Sustainable bush produce systems – Post-harvest storage of *Solanum centrale* and impact on produce quality

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Sustainable bush produce systems –
Post-harvest storage of *Solanum centrale*
and impact on produce quality

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2009
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<td>APY</td>
<td>Anangu Pitjantjatjara Yankunytjatjara</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>DKCRC</td>
<td>Desert Knowledge Cooperative Research Centre</td>
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<tr>
<td>LT</td>
<td>Lethal temperature</td>
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<tr>
<td>NT</td>
<td>Northern Territory</td>
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<td>SA</td>
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<td>SPSS</td>
<td>Statistical Package for the Social Sciences (when first released in 1968)</td>
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<td>TPY</td>
<td>Tanglun Piltengi Yunti</td>
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Sustainable bush produce systems – Post-harvest storage of Solanum centrale and impact on produce quality
Introduction to the sustainable bush produce systems project

*Solanum centrale* (JM Black) is the focal species of the research reported here because it has an existing commercial value and has provided the bulk of commercial bush food produce sourced from desert Australia. The standard common name in the Northern Territory and Western Australia for *S. centrale* is Desert raisin (Latz 1995, HWA 1998, Albrecht et al. 2007). The fruit resembles a raisin in size and shape but certainly not in taste. The wider native food industry calls this fruit the bush tomato (Robins & Ryder 2004). Note that in central Australia the fruit of other species is commonly called bush tomato (Latz 1995). All Aboriginal dialects have names for the plant, which include Akatyerr(e), Katyerre, Kampurarrp and Yakajirri. This report consistently uses the Latin species name *Solanum centrale* when referring to the plant or to the fruit of the plant.

*Solanum centrale* is found naturally throughout the central and western desert regions of Australia (SA, WA and NT) that are low rainfall, arid regions (Figure 1 & Photo 1).

*Solanum centrale* has been, and still is, an important food plant for Aboriginal people in desert Australia. It is a plant that requires water (from rainfall or irrigation) for flowering and fruiting; however, it is well able to withstand and survive periods of drought. The plant responds positively to disturbances such as fire and mechanical damage (e.g. roadside grading) (Latz 1995).

In the modern native foods industry, which dates back approximately 30 years, the fruit of *S. centrale* has held an important place. The fruit has been in demand over this period and continues to be sought after as an ingredient for a variety of end uses in the food industry.

The fruit is often allowed to sun-dry on the plant, so that before harvesting it appears shrivelled and dark red-brown in colour (Robins & Ryder 2004); but it is also harvested for customary and commercial use as ripe, yellow fruit, which can then also be sun-dried.

*Figure 1: Approximate Solanum centrale distribution* (Robins & Ryder 2004)  
*Photo 1: Solanum centrale plant*
Research on native foods in Australia has increased over the past 10–15 years (see research reports published at www.rirdc.gov.au). This has resulted in a series of reports that have dealt with issues from food safety, toxicology (Hegarty et al. 2001) and market prospects (Cherikoff 2000) to the cultivation of either specific species or a range of species (Ryder & Latham 2004). However, there has been little coordinated effort in native food research across the value chain in a single project, nor has there been such a serious attempt to engage Aboriginal people in the participatory approach undertaken in this project. The research reported here focused primarily on desert native food species with a particular focus on *S. centrale*.

The native foods industry is largely based on traditional Aboriginal knowledge of what is edible from the Australian flora and fauna. The industry also involves Aboriginal people at various levels. However, there are many unresolved issues relating to the roles played by Aboriginal people and subsequent questions about what benefits they may be gaining from the industry. Traditional knowledge and traditional methods are being used, but little is really known about how Aboriginal people may wish to be involved, nor how they are either benefiting from, or being bypassed by other participants in, the industry.

The industry itself is still growing and suffers from the well-known problems of fledgling new crop industries (Fletcher & Collins 2004a, 2004b). These include, for example, matching supply with demand, market development, development of production capacity, education and awareness. The industry is also based on a small number of small to medium businesses, which are not able to make large investments in research and development. Also, the industry tends to be fragmented, although some industry participants certainly favour cooperative approaches.

In the case of the Australian native food plants we have the added challenge of plant domestication (in the western scientific sense). For many desert food plants there is a wealth of genetic diversity that could be developed appropriately to generate wealth for the people of the desert region from which the plants came.

One of the major goals of the Desert Knowledge CRC (DKCRC) is to facilitate the development of enterprises by Aboriginal communities or interests that will improve their livelihoods. Such enterprises will need to be focused on species that have the potential to provide an income stream for participants. *Solanum centrale* has been identified as a species that has growing market demand and is therefore emerging as an important bush food plant. It is being cultivated in various parts of Australia, including SA, NT and WA, but it is thought that a large proportion of fruit currently going into commercial food products is harvested from the bush.

This project aimed to help the native foods industry expand, focusing on desert species, especially *S. centrale*. For example, we aimed to create opportunity through genetic and plant improvement studies, accompanied by the development of appropriate intellectual property–sharing models. We also aimed to facilitate the sustainable development of bush harvest activity and to solve problems in post-harvest storage of produce.

The research team looked to build effective partnerships with Aboriginal people who are involved in both bush harvest and cultivation of bush produce, through cross-cultural learning about the value of traditional methods to the native foods industry. This research intended to address one of the major and ongoing goals of the DKCRC, which is to facilitate the development of enterprises by Aboriginal people or interests that will improve livelihoods by providing an alternative source of income for desert Australians.
Components of the sustainable bush produce systems project

The project is based around a value chain approach (Figure 2) in which the research subprojects are targeted as areas of weakness and where maximum benefit to desert people can be gained.

The set of subprojects that formed the first round of work in this area was developed from a stakeholder workshop held in Adelaide in March 2004. Project proposal development continued through substantial liaison with industry and researchers until October 2004. A second stakeholder workshop was held during the project (October 2005) to report results and to obtain stakeholder feedback.

The research comprised the following subprojects:

- Sustainable bush harvest
- Post-harvest storage and produce quality
- Horticultural production of *Solanum centrale*
- Genetics and plant improvement
- Steroidal glycoalkaloids in the fruit of *Solanum centrale*
- Aboriginal livelihoods and the emerging bush produce industries.

This report describes the results from the second of these sub-projects. Brief details of the other sub-projects can be found below. The results from these components are reported in Ryder, Walsh et al. (2009).
Sustainable bush harvesting: exchanges between traders and harvesters

This subproject examined factors that influenced the sustainability of harvest from natural (‘wild’) populations of bush food seeds and fruits. In central Australia, there has been a small-scale commercial trade in bush produce for more than 30 years. This research focused on exchanges between traders and harvesters, because they were found to be critical to the sustainability of trade within the context of the wider economic value chain. Traders were both Aboriginal- and non-Aboriginal- owned businesses. Subsequent research focuses on bush harvest activity exclusively conducted by Aboriginal harvesters.

The research investigated the nature of trader operations in terms of who managed the businesses and how, what species were traded for what purpose, from where those species were sourced, what tasks and roles the traders fulfilled and what motivated them. The research then identified key sustainability factors that underpinned the exchanges between Aboriginal harvesters and the trader enterprises.

Major findings included identification of the critical roles trader enterprises fulfilled, the influence of rainfall on extreme variations in trade weights for particular species and trade in a suite of species for food and land rehabilitation purposes. Bush resource harvesting and trade has provided a relatively small, highly variable income for traders and harvesters over many years. Traders have developed multiple strategies to accommodate this variation. There appear to be significant non-monetary benefits from trade, but these were insufficient for either traders or harvesters to be reliant upon trade as a sole income. A preliminary assessment of the ecological sustainability indicated low species vulnerability to overharvest and likely secondary ecological benefits from careful harvest management such as monitoring and burning. Assessments of ecological sustainability of the central Australian trade were confounded by extrinsic ecological drivers (rainfall). Furthermore, it was concluded that in central Australia social and economic factors had a more powerful influence upon the sustainability of bush resource trade than ecological factors.

Horticultural production of Solanum centrale

While bush harvest activity is important and should remain as a component of the native foods industry, horticultural production of native food plants is also desirable, and is increasing, for several reasons. For crops such as S. centrale, supply from the bush is highly variable, with a good crop occurring only every 5–8 years, depending on seasonal conditions. Minor harvests can be expected in between these high yield events, but the key point is that supply is highly irregular and unpredictable.

In order to develop in an organised way, the native foods industry needs to have access to quality produce that is available reliably, in appropriate quantity. Also, while many Aboriginal groups in the desert region do have access to bush harvest activity, not all communities have this option. Aboriginal groups in the urban and peri-urban areas also may wish to participate in the native foods industry and one way to do this is via horticultural production. Indeed, communities that engage in bush harvest may want to cultivate S. centrale, for example, to ensure reliable supply when the bush harvest is poor. In addition, western-style crop improvement has begun with some of the desert region native food species (e.g. S. centrale, limes, quandong), and these improved plants must be cultivated from nursery-propagated stock plants.

The actual horticultural production systems are in the very early stages of development. It is not known, for example, how S. centrale must be managed in horticultural production to ensure a reliable yield year after year. The management of S. centrale in cultivation may well be improved by utilising local Aboriginal knowledge about augmentation or management of the bush harvest (e.g. by soil disturbance, water management, fire management; see Peterson 1979).

In this sub-project, S. centrale plants originating from four different locations or regions in central Australia were planted in small horticultural plots in four locations (e.g. on outstations) to help us determine what characteristics have genetic versus environmental origins. We also aimed to find out more about how to produce good quality S. centrale crops.
Genetics and plant improvement of *S. centrale*
This subproject aimed to examine the development of new food products with a distinctly Australian flavour. New product development and market acceptance requires reliable sources of marketable product, preferably with highly valued palatability. At present, desert bush foods are primarily obtained for market through bush harvest activities, with some efforts to establish plantations. The bush harvest plant material collected is highly variable, both in availability and palatability. Thus, for the benefit of industry development, we need to understand the basis of variability in plant characteristics, both desirable and undesirable.

Plant variability is determined by a combination of genetic and environmental factors. Many key plant traits are controlled by plant genotype. Traits such as palatability are the result of a combination of gene products, usually involved with plant anti-herbivory defences. One of the first steps in the production of cultivated lines is to establish the basis for plant variability in wild populations and identify a desirable plant ‘ideotype’. Taking this approach using morphological, environmental and genetic tools, a detailed understanding of how the plants vary may be established.

The research conducted in this subproject aimed to contribute to the future success of both the bush harvest activity and the cultivation of *S. centrale*. Aboriginal communities in the desert region are interested in cultivation of these native food crops, and some have begun to do so. Given that the produce is, or can be, grown for both local community use and sale to the commercial sector, this research can potentially also benefit the industry as a whole in several ways.

Steroidal glycoalkaloids in the fruit of *Solanum centrale*
The fruit of many *Solanum* species contain steroidal glycoalkaloids, which are bitter and toxic compounds. Whether these glycoalkaloids present a problem with food safety and taste in foods derived from *Solanum* depends on the chemical nature of the glycoalkaloids and the levels present in the produce. For example, the outer layer of greened potatoes contains high levels of the compounds α-solanine and α-chaconine (Friedman 2006). While the immature green fruits of *S. centrale* are very bitter, the ripe fruits are very often sweet or only slightly bitter. Hegarty et al. (2001) reported that the main glycoalkaloid present in the fruit of *S. centrale* was β2-chaconine. As a result of their research, Hegarty et al. (2001) recommended that commercial batches of bush tomato be monitored for levels of glycoalkaloids.

In this project we investigated the nature and levels of glycoalkaloids present in the fruit of *S. centrale* in an attempt to confirm the results of Hegarty et al. We were unable to find evidence of β2-chaconine but did find a number of other steroidal glycoalkaloids and closely related compounds in the ripe and in the green fruit. The pattern of glycoalkaloid compounds present appeared to vary between *S. centrale* from obtained different sources.

Aboriginal livelihoods and the emerging bush produce industries
The aims of this PhD project are to generate knowledge of the impacts of involvement in bush produce industries on Aboriginal people and communities using a participatory action research approach. This includes consideration of how Aboriginal people and communities participate, how they prefer to participate, and how they can be involved to maximise the benefits to them.

There are numerous potential benefits from involvement in the industry, but there is also a range of potential negative impacts. This project investigated the underlying assumption that involvement in bush produce industries is inevitably good for Aboriginal people and their communities and aimed to provide a foundation for future developments that maximise the benefits and minimise the negative impacts.
The project uses a ‘sustainable livelihoods’ framework developed specifically for Australian contexts, and a case study methodology. This subproject began in February 2006. The candidate has engaged with the residents of Aboriginal settlements where case studies and data collection have begun.

Concluding remarks
The research strategy in the sustainable bush produce systems project was to develop a coordinated set of sub-projects that targeted several points along the bush foods value chain. The bush foods industry had already identified a serious problem with the long-term storage of S. centrale fruit after harvest. We therefore considered this an important topic for research. Insect pest infestations in stored S. centrale fruit have been common, leading to both a loss of product and also a loss of confidence in the ability to purchase quality produce in sections of the industry. We established a sub-project with the aims of identifying the main insect pests of stored S. centrale fruit and then developing suitable and effective pest control methods. The report that follows presents the results of this research.
Post-harvest storage of *Solanum centrale* and impact on produce quality

Maria José de Sousa-Majer, Zora Singh, Francis de Lima and Maarten Ryder

**Introduction**

*Solanum centrale* fruit production is still mostly by bush harvesting, but small-scale commercial cultivation is starting in locations such as the Yorke Peninsula through to Riverland, South Australia, Ceduna, Murray Bridge and central Australia. There is an important supply chain for *S. centrale* that provides a valuable income for Aboriginal people.

This native crop is one of the most marketable products from the Australian native food industry, and it is used as an exotic flavouring in seasoning. It is now marketed by national supermarkets and its acceptance by the international food industry is growing (Robins & Ryder 2004). In the green stage (immature), *S. centrale* should not be harvested for human consumption because it contains glycoalkaloid toxins similar to the toxins found in green potato (Ryder, O’Hanlon et al. 2009). The fruit should be left to dry out on the plant; otherwise it will be need to be further dried after harvesting (Robins & Ryder 2004). Unfortunately, insects such as the Pumpkin beetle and a relative of the Rutherglen bug can attack the plant and fruit (Hele et al. 2006). Storage of post-harvest bush fruit has been found to be a challenge, much as it is with any other dried fruit commodity.

**General problems with stored-product pests in commodities**

Stored-product pests have a major economic impact on the food industry due to the costs associated with their treatment and monitoring, plus rejection and return of contaminated products due to failure to pass inspection or to meet the country’s quarantine regulations (Campbell & Arbogast 2004). An elegant review about post-harvest entomological research reported that the dried fruit and tree nut industries in the San Joaquin and Sacramento Valleys of the USA annually produce commodities worth about $2.5 billion, meaning that these are relatively high value commodities (Throne et al. 2003). All of this is potentially at stake, as the market for post-harvest dried fruits and nuts has much lower tolerance for insect infestation than markets for other durables, particularly when the product is destined for foreign markets. An equivalent problem exists with *S. centrale*.

Worldwide, the Indian meal moth, *Plodia interpunctella* Hübner (Lepidoptera: Pyralidae), is a major pest problem during processing and storage of dried fruit and nuts. Its importance as a stored-product pest is followed by the Rust red flour beetle, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae), the Sawtoothed grain beetle, *Oryzaephilus surinamensis* L. (Coleoptera: Silvanidae) and the Warehouse beetle, *Trogoderma variabile* Everts (Coleoptera: Dermestidae).

These stored-product pests are major or secondary pests that attack many commodities around the world. Post-harvest pests of dried fruit and nuts can be divided into two categories: pests that infest product in the field and which are brought into storage; and pests that infest product after it reaches storage (Throne et al. 2003). These insects infest flourmills, oats, macaroni, sugar, spices, breakfast food, raisins and other dried fruits. They are found anywhere where cereal products and other dried foods are processed and stored. It is not a surprise then, that these stored-product pests are a problem with *S. centrale* in storage. Tarr et al. (1994) reported that surveys of Australian dried fruit processors have confirmed the presence of the first three insect species in recent years.
The need to eliminate methyl bromide fumigation to control insects in stored commodities was addressed under the terms of the Montreal Protocol (United Nations Environment Programme 1998). Some storage facility managers have shown increased interest in the usage of high temperature (Tang et al. 2000, Hansen et al. 2004) and/or vacuum treatment (Mbata & Phillips 2001, Finkelman et al. 2004) to control insects, a trend that is driven by a need to maintain the quality of the product. Public awareness of the health benefits of fruit/vegetables is increasing, and interest in food without chemical residues is growing.

Based on traditional Aboriginal knowledge of what is edible in the Australian flora, the native food industry is encouraging research for plant improvement (Cribb et al. 2005). As mentioned before, \textit{S. centrale} is one of the most marketable products from the Australian native food industry (Robins & Ryder 2004). Therefore, the use of non-chemical approaches to control any stored-product pests on it, plus knowledge of the beneficial effects of this crop, would increase its uptake by national supermarkets and its wider acceptance by the international industrial food industry.

**Non-chemical controls for stored-product pests**

**Use of high temperature treatment to control stored-product pests**

High temperatures can be used in bulk grain stores and building structures for disinfestation, and this treatment has been used in the USA for over 50 years (Nickson & Firth 2000). The recent increased interest in heat treatment for disinfestation has to be considered against the need to develop a rapid, reliable and economic strategy for disinfestation (Qaisrani & Banks 2000).

Several potential ways for disinfesting products include: a) ordinary heat: e.g. fluidised bed or spouted bed, conductive, convective or pneumatic conveying; and b) radiative heat: e.g., infrared, microwave or radio frequency (Banks 1998).

A useful way to eradicate all stages of Cowpea weevil, \textit{Callosobruchus maculatus} (L.) (Coleoptera: Bruchidae) in stored grain is by solar heating using a dark cloth and translucent plastic sheeting. Under plastic, with temperatures reaching $>60^\circ$C and with exposure time of approximately 100 minutes, this treatment has been reported to be highly successful (Murdock & Shade 1991, Vincent et al. 2003). In India, all stages of \textit{Callosobruchus} spp. were killed in polyethylene bags when Pigeonpea, \textit{Cajanus cajan} (L.) Millisp. was exposed to solar heat (Chauhan & Ghaffar 2002, Vincent et al. 2003).

The mortality of insects depends on the temperature and the time for which they are exposed; the effect also varies from insect to insect (Qaisrani & Banks 2000). According to Banks (1998), who considered grain disinfestation, there are several attributes of an ideal disinfestation process, and heat treatment scores well when placed against these attributes. Its attributes include being cheap, fast and intrinsically safe; the ability to maintain or improve food quality; minimal environmental impact; low global warming potential; no registration requirement; and versatility. Heat treatment is thus considered to be a non-toxic alternative to chemical insecticides for the control of insects in stored products (Banks 1998, Dowdy & Fields 2002, Fields 1992).

High temperatures increase the respiratory and metabolic rates of exposed insects, consequently causing rapid mortality from increased heat stress (Adler et al. 2000, Mbata & Phillips 2001). Mbata and Phillips (2001) reported that \textit{P. interpunctella} is more susceptible to higher temperatures, such as 33–40°C, than \textit{T. castaneum} and \textit{Rhyzopertha dominica} (F.) (Coleoptera: Bostrichidae) (Lesser grain borer). Their results are supported by those of Johnson et al. (1995). Nevertheless, heat treatment to kill insects in stored products normally requires temperatures up to 50°C for many hours, consequently causing damage to the food products (Burks et al. 2000). Banks (1998) and Qaisrani and Banks (2000) reported that there appears to be a ‘window of opportunity’ between the heat dosage (temperature x time) required to kill insects and that which causes significant damage to the grain. The negative effect of heat treatment could be minimised if a good controller dryer is used, and also if rapid cooling is
applied immediately after the heat treatment (Banks 1998). Products such as *S. centrale* are known to grow in high temperature environments, so they may not be so adversely affected by high temperature treatments as other crops can be.

**Use of vacuum low-pressure treatment to control stored-product pests**

Another non-toxic approach to disinfestation and to extend the post-harvest life of fruit is to subject the product to controlled or modified atmosphere (Ke & Kader 1992, Whiting et al. 1992, Chervin et al. 1996, Donahaye & Navarro 2000). The use of low pressure to control stored-product pests was initially investigated by Back and Cotton (1925), followed by many others, such as Calderon et al. (1966), Calderon and Navarro (1968), Navarro and Calderon (1972) and Navarro and Donahaye (1972). Bailey (1965) demonstrated how low oxygen concentration, rather than high carbon dioxide in hermetic storage, caused mortality of stored-product insects in grain. For quarantine infestation treatment to be used at an industrial scale, a gas-tight structure that can be used either for modified atmosphere or hermetic storage has been developed and used (Navarro et al. 1994; Navarro et al. 2001a). De Lima (1990) elegantly demonstrated that low pressure is more effective at high temperatures. Also, most applications of controlled atmosphere are developed in large containers, such as those for transport and silos, usually leading to a reduction of O$_2$ and an increase of CO$_2$ (Chervin et al. 1996). The direct physiological response to reductions of O$_2$, increases of CO$_2$, or a combination of both, can stimulate increased spiracle opening, leading to water loss and eventual desiccation of the pests (Wigglesworth 1972, Damcevski et al. 1998).

At low pressure, the egg stage has been shown to be the most resistant in all species tested, such as *P. interpunctella*; Cocoa moth, *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae); *T. castaneum*; and Lesser grain borer, *R. dominica* (Finkelman et al. 2003a, 2004; Mbata & Phillips 2001). Finkelman et al. (2004) reported on a study of the efficacy of vacuum-hermetic technology (i.e. the effects of low pressures and exposure times) on the mortality of insects at 30°C under storage conditions. Higher temperature under low pressure presumably increased the respiratory and metabolic rates of exposed insects, consequently causing more rapid mortality from increased stress due to low oxygen levels (Adler et al. 2000; Mbata & Phillips 2001). However, storage under low pressure can prevent oxidation processes within stored commodities, with consequent loss of aroma and flavour (e.g. in cocoa beans – Challot & Vincent 1977; Finkelman et al. 2003a, 2004; Tarr & Clingeleffer 2005). Challot & Vincent (1977) used polyethylene bags to apply and maintain a low pressure of 600 mmHg to preserve the quality of the product. Although this procedure prevents the ingress of insects, storage insects can tolerate this pressure, and a low pressure below 100 mmHg might be required (Navarro et al. 2001b).

In Australia, Tarr and Clingeleffer (2005) reported that 100% mortality of *T. castaneum* adults was obtained in 500 g hermetically sealed packs of sultana raisins using a commercial O$_2$ Ageless® absorber at 30°C / 9 days, or 22.5°C / 20 days. However, adults at 15°C / 45 days produced variable results, with mortality around 40%. Eggs and pupae survived at 15°C / 45 days, and mortality was not significantly different from the control. It therefore appears that this treatment at temperatures above 30°C presents an advantage in relation to others, as no toxic chemicals are used (Finkelman et al. 2003b).

**Aim of this investigation**

The main objective of this research was to develop a post-harvest handling (storage) system for wild and cultivated *S. centrale* crops that is of benefit to the industry, to Aboriginal communities and to national and international consumers. The first step of this subproject was to identify the insect pest(s) that affect *S. centrale* fruit in the wild and in storage. Following from this survey work, the aim was to test the effectiveness of different methods of pest control and to try to ensure that produce quality is maintained during and after treatment.
To summarise, the specific objectives of this pilot study were:

1. to establish the best approach to post-harvest disinfestation of *S. centrale* fruit
2. to examine the impact of high temperature on the mortality of its insect pests
3. to test the possibility of using vacuum treatment alone at room temperature
4. to preserve the *S. centrale* fruit free from pest re-infestation after treatment using a non-chemical strategy
5. to evaluate the effect of different temperatures and exposure times and non-treated *S. centrale* fruit.

**Materials and methods**

**Survey and identification of post-harvest pests in bush tomato**

Insects were collected in 2005 from *S. centrale* fruit samples from the NT (Utopia and Ti Tree), WA (Blackstone, Calingiri and Perth) and SA (Nepabunna Community in the north Flinders Range, Tanglun Piltengi Yunti (TPY) Community at Murray Bridge and Mimili Community in the Anangu Pitjantjatjara Yankunytjatjara (APY) lands). *S. centrale* fruit was scored and dissected for pests under a digital magnifier (Merlin® – USA) (Photos 2 (a) and (b)) and under the microscope. Confirmation of the insect pests present was made by staff from the WA Department of Agriculture and Food.

**Laboratory insect colonies for bioassays**

*P. interpunctella* was collected from *S. centrale* in Alice Springs and in Queensland to establish a colony. Eggs, larvae and pupae were reared on a diet of 40% ground rice, 20% polenta (corn), 20% rolled organic oats, 10% glycerin, 5% brewer’s yeast and 5% honey at 28 ± 2°C, and 70% r.h. under a 14:10 h (L:D) photoperiod, as described by Hirashima et al. (2003) and Rafaeli and Gileadi (1995) but with some modifications. The insects were kept in 1 L jars containing the rearing media (Photo 3).
Laboratory colonies of *T. castaneum* were kept in jars with 400 g organic wheat flour containing 20 g of brewer’s yeast, using initial cohorts of 500–1000 adults. Colonies of *O. surinamensis* were reared in jars, using 250 g of rolled oats containing 20 g of brewer’s yeast. These two beetle colonies were incubated at 30± 2°C and 70% r.h. Initial insects of both species were provided by WA Department of Agriculture and Food.

**Artificial infestation of the bush tomato for bioassays**

Batches of *S. centrale* fruit from Alice Springs were infested twice with adults and larvae of *P. interpunctella*, adults of *T. castaneum* and adults of *O. surinamensis*. They were then kept at 22–23°C / ~45% r.h. for at least two months.

**Exposure of insects and infested *S. centrale* fruit to high temperature treatment**

Two experiments were set up for the heat treatment, using nine different temperature regimes:

- **Control** = 28 ± 2°C
- High temperature, each with both 6 h and 12 h exposure:
  - 40 ± 2°C
  - 42 ± 2°C
  - 45 ± 2°C
  - 48 ± 2°C
  - 50 ± 2°C
  - 60 ± 2°C
- And also extremely high temperature:
  - 70–80°C (exposure of 2 hours)
  - 70–80°C (exposure of 3 hours)

This experiment was conducted on eggs, larvae, pupae and adults of *P. interpunctella*, but only on adults of *T. castaneum* and *O. surinamensis.*
This experiment followed the methodology of Mbata and Phillips (2001), with some modifications. For *ex-situ* (i.e. insects without the fruit) Experiment No.1 we used the target insect pests (*P. interpunctella, T. castaneum* and *O. surinamensis*) alone, using the insects from the laboratory colonies mentioned above. *T. castaneum* and *O. surinamensis* were sieved (210–500 µm mesh) from the food after the treatment and subsequently counted. In all experiments, hours of exposure to heat, the number of insects treated, and number and stage of killed insects were observed and registered. Estimated exposure times to reach 99–100% mortality for each life cycle stage of the target insect were recorded for each of the nine temperatures.

For *in-situ* (i.e. infested fruit, with insects inside it) Experiment No. 2, a small trial was set up using *S. centrale* fruit infested with the same three pests using high temperature = 50°C and 60°C ± 2°C, for 6 h and 12 h; and extremely high temperature= 70°C and 80°C ± 2°C, with short exposure of 2 h and 3 h. The actual count of live and dead insects was performed at two or more weeks after treatment (Navarro et al. 2001a), in order to allow any survivors to recover. Except for adults of *P. interpunctella*, mortality was always determined after the end of the treatment.

**Exposure of insects and infested *S. centrale* fruit to low pressure treatment**

The treatments were conducted by setting up vials (containing diet) of target individuals of each stage of *P. interpunctella* (eggs, wandering larvae, pupae and adults), but only adults of *T. castaneum* and *O. surinamensis*, in a vacuum desiccator (22.930 L) using a Büchi*® V-800 vacuum controller (hysteresis dP = 2mbar). The volume of the desiccator was calibrated from the amount of water that it could hold.

For *ex-situ* Experiment No. 3, the target insect pests (*P. interpunctella, T. castaneum* and *O. surinamensis*) were used alone, using the insects from the laboratory colonies. This experiment followed the methodology of Mbata and Phillips (2001), with some modifications. For *in-situ* Experiment No. 4, a small trial was set up with three replicates (R1, R2 and R3) of *S. centrale* fruit (550–650 g each) infested with the same three stored-product pests. This set up was replicated for each low pressure of 32, 50 and 100 mm Hg, with exposure time of 12 days (288 h; Photo 4). An untreated control desiccator containing three replicates of infested *S. centrale* fruit samples (550–580 g each) was set up in a vacuum desiccator. No pressure was applied (septum opened), so pressure was considered to be 760 mmHg, i.e. 1 atm. Both treatment and control were kept at room temperatures of approximately 21± 2°C /~ 45% r.h.

*Photo 4: Infested *S. centrale* fruit under low pressure at 32 mmHg.*
In all experiments, the number of insects treated and number and stage of insects killed were observed and registered. Scoring of mortalities of insects in *S. centrale* fruit was performed under a digital magnifier and under the microscope. The actual count of live and dead insects was performed at two or more weeks after treatment (Navarro et al. 2001a), in order to allow time for any survivors to recover. Except for adults of *P. interpunctella*, mortality was always determined after the end of the treatment.

**Statistical analysis**

The percentage mortalities of each insect species and, where appropriate, each stage of the life cycle, were calculated for each temperature and exposure time combination and also for each low pressure treatment. For each experiment, mortalities were plotted against increasing temperature or decreasing atmospheric pressure in order to provide a visual representation of the responses to these variables. Where the data permitted, percentage mortalities were analysed against treatment level for both short- and long-exposure time by probit analysis, using the SPSS (2005), version 14.1 for Windows statistical package. Using the temperature vs. time relationship provided by the probit analysis, the lethal temperature LT50% and LT99% could be calculated. In our case, the treatment level that caused 99% mortality was extracted for comparisons between stages of life cycle, insect species and length of exposure time. In cases where it was not possible to apply probit analysis, generally due to the short range of treatment levels over which the responses were measured, trends were either visually inspected or the Mann–Whitney U test was used to compare responses between short- and long-exposure regimes.

**Results and discussion**

**Survey and identification of post-harvest pests in *S. centrale* fruit**

Insects were found and identified in *S. centrale* fruit samples from the NT (Utopia and Ti Tree), from WA (Blackstone and Calingiri). To date, the following insect pests in stored *S. centrale* fruit have been identified: Indian meal moth, *P. interpunctella* (Photo 5); Rust red flour beetle, *T. castaneum* (Photo 6); Saw-toothed grain beetle, *O. surinamensis* (Photo 7); and Warehouse beetle, *T. variabile* (Photo 8). Also, the Eggfruit caterpillar, *Sceliodes cordalis* Doubleday (Lepidoptera: Crambidae) (Photo 9) was found attacking green *S. centrale* fruit grown in the field trial area in Bentley, Perth, WA.

*Photos 5 (a) to (e): Indian meal moth, Plodia interpunctella, eggs (a), larva (b), pupa (c), pupal cocoon (d) and adult (e).*
Photos 6 (a) and (b): Rust red flour beetle, Tribolium castaneum, larva (a) and adult (b).
Photos courtesy of Rob Emery and Rebecca Graham, DAFWA.

Photos 7 (a) and (b): Adult Saw-toothed grain beetle, Oryzaephilus surinamensis, showing dorsal view (a), and individuals feeding on diet of rolled organic oats (b).
Photos courtesy of Rob Emery and Rebecca Graham, DAFWA.

Photo 8: Larva of Warehouse beetle, Trogoderma variabile.
Photo courtesy of Rob Emery and Rebecca Graham, DAFWA.
Infestation of *S. centrale* fruit at different localities

Samples of *S. centrale* fruit from Utopia (n = 9), Ti Tree (n = 3), Blackstone (n = 3) and Calingiri (n = 3) all showed considerable levels of infestation (Table 1). The weight of 100 *S. centrale* fruit varied from 37.06 g to 87.84 g, and several of the samples showed damage, including decay and loss of integrity, such as rupture of the skin surface. Infestation of *S. centrale* fruit with these insects ranged from 31–41% in the NT and from 20–37% in WA. Percentage damage of undried samples from SA ranged from 5–27%, mostly due to fungi and the Eggfruit caterpillar, *S. cordalis*, which attacks green fruit in the field. No stored-product insects were found in SA samples.

**Table 1: Mean infestation levels in stored *S. centrale* fruit from various Australian localities (mean ± SE)**

<table>
<thead>
<tr>
<th>State</th>
<th>Locality</th>
<th>n</th>
<th>Total fruit scored</th>
<th>No. of non-damaged fruit</th>
<th>No. of damaged fruit</th>
<th>Percentage infestation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NT</td>
<td>Utopia</td>
<td>9</td>
<td>199.4 ± 13.63</td>
<td>136.7 ± 7.02</td>
<td>62.8 ± 6.62</td>
<td>31.5</td>
</tr>
<tr>
<td></td>
<td>Ti Tree</td>
<td>3</td>
<td>206.7 ± 15.78</td>
<td>121.7 ± 9.35</td>
<td>85.0 ± 6.43</td>
<td>41.2</td>
</tr>
<tr>
<td>WA</td>
<td>Blackstone</td>
<td>3</td>
<td>204.3 ± 26.54</td>
<td>129.0 ± 11.79</td>
<td>75.3 ± 14.75</td>
<td>36.9</td>
</tr>
<tr>
<td></td>
<td>Calingiri</td>
<td>3</td>
<td>192.7 ± 11.79</td>
<td>152.7 ± 5.55</td>
<td>40.0 ± 6.24</td>
<td>20.8</td>
</tr>
</tbody>
</table>

n = number of samples for each locality

Insect colonies

Colonies of *P. interpunctella*, *T. castaneum* and *O. surinamensis* were established and run for a full cycle. We were unable to find any other samples of *Trogoderma variabile* and were hence unable to establish a colony of this species.

High temperature treatment

Results from Experiment No. 1 (Figures 3–8) showed that temperatures of 50 ± 2°C and 60 ± 2°C with 6 h and 12 h exposure resulted in mortality of 99–100% of *P. interpunctella* eggs, larvae, pupae and adults. In the same experiment, mortality of adult *T. castaneum* and *O. surinamensis* was 100% at both 50 ± 2°C and 60 ± 2°C, with 6 h and 12 h exposure. At 48 ± 2°C with both 6 h and 12 h exposure time there was a sharp increase to 100% mortality of *T. castaneum* and *O. surinamensis* when compared with 45 ± 2°C. There was 100% survival at both 28 ± 2°C, 70% r.h. control and 40 ± 2°C, both with 6 h and 12 h exposure. It is likely that different stages of the life cycle may have different tolerances to temperature (Arthur 2006).
Figure 3: The effect of different temperature treatments on 3-day-old eggs of Plodia interpunctella, with 6 h and 12 h exposure times

Figure 4: The effect of different temperature treatments on Plodia interpunctella wandering larvae, with 6 h and 12 h exposure times
Figure 5: The effect of different temperature treatments on Plodia interpunctella pupae, with 6 h and 12 h exposure times.

Figure 6: The effect of different temperature treatments on Plodia interpunctella adults, with 6 h and 12 h exposure times.
In this research, the LT99% mortality criterion was adopted for the probit analysis, because this was a small pilot trial that was designed to provide dose-mortality readings that could be used to compare the efficacy of the various treatments. It should be emphasised that this work is not about quarantine treatment, but rather was designed to find the direction that this work should follow. The probit analysis shows that, in this study, 0.2% of insects will die from natural causes, with the other deaths being due to the treatments. Thus, the treatments were very effective.
When these temperatures mentioned above, plus the 70 ± 2°C and 80 ± 2°C, 2 h and 3 h exposure treatments, were applied to insects within infested *S. centrale* fruit during in-situ Experiment No. 2, 50 ± 2°C with 6 h exposure still controlled *P. interpunctella* but failed to control adult *T. castaneum* and *O. surinamensis*. The Mann–Whitney U test was used to analyses the effect of exposure time at 50 ± 2°C in *T. castaneum* and *O. surinamensis*, and it was found that at this temperature significantly more insects were killed after 12 h exposure than after 6 h, P< 0.05. Temperatures of 60 ± 2°C, 6–12 h exposure also successfully controlled all three target insects. An exposure time of 6 h at 60°C is sufficient to kill all life cycle stages of the major insect pests, but using a 12 h exposure is considered to be a safer course of action.

The impact of elevated temperatures (lethal), such the ones used in the current experiments, are variable and depend on relative humidity, on the species of target insect under investigation and on the developmental stage (Davison 1969; Fields 1992; Mahroof et al. 2003a, 2003b). After the experimental treatment at 50°C for 6 h, some *T. castaneum* and *O. surinamensis* adults were found alive. From the results of this study, the recommended temperature to effectively kill all three pests within the fruit is 60°C for 12 h. This exposure must be uniformly applied throughout the product, so it may be necessary to turn over the product during heating to ensure that all material is subjected to the required lethal temperature, and to allow the entire batch to reach 60°C more quickly, otherwise under-heating of the centre of the product may allow insects to survive (Fields 1992). Our results indicate that heat treatment is very effective for controlling *P. interpunctella*, *T. castaneum* and *O. surinamensis* when the recommended temperature and exposure times are applied.

On the other hand, overheating could damage the product. The use of high temperature/short-exposure-time treatments is normally used in the food industry to kill pathogens and to minimise thermal degradation of processed food (Ohlsson 1980; Tang et al. 2000). In our experiment at 70 ± 2°C to 80 ± 2°C with 2 h and 3 h exposure times, a heat-sensing probe (tiny-tag/recording every 2 min) was used to measure how long the fruit would take to heat up and reach the set-temperature of the oven (air-ventilated). Our records show that the required increase in temperature took at least 2–3 h to achieve and stabilisation of temperature within the *S. centrale* fruit would take at least 3–4 h, although the temperature regimes for 2 h and 3 h were not necessarily the final temperatures inside the fruit. It is also important to emphasise that in tests with *S. centrale* fruit using Petri dishes to measure the water loss during 6, 12 and 24 h at 60°C, no more than ~1% of water loss occurred. Thus, these temperatures used in our study are likely to have only a small effect the water content of the product.

### Low pressure treatment

Our results show that low pressures required a reasonably long exposure time period (12 days or more) to kill the three insect pests under ex-situ conditions. The actual count of live and dead insects was performed ~2 weeks after treatment, in order to allow time for any survivors to recover. This resulted in varied percentage mortality for *P. interpunctella* (eggs, larvae, pupae and adults), adult *T. castaneum* and adult *O. surinamensis* (Table 2).
Percentage mortality for these three storage pests under 32 mmHg at room temperature (approximately 21 ± 2°C / ~45% r.h.) ranged from 8 to 100%. In this case, *P. interpunctella* eggs (3 days old) were most tolerant, while larvae suffered 92.6% mortality and adult *P. interpunctella*, *T. castaneum* and *O. surinamensis* suffered 100% mortality. Unexpectedly, wandering larvae were found in treatments at 50 mmHg, and were covered in silk, suggesting survival to pupation (100%). They were considered alive and surviving to the next life stage. The explanation for this could lie in the temperatures used (21 ± 2°C / ~45% r.h.), and the insects’ metabolism, which might be low at under these conditions, meaning that the larvae may need more exposure to be killed. Percentage mortality of *P. interpunctella* eggs (3 days old) at 50 mmHg was 18.7%. It was not possible to test eggs and larvae at 100 mmHg, although percentage mortality of *P. interpunctella* pupae and adults was 100%. In the case of adult *T. castaneum* and *O. surinamensis*, percentage mortalities were 98.3 and 100%, respectively. In our controls (760 mmHg at room temperature of approximately 21 ± 2°C / ~45% r.h.), mortality was < 2%.

For in-situ Experiment No. 4 (Table 3), *P. interpunctella* larvae developed inside the fruit and destroyed the fruit contents or were found outside broken fruits. *T. castaneum* and *O. surinamensis* were found inside the fruit, and their activity was always found when the fruit had pre-existing skin damage (exit holes) or when the fruit had been broken by handling. An exit hole made by wandering larvae of *P. interpunctella* makes a good entry point for both stored-product beetle species, which may be the reason why they prefer to attack damaged fruit. *T. castaneum* and *O. surinamensis* might not feed on undamaged *S. centrale* fruit.

In our control treatments, several *T. castaneum* adults were observed aggregating inside the fruit, producing a strong acidic smell. This may have some effect on the quality of the product. This is a very important observation, because it would help to draw a good understanding of how the product should be handled after harvest. After the treatment, the product should be kept in a cool, dry, clean storage area and should be periodically monitored for pest activities. It should also be protected from re-infestation by using airtight containers.

We observed that under treatment at 21 ± 2°C/ ~45% r.h. (for example at 32 mmHg), eggs laid outside of the bush tomato fruit were dried out and failed to hatch. Perhaps these were new eggs that had been laid before the adults died. The larvae were also flattened and pupae broke easily or were flat. Larvae of *P. interpunctella* are susceptible to low-oxygen conditions through the use of modified atmospheres, but they can survive up to 6 days under such conditions (data in Table 2 and our own unpublished observations), which is in agreement with the finding of Locatelli et al. (2002). The insects suffered desiccation. Thus, this treatment completely killed *P. interpunctella* (100% mortality), although we do not know the situation for eggs, as they were not measured (Table 3). Percentage mortality for *T. castaneum* adults was 100%. Very few pupae and larvae were found in these samples; those that were found were dead. *O. surinamensis* adults suffered ~95% mortality, but no live or dead larvae and

#### Table 2: Mean ex situ mortality of the different stages of Plodia interpunctella, and adults of Tribolium castaneum and Oryzaephilus surinamensis in control and three low pressure treatments

<table>
<thead>
<tr>
<th>Species</th>
<th>Developmental stage</th>
<th>Pressure (mmHg)</th>
<th>Control</th>
<th>100</th>
<th>50</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. interpunctella</em></td>
<td>Eggs</td>
<td></td>
<td>0 ± 0</td>
<td>NA</td>
<td>18.7 ± 10</td>
<td>7.8 ± 2.8</td>
</tr>
<tr>
<td></td>
<td>Wandering larvae</td>
<td></td>
<td>0 ± 0</td>
<td>NA</td>
<td>0 ± 0</td>
<td>92.6 ± 7.4</td>
</tr>
<tr>
<td></td>
<td>Pupae</td>
<td></td>
<td>0 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td></td>
<td>0 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td><em>T. castaneum</em></td>
<td>Adults</td>
<td></td>
<td>0 ± 0</td>
<td>98.3 ± 0.3</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td><em>O. surinamensis</em></td>
<td>Adults</td>
<td></td>
<td>0 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
</tbody>
</table>

Note: Mean ± SE ex-situ % mortality, with two replicates for each treatment and n = 20 for each replicate
NA = not available

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pupae were found in these samples. All *P. interpunctella* suffered 100% mortality under low pressure at 50 mmHg. At this level, the partial pressure of oxygen is equivalent to 1.4%, which is similar to the target oxygen concentration under atmosphere obtained by nitrogen flushing (Finkelman et al. 2004).

Table 3: In-situ mortality (%) of different life cycle stages of *Plodia interpunctella, Tribolium castaneum* and *Oryzaephilus surinamensis* at atmospheric pressure (control) and three low pressure treatments

<table>
<thead>
<tr>
<th>Species</th>
<th>Developmental stage</th>
<th>Control</th>
<th>100</th>
<th>50</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. interpunctella</em></td>
<td>Eggs</td>
<td>0 ± 0</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Larvae</td>
<td>0 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td></td>
<td>Pupae</td>
<td>0 ± 0</td>
<td>57.1 ± 14.3</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>0 ± 0</td>
<td>76.1 ± 3.1</td>
<td>100 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td><em>T. castaneum</em></td>
<td>Larvae/Pupae</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>0 ± 0</td>
<td>100 ± 0</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>0 ± 0</td>
<td>81.6 ± 3.1</td>
<td>93.7 ± 6.4</td>
<td>100 ± 0</td>
</tr>
<tr>
<td><em>O. surinamensis</em></td>
<td>Larvae/Pupae</td>
<td>0 ± 0</td>
<td>NA</td>
<td>50 ± 50</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Adults</td>
<td>0 ± 0</td>
<td>100 ± 0</td>
<td>87.3 ± 6.4</td>
<td>95.2 ± 4.8</td>
</tr>
</tbody>
</table>

Note: Values are mean ± SE; three replicates for each treatment

NA = not available

In our experiments using *S. centrale* fruit under pressure of 100 mmHg showed that insects are still able to survive under this condition. Thus it appears that longer exposure is required, making the 100 mmHg treatment unviable. Due to the small number of larvae and pupae, we could not evaluate the effects of this treatment with confidence. *O. surinamensis* suffered 100% mortality, and no live or dead larvae and pupae were found in these samples. In this study, low pressures of 32 mmHg provided the best outcome under our conditions. When probit analysis was used for this experiment we found that to produce 99% mortality of pupae and adult of *P. interpunctella* in infested *S. centrale* fruit we need to apply 25 mmHg and 46 mmHg, respectively for 12 days. Also, for adults of the two beetle species, 37–77 mmHg for 12 days is needed to kill 99% of individuals, with a 95% confidence limit. Larvae and pupae of *T. castaneum* required a much lower pressure of 25 mmHg for 12 days, with a 95% confidence limit. Insufficient data were available for larvae or pupae of *O. surinamensis* to be analysed.

The variation in our results could be explained by the fact that the headspace volume of the container was large (approximately 20 L), it being a rigid container (glass vacuum desiccator) that was only partially filled with about 2 kg of infested *S. centrale* fruit (in jars) or insects only (in vials). It has been reported that flexible structures under hermetic storage can produce complete mortality for *P. interpunctella, T. castaneum, E. cautella,* and some mortality for *T. granarium* (Navarro et al. 2001a, 2001b).

Researchers in Australia have reported that silos and warehouses have been modified for hermetic seal and also for airtight storage of grain (Delmenico 1993, De Lima 1990). Our results have shown that low pressure can be used to control stored-product pests in *S. centrale* fruit, but much higher temperatures are needed to achieve 100% mortality, which is the nil tolerance requirement for exportation. This non-toxic approach to disinfestation might help to extend the post-harvest life of the fruit. However, it is complicated to install in remote areas, and is better used in conjunction with elevated temperatures of 30–40°C. This would bring the additional benefit of reducing the exposure time of the treatment.
Effect of treatments on fruit quality

The impact of insect control treatments on product quality is very important. The effect of high temperature and low-pressure treatments on product quality, as measured by antioxidant content and vitamin C content, were assessed. Neither type of treatment decreased antioxidant levels; indeed, antioxidant content increased with longer exposure time (6–12 hours) in all the high temperature treatments of 50ºC or greater (data not shown).

Conclusions and recommendations

This study is a pilot study, that is, a small trial, which was performed to allow us to design the best approach for a large-scale trial for quarantine purposes; one where only non-chemical treatments are required. The heat treatment used in this study is cheap, fast, and reliable if the heat is homogeneously applied and the product reaches the required temperature. Furthermore, it does not have any adverse effect on measures of fruit quality.

Low-pressure treatment for disinfestation is a good approach if it is combined with high temperature to reduce the exposure time.

Our recommended treatment is high temperature at 60 ± 2ºC (interior batch temperature) with exposure time of 12 h. According to some literature for flourmills, it is better still to expose the product up to 24 h. We conclude that 60 ± 2ºC for 12 h was lethal for the four main storage pests and maintained S. centrale fruit quality.

After the treatment, hygienic storage in sealed polyethylene bags or sealed airtight plastic containers is essential, as there is a need to prevent the product being re-infested. We recommend that after heat treatment fruit be placed in cool, dry storage at temperatures below 8ºC in order to help preserve product quality.

Future research

On the basis of this small pilot trial with infested S. centrale fruit, we can see the benefits of heat treatment. A large-scale experiment now needs to be performed as a confirmatory test, using infested S. centrale fruit. In accordance with Hansen et al. (2004), development of a thermal post-harvest treatment would be of great benefit to the export industry.
References


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