 4-CA (Mohammed, 2012). In view of this, an important and a praise worthy decision was taken by European Commission in 2012 wherein, it was decided that along with CIPC, 3-CA will also be included for arriving at the value of MRL and as a true indicator towards the assessment of consumers' exposure to CIPC residues *via* food items (EC, 2012). Here it becomes important to mention that besides the 3-CA, there are other breakdown products of CIPC which are also reported to be highly toxic, pollutants, cytolytic, carcinogenic and responsible for hindering ATP production and altering cellular permeability (Kidd and James 1991; Orejuela and Silva 2005; Smith and Bucher, 2012). These include: 3-chloro-4-hydroxyaniline; 1-hydroxy-2-propyl-3-chlorocarbanilate; isopropyl N-(3-chloro-4-hydroxyphenyl) carbamate; 3'-chloroacetanilide; isopropyl-*N*-5-chloro-2-hydroxyphenyl carbamate; 3, 3'-dichloro azobenzene; isopropyl *N*-4-hydroxy-3-chlorophenyl carbamate; p-methoxy-chlorpropham; 3-chloro-4-methoxyaniline; and isopropyl N-(3-chloro-4-methoxyphenyl) carbamate. Formation of all such breakdown products further substantiate the growing concerns about the toxicity status of CIPC. This indicates that the overall toxicity of CIPC (taking together the residue of breakdown products) is more severe and broader than actually described and presumed so far (Paul *et al.*, 2016; Smith and Bucher, 2012).

According to Mohammed (2012), out of total CIPC taken in by mammalian body about 20% gets metabolised into 3-CA. The work of Skidmore *et al.* (2002) and Mohammed (2012) also suggested a strong binding of 3-CA in mammalian system. Due to strong binding of 3-CA, the dietary risk of 3-CA could not be assessed accurately (Smith and Bucher, 2012). This finding further raised the seriousness of 3-CA and CIPC in terms of their toxicity and toxicological implications. Smith and Bucher (2012) have also studied the degradation kinetics of CIPC and its breakdown products (which are formed by biolysis, hydrolysis, photolysis and due to thermal degradation of CIPC) along with their bifurcation into air, soil and water. Results obtained clearly pointed out for the overestimation of degradation under the lab conditions. This necessitates the need for more of such studies with an aim to take up more accurate decision/revision for MRL and ADIL with respect to CIPC by different regulatory agencies as this approach is more comprehensive and holistic and thereby closer to reality. It is important to mention that besides the formation of breakdown products (as described above and evident in mammalian and biological systems), formation of any specific conjugated product and its toxicity also needs the attention of researchers and regulatory agencies.

It is interesting to note that around thirty years back it was proposed by Van Es and Hartmans (1987b) and then by Afek and Warshavsky (1998) that in view of environmental and safety concerns the use CIPC may be restricted in future by several countries. Today, this can be realised from these evidences:

- Sweden with consumption of 160 g of potato/head/day and which is not on higher side has banned CIPC (Gomez-Castillo *et al.*, 2013).
- Besides using CIPC, countries like the Netherlands (with 257 g of potato being consumed/head/day) and Switzerland (with 114 g potato consumed/head/day) are also using S-carvone for sprout suppression at commercial scale (Gomez-Castillo *et al.*, 2013).
- Mexico has not registered any sprout suppressant to be used on potatoes (NAPPO, 2013). This is, in spite of having only 37 g of potato consumption/head/day.
- Japan, with very low potato consumption (58 g/head/day), is also not using CIPC for sprout suppression. Gamma irradiation facility at Hokkaido in Japan is one example of commercial use of irradiation to control sprouting on potatoes for fresh market consumption. It is treating more than 100,000 metric tons of potatoes annually for the consumption of potatoes in Japan (Olsen *et al.*, 2013).
- CIPC and its metabolic products can also be the potential threat to environment as pollutants.

Some details justifying that CIPC and its metabolic products are threat to environment as pollutants are as follows. CIPC is slightly volatile and it undergoes temperature dependent volatilisation (EXTOXNET, 1993; WSSA, 1989). The volatilisation of CIPC may get enhanced when it is mixed with a carrier like methanol (used as a solvent of CIPC for giving fogging treatment). In this way, CIPC not only poses the health threat to the workers within the storage space but also to the immediate environment and to the people in the nearby areas. CIPC is also sparingly soluble in water, about 89 mg per litre (NAPPO, 2013; O'Neil *et al.*, 2006). As a routine practice, after the removal of potatoes (meant for processing) from store they are subjected to washing/blanching. This results in the fraction of CIPC move along with the washed out water (Park, 2004) and becoming a possible source of contamination to water bodies. Further, environmental issues relating to one of the major breakdown and highly toxic product of CIPC, i.e. 3-CA, was also documented by many workers (Mohammed *et al.*, 2014; Park, 2004; Sihtmaee *et al.*, 2010). It is already pointed out that the breakdown of the CIPC into 3-CA can occur during application of CIPC (due to thermal fogging) inside the potato tuber during the period of storage (due to microbial degradation). Unlike CIPC, 3-CA has higher volatility and toxicity than its parent compound itself (Park, 2004). Thus, the 3-CA has more potential and poses higher risk as environmental pollutant (Mohammed *et al.*, 2015; Park, 2004). Possibility of this happening on regular basis is quite high because ventilation of stores just after the treatment with CIPC is considered as one of the important instructions and essential components of overall process of CIPC treatment. Besides this, frequent and regular ventilation of stores is also practiced to avoid the build-up of higher concentration of CO_2 inside the store. Thus, the movement of CIPC and 3-CA outside the storage area into the open environment must be taking place. In fact, a study by Bos *et al.* (2011) has actually shown the emission of CIPC from the store to the outside environment *via* ventilation air and air leaks. As per this study, the largest CIPC emission took place just after the potatoes had been stored and during the second CIPC treatment. During the remainder of the storage period, the emission on an average was about 2.8 g CIPC per day. This study has however not taken into consideration the emission of 3-CA from the store environment to the open air. But, this study indirectly provide proof for the 3-CA as well because the volatility of 3-CA is higher than the CIPC. In this way, the CIPC and its metabolic products pose threat to environment as pollutants.

It was proposed by Sakaliene *et al.* (2009) that till there is a proper risk assessment and risk management strategies for residue and other issues related with CIPC, especially on the most vulnerable groups such as infants and children, attention should be focused on the use of those potato cultivars that exhibit storage potential of 6 or more months without the CIPC treatment. But the use of CIPC is still continuing as potato sprout suppressant due to its effectiveness, wider use with strong commercial base and also in view of non-availability of any other alternative with equal efficacy and economic viability. This is happening in spite of growing evidences on health related issues and environmental safety due to CIPC and its break-down products. At the same time it is a known fact that in absence of any sprout suppressant potatoes can only be stored for about 3 to 4 weeks and this will result in enormous loss to potatoes and potato processing industry.

Today, a relook is needed with more of environmental and eco-friendly considerations along with a vision that should not overemphasise only the commercial angle of CIPC. There is a need to take into consideration the long-term effects and far reaching implications of toxic residues and contaminants that are either present in edible commodity or can be formed later in the human body (during the process of its breakdown, metabolism or in the process of digestion) on the consumption of treated commodity or products made from it. Further, it is not only the toxicity or harm to humans that is to be kept in mind but there is a definite need to address similar concerns for immediate and critical components of our ecosystem as well. This can be understood very well from the fact that out of the total potato production, around 60% is utilised by humans, about 15% is used as seed tubers for the next year planting and the remaining 20 to 25% is used for industrial purpose, pharmaceutical products and as feed for animals (Topcu *et al.*, 2010). The last use of potatoes once again indicates the similar type of risks and concerns for animals as well.

At present, no method is available that can rapidly degrade CIPC into totally non-toxic products or that can decontaminate the storage space/cold store where the CIPC application was done (Paul *et al.*, 2016). The urgency and the need for such a method can be judged from the fact that due to prolong and continuous use of CIPC there is gradual accumulation of CIPC and its breakdown products. As per Smith and Bucher (2012), about 2/3 of the CIPC which is applied to stored potatoes is actually retained by storage space/store fabric and its immediate surroundings (atmosphere, soil and water). The toxicity and hazards due to this and the built-up levels of CIPC have now started getting the attention. Yet another important issue with CIPC is its cross-contamination (http://tinyurl.com/ybgah7yh; Park, 2004). This can happen to other edible commodities, which are being either stored in the same cold store where the potatoes (treated with CIPC) are being stored or when such commodities are stored after the removal of potatoes from the store. The CIPC, which was used for treating the potato tubers in a given cold store, can be the source of cross-contaminate when it moves to distant places along with the potatoes and their baggage/boxes on their transportation from cold store to the market and other places.

7. Approaches/options to reduce the overall use of CIPC

In the recent past, efforts have been made to reduce the use of CIPC by:

- Enhancing the effectiveness and efficiency of CIPC.
- Use of sprout suppressants other than CIPC, especially those of botanical origin which are effective and safer such as essential oils like S-caraway, 1, 8-cineole, clove oil, mint oils, eucalyptus oil, etc., and SmartBlock® and via other sprout suppressants such as 1, 4-dimethyl naphthalene, 2, 6-diisopropyl naphthalene, 3-decen-2-one, gamma-irradiation, ethylene, ozone, UV-C light, etc., either alone or in sequence with only single application of CIPC.
- Timely and better storage technologies.
- Short-term storage of potatoes at 8-12 °C for 2-3 months without the use of any sprout suppressant.
- Short-term storage of potatoes at 8-12 °C for 3-5 months either with the use of any alternative of CIPC or with only single application of CIPC.
- Storage of potatoes for 2-3 months under ambient conditions by selecting suitable on-farm/traditional method of potato storage. Traditional methods for storing potatoes are being practiced world over. Some of the most common methods in this category are heap, pit, hanging bamboo baskets, bins, dark room storage and evaporative cool store, etc.
- Fulfilling the annual requirement of potatoes from at least two different geographical regions such as plains and hills so that the harvesting of potatoes can be done in different seasons. This practice extends the period of availability of fresh and short-term stored potatoes wherein no sprout suppressant is used. This approach is followed probably in the best possible way in Japan where potatoes are cultivated in all the four seasons (summer, winter, spring and fall). Japan has achieved this by breeding varieties that are suitable for each season and different regions of the country along with the ability to meet the different demands due to integration of suitable traits/quality parameters (Mori *et al.*, 2015).

Recent progress made in the understanding on toxicological profile of CIPC do emphasise upon the urgency and the need to overcome our dependency on only this sprout suppressant. Selecting and practicing a few or more approaches from the above listed options along with any new or innovative approaches will bring about overall reduction in the use of CIPC and this will also narrow down our existing dependency on CIPC. Above said approaches need to be strengthened in developed nations, especially where the average and daily consumption of potatoes (table or processed) on per capita basis is high (around 300 g or more) and CIPC is still the major chemical being used for suppression of sprout growth on potatoes. For the developing countries and the third world countries, more efforts in the direction of above listed approaches become important because till today most of these countries are primarily dependent only on the CIPC for the suppression of sprout growth on potatoes during storage. In addition to this, other problems such as insufficient and poor infrastructure, outdated storage facilities and tendency of indiscriminate and non-judicious use of CIPC also need the attention as they contribute towards higher residue levels and thereby higher risks in these countries.

8. Simple advisories

Some of the very simple and well known advisories such as peeling of potatoes, rigorous washing, soaking in water, blanching and using CIPC treated potatoes only after a gap of 21 days or more (from the time when the last CIPC treatment was given) have now become more relevant and essential to be followed. These simple steps can be easily practiced before the use of potatoes either for table or processing purposes. Above said advisories require minimum inputs but provide effective of lowering the residue of CIPC.

9. Researchable issues

In view of the present state of affairs and problems pertaining to CIPC, a few researchable areas that have now assumed priority are as follows:

- Developing potato varieties that are resistant to cold-induced sweetening so that the harvested potatoes can be stored for long-term at 2 to 4 °C (this storage temperature does not allow the sprout growth and thereby there is no need to use any of the sprout suppressant).
- To prolong the dormancy of potato up to 5-6 months or even more. This can either be done for varieties that are very popular and can serve the purpose of table as well as processing or new varieties with the trait of extended dormancy can be developed.
- Search for more effective, safer, novel, cost-effective and viable sprout suppressants should continue. One of the important examples in this direction is the possible use of beam of electrons.

Japanese researchers have reported that a quick dose of low-energy electron can stop sprouting on potatoes up to 4 months. For this, Van der Graaf generator was used to deliver a beam of electrons to potatoes moving along a conveyor belt. The electron beam works by preventing cell division within the sprout bud tissues, in a way similar to that of radiotherapy treatment that is being used to stop multiplication of cancer cells (Todoriki and Hayashi, 2004). In one way, the action of electron beam is comparable to that of CIPC.

In possibility of enhancing dormancy and delay in sprouting of potato tubers by altering the endogenous levels of strigolactones (SLs) also need to be probed. SLs are a class of plant hormones that inhibit shoot branching (Gomez-Roldan *et al.*, 2008). SLs participate in regulation of apical dominance (paradormancy) and thereby they also play major regulatory role in outgrowth of lateral buds (Dun *et al.*, 2009; Pasare *et al.*, 2013). Today many synthetic SL (analogs of SL) such as GR24, CISA-1, EGO10, etc., are available. External application of a synthetic SL near the base of mutant plants (deficient in SLs) was found to inhibit development of lateral buds above and thereby the mutants restore to normal branching. Experiments wherein SLs biosynthetic pathway was silenced by RNA interference suggest that decline in the levels of SLs (solely or in combination with other phytohormones) resulted in altered morphology of potato plants having more lateral and main branches, reduction in stolon formation, premature sprouting and excessive sprout branching (Pasare *et al.*, 2013). Tubers of these transgenic lines exhibited more of secondary growth and less of dormancy and thereby indicating a negative control of SLs on sprouting of potato tubers.

It is already known that phytohormones like cytokinins (CK) and gibberellin (GA) also play important roles in releasing the potato tuber from dormancy and thereby, in promoting the sprouting. Reactivation of meristem activity and growth of sprout on potato tubers require both the hormones, i.e. CK and GA. CK is essential in controlling the release from dormancy while, GA requires CK to stimulate the resumption of meristematic activity. But later on, GA is sufficient to support the sprout growth once the bud break (resumption of meristematic activity) has occurred (Hartmann *et al.*, 2011). Better understanding in this area led Sonnewald and Sonnewald (2014) to propose that SLs act as negative regulator downstream to GA and CK. Thus, the levels of SLs (solely or in combination with other phytohormones) appear to control tuber dormancy, sprouting and sprout branching. It is also important to mention that higher levels of SLs at whole plant level may not prove to be of much use as this might lead to altered plant morphology/architecture along with other deformities. So, in light of existing information, we hypothesise that enhancing the levels of SLs in the potato tubers may result in enhanced dormancy and delay in sprouting and sprout growth, although any abnormality/deformity in plant or tubers cannot be ruled out. But, any of such abnormalities or adverse effect can altogether be avoided by postharvest application of SL or its safe analogue. So, the above hypothesis needs to be tested in terms of the ability of SL to enhance the natural duration of dormancy of the potato tuber, since this has not been attempted so far.

References

Afek, U. and Warshavsky, S., 1998. Problems in storage of potatoes in Israel. In: Levy, D. (ed.) Potato in hot climate [in Hebrew with English abstract]. Israel Agresearch, Journal of the Agricultural Research Organization 9: 97-114.

Allison, R., 2015. Lower limit for potato sprout suppressant CIPC introduced. Farmers Weekly 1040: 1. Available at: http://tinyurl.com/ycqcs45o.

Ashton, F.A. and Crafts, A.S., 1981. Mode of action of herbicides (2nd Ed.). Wiley, New York, NY, USA.

Balaji, V., Chandra, S., Goswami, D.A., Das, S.K., Mandal, T.K., Chakraborty, A.K. and Bhattacharyya, A., 2006. Toxicokinetics, metabolism, and microsomal studies of chlorpropham in rats. CIPC Suppliers Prepared for Residue Limit 88: 527-539.

Bos, D., Van der Schans, D.A. and Losada, J.M., 2011. Air flow and chlorpropham (CIPC) emissions from a potato storage. PPO, Wageningen UR, Wageningen, the Netherlands.

Bradshaw, N. and Ogilvy, S., 2006. Food standards agency pesticide residue minimization crop guide – potatoes. Food Standards Agency, London, UK. Available at: http://tinyurl.com/y9l7u8me.

Camire, M.E., Bushway, R.J., Zhao, J.X., Perkins, B. and Paradis, L.R., 1995. Fate of thiabendazole and chlorpropham residues in extruded potato peels. Journal of Agricultural Food Chemistry 43: 495-497.

Carrera, G., Alary, J., Melgar, M.J., Lamboeuf, Y. and Pipy, B., 1998. Metabolism and cytotoxicity of chlorpropham (CIPC) and its essential metabolites in isolated rat hepatocytes during a partial inhibition of sulphation and glucuronidation reaction: a comparative study. Archives of Environmental Contamination and Toxicology 35: 89-96.

Cools, K., Del Carmen Alamar, M. and Terry, L.A., 2014. Controlling sprouting in potato tubers using ultraviolet-C irradiance. Postharvest Biology and Technology 98: 106-114.

Costa, E., Silva, M., Galhano, C.I.C. and Moreira da Silva, A.M.M.G., 2007. A new sprout inhibitor of potato tuber based on carvone/b-cyclodextrin inclusion compound. Journal of Inclusion Phenomena Macrocyclic Chemistry 57: 121-124.

Daniels-Lake, B.J., Pruski, K. and Prange, R.K., 2011. Using ethylene gas and chlorpropham potato sprout inhibitors together. Potato Research 54: 223-236.

Dun, E.A., Brewer, P.B. and Beveridge, C.A., 2009. Strigolactones: discovery of the elusive shoot branching hormone. Trends in Plant Sciences 14: 364-372.

El-Awady Aml, A., Moghazy, A.M., Gouda, A.E.A. and Elshatoury, R.S.A., 2014. Inhibition of sprout growth and increase storability of processing potato by antisprouting agent. Trends in Horticultural Research 4: 31-40.

European Commission (EC), 2012. Commission implementing regulation (EU) No 788 (2012). Concerning a coordinated multiannual control programme of the Union for 2013, 2014 and 2015 to ensure compliance with maximum residue levels of pesticides and to assess the consumer exposure to pesticide residues in and on food of plant and animal origin. Official Journal of the European Union L 235: 8-27.

European Food Safety Authority (EFSA), 2012. Review of the existing maximum residue levels (MRLs) for chlorpropham according to Article 12 of Regulation (EC) No 396/20051. EFSA Journal 10: 2584.

Extension Toxicology Network (EXTOXNET), 1993. Chlorpropham. Available at: http://tinyurl.com/6h3q37x.

Ezekiel, R. and Singh, B., 2007. Effect of cooking and processing on CIPC residue concentrations in potatoes and processed potato products. Potato Research 50: 175-184.

Ezekiel, R., Dahiya, P.S. and Shekhawat, G.S., 2002. Traditional methods of potato storage in the Malwa region of Madhya Pradesh. Technical Bulletin No. 57. Central Potato Research Institute (CPRI), Shimla, HP, India.

Ezekiel, R., Mehta, A., Singh, B., Kumar, D., Kumar, N.R., Paul, V. and Das, M., 2005b. CIPC [Isopropyl N-(3-chlorophenyl) carbamate] for sprout suppression in potatoes during storage. Technical Bulletin No. 69. Central Potato Research Institute (CPRI), Shimla, India.

Ezekiel, R., Singh, B., Kumar, D. and Paul, V., 2003. Processing quality and CIPC residue in potatoes stored at 10-12 °C in commercial cold stores applying CIPC. Indian Journal of Plant Physiology: 489-494.

Ezekiel, R., Singh, B., Kumar, D., Paul, V. and Das, M., 2005a. Storage of potatoes at 10-12 °C with CIPC treatment in commercial cold stores. Potato Journal 32: 211-212.

Farawela, J., 2009. Microbial degradation of carbamate pesticides. Available at: http://tinyurl.com/m5l54e.

Gomez-Castillo, D., Cruz, E., Iguaz, A., Arroqui, C. and Virseda, P., 2013. Effect of essential oils on sprout suppression and quality of potato cultivars. Postharvest Biology and Technology 82: 15-21.

Gomez-Roldan, V., Fermas, S., Brewer, P.B., Puech-Pages, V., Dun, E.A., Pillot, J.P., Letisse, F., Matusova, R., Danoun, S., Portais, J.C., Bouwmeester, H., Becard, G., Beveridge, C.A., Rameau, C. and Rochange, S.F., 2008. Strigolactone inhibition of shoot branching. Nature 455: 189-194.

Hartley D. and Kidd, H., 1991 The agrochemicals handbook (3rd Ed.). Royal Society of Chemistry Information Services, Cambridge, UK.

Hartmann, A., Senning, M., Hedden, P., Sonnewald, U. and Sonnewald, S., 2011. Reactivation of meristem activity and sprout growth in potato tubers require both cytokinin and gibberellin. Plant Physiology 155: 776-796.

Health and Safety Executive (HSE), 2009. EU maximum residue levels (MRLs) – basic guidance. HSE, Bootle, UK. Available at: http://tinyurl.com/ya8z5mks.

Kidd, H. and James, D.R. (eds.), 1991. The agrochemicals handbook (3rd Ed.). Royal Society of Chemistry Information Services, Cambridge, UK.

Kleinkopf, G.E., Oberg, N.A. and Olsen, N.L., 2003. Sprout inhibition in storage current status, new chemistries and natural compounds. American Potato Journal 80: 317-327.

Kumar, D., Paul, V. and Ezekiel, R., 2005. Chipping quality of potatoes stored in heap and pits in sub-tropical plains of India. Horticultural Science 32: 23-30.

McGowan, G., Duncan, H., Briddon, A., Cunnington, A., Jina, A. and Saunders, S., 2009. Research report – evaluation of the impact of modified storage practices on sprout suppression. Potato Council, Stoneleigh, Warwickshire, UK.

Mehta, A. and Singh, B., 2016. On-farm storage of table and processing potatoes in heaps. Indian Journal of Horticulture 73: 82-86.

Mehta, A., Singh, B., Ezekiel, R. and Kumar, D., 2010. Effect of CIPC on sprout inhibition and processing quality of potatoes stored under traditional storage system. Indian Potato Research 53: 1-15.

Mohammed, N.M.S., 2012. Extraction and HPLC analysis of potato sprout suppressant chemicals. PhD thesis, University of Glasgow, Glasgow, UK. Available at: http://theses.gla.ac.uk/3454.

Mohammed, N.M.S., Flowers, T.H. and Duncan, H.J., 2014. Development and validation of an HPLC method for the analysis of chloropropham and 3-chloroaniline in potato extract. Chromatography Research International, Article ID: 108694.

Mohammed, N.M.S., Flowers, T.H. and Duncan, H.J., 2015. HPLC-UV method for analysis of potato sprout inhibitor chloropropham and its metabolite 3-chloroaniline in potatoes. IOSR Journal of Environmental Science, Toxicology and Food Technology 9: 78-85.

Mori, K., Asano, K., Tamiya, S., Nakao, T. and Mori, M., 2015. Challenges of breeding potato cultivars to grow in various environments and to meet different demands. Breeding Science 65: 3-16.

Noel, S., Huyghebaert, B., Pigeon, O., Weickmans, B. and Mostade, O., 2004. Study of potato sprout inhibitor treatments with chlorpropham (or CIPC). Aspects of Applied Biology 71: 65-73.

North American Plant Protection Organisation (NAPPO), 2013. NAPPO science and technology documents – ST 02: efficacy of potato sprout control products to minimize sprout production. NAPPO, Raleigh, NC, USA.

O'Neil, M.J., Heckelman, P.E., Koch, C.B., Roman, K.J., Kenny, C.M. and D'Arecca, M.R., 2006. The Merck index – an encyclopedia of chemical, drugs, and biologicals (14th Ed.). Merck and Co Inc., Whitehouse Station, NJ, USA.

Olsen, N., Frazier, M.J. and Kleinkopf, G., 2013. High-energy ionizing treatment for potato sprout control. Available at: http://tinyurl.com/y9euxfay.

Orejuela, E. and Silva, M., 2005. Rapid determination of aniline metabolites of chlorpropham in potatoes by micellar electrokinetic chromatography using negative-charged mixed micelles and laser-induced fluorescence detection. Electrophoresis 26: 2991-2998.

Park, L., Duncan, H., Briddon, A., Jina, A., Cunnington, A. and Saunders, S., 2009. Review and development of the CIPC application process and evaluation of environmental issues. AHDB-Potato Council, Agriculture and Horticulture Development Board, Kenilworth, UK.

Park, L.J., 2004. Chlorpropham distribution in potato stores and evaluation of environmental issues relating to its use. PhD thesis, University of Glasgow, Glasgow, UK. Available at: http://theses.gla.ac.uk/4402/1/2004ParkPhD.pdf.

Pasare, S.A., Ducreux, L.J.M., Morris, W.L., Campbell, R., Sharma, S.K., Roumeliotis, E., Kohlen, W., Van der Krol, S., Bramley, P.M., Roberts, A.G., Fraser, P.D. and Taylor, M.A., 2013. The role of the potato (*Solanum tuberosum*) *CCD8* gene in stolon and tuber development. New Phytologist 198: 1108-1120.

Paul, V. and Ezekiel, R., 2013.Scientific storage options crucial for potatoes. Agriculture Today, New Delhi, India.

Paul, V., Ezekiel, R. and Pandey, R., 2016. Sprout suppression on potato: need to look beyond CIPC for more effective and safer alternatives. Journal of Food Science and Technology 53: 1-18.

Paul, V., Ezekiel, R., Pandey, R. and Kumar, D., 2014. Potential of glyphosate as a sprout suppressant of potato (*Solanum tuberosum* L.) tubers during storage. Indian Journal of Plant Physiology 19: 293-305.

Ritchie, W., Boyd, I.M.G. and Duncan, H.J., 1983. A method for the determination of chloropropham residues in crisps and crisp frying oil. Potato Research 26: 73-77.

Sakaliene, O., Koskinen, W.C., Blazauskiene, G. and Petroviene, I., 2009. Level and fate of chlorpropham in potatoes during storage and processing. Journal of Environmental Science and Health, part B 44: 1-6.

Sanli, A., Karadogan, T., Tonguc, M. and Baydar, H., 2010. Effects of caraway (*Carum carvi* L.) seed on sprouting of potato (*Solanum tuberosum* L.) tubers under different temperature conditions. Turkish Journal of Field Crops 15: 54-58.

Sawyer, R.L. and Malagamba, J.P., 1987. Sprout inhibition. In: Talburt, W.F., Smith, O. (eds.) Potato processing. Van Nostrand Reinhold, New York, NY, USA, pp. 183-202.

Sihtmaee, M., Mortimer, M., Kahru, A. and Blinova, I., 2010. Toxicity of five anilines to crustaceans, protozoa and bacteria. Journal of Serbian Chemical Society 75: 1291-1302.

Singh, B. and Ezekiel, R., 2010. Isopropyl *N*-(3-chlorophenyl) carbamate (CIPC) residue in potatoes stored in commercial cold stores in India. Potato Research 53: 111-120.

Skidmore, M.W., Paulson, G.D., Kuiper, H.A., Ohlin, B. and Reynolds, S., 2002. Bound xenobiotic residues in food commodities of plant and animal origin. Pest Management Science 58: 313.

Smith, M.J. and Bucher, G., 2012. Tools to study the degradation and loss of the *N*-phenyl carbamate chloropropham – comprehensive review. Environment International 49: 38-50.

Sonnewald, S. and Sonnewald, U., 2014. Regulation of potato tuber sprouting. Planta 239: 27-38.

Todoriki, S. and Hayashi, T., 2004. Sprout inhibition of potatoes with soft-electron (low-energy electron beams). Journal of the Science of Food and Agriculture 84: 1989-2144.

Topcu, Y., Uzundumlu, A.S. and Guler, I.O., 2010. Economic effectiveness analyses of potato farms: the case of Erzurum province, Turkey. Scientific Research Essays 5: 2560-2566.

United States Environmental Protection Agency (US EPA), 1996. Registration eligibility decision (RED) – Chlorpropham (EPA-738-R-96-023). EPA, Washington, DC, USA.

United States Environmental Protection Agency (US EPA), 2002. EPA completes CIPC reassessment. Potato grower. EPA, Washington, DC, USA. Available at: http://tinyurl.com/y8sufhnm.

Van Es, A. and Hartmans, K.J., 1987a. Starch and sugars during tuberization, storage and sprouting. In: Rastovski, A. and Van Es, A. (eds.) Storage of potatoes: post-harvest behavior, store design, storage practice and handling. Pudoc, Wageningen, the Netherlands, pp. 79-113.

Van Es, A. and Hartmans, K.J., 1987b. Dormancy, sprouting and sprout inhibition. In: Rastovski, A. and Van Es, A. (eds.) Storage of potatoes: post-harvest behaviour, store design, storage practice, handling. Pudoc, Wageningen. the Netherlands, pp. 114-132.

Vaughn, K.C. and Lehnen, L.P., 1991. Mitotic disrupter herbicides. Weed Science 39: 450-457.

Weed Science Society of America (WSSA), 1989. Herbicide handbook of the WSSA Herbicide Handbook Committee (6th Ed.). WSSA, Champaign, IL, USA.

Wustman, R., Haverkort, A., Zhang, X. and Rathee, G., 2011. An overview of the potato sector in India and prospects of Indo and Dutch cooperation. Project No. 3250214811. Applied Plant Research, Wageningen UR, Wageningen, the Netherlands. Available at: http://edepot.wur.nl/192686.