



The Bush Tomato Handbook

Ange Vincent



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Contributing author information

Ange Vincent: Research Analyst, Bush Products, Desert Knowledge CRC,
Alice Springs, NT.

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For additional information please contact

Ninti One Limited

Publications Officer

PO Box 3971

Alice Springs NT 0871

Australia

Telephone +61 8 8959 6000

Fax +61 8 8959 6048

www.nintione.com.au

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Since the arrival of humans in Australia, plants have been used for food, medicine, tools, shelter and firewood. Today, native plants still have an important role for many Aboriginal people. Wild harvesting for cultural practice, personal consumption and income generation is practised in many communities. A growing number of communities are also engaged in the horticultural production of various bush food plants in an effort to generate income.

Many of these traditional foods are now marketed under the labels of bush food or native food. Thorough knowledge is essential for the correct selection, collection, preparation and preservation of food plants. This is of particular importance in the Solanaceae family, where plants that are poisonous or require special processing before consumption may have a very similar appearance to non-poisonous varieties (Hiddens 2001).

The Australian bush food industry has grown substantially since its establishment in the early 1980s. Although there are no conclusive statistics on the size of the industry, estimates have put the value of the industry at \$10–\$12m per year in 1995/1996 (Graham & Hart 1997), \$14m in 1997 (Stynes 1997), \$10–\$16m in 2000 (Cherikoff 2000), \$16m in 2002 (Hele 2001) and \$15–\$20m per year in 2004 (Miers 2004). The above figures do not include the macadamia nut industry, which was valued at \$101.5m over the 2003–04 financial year (ABS 2005).

Although Aboriginal people traditionally used most bush food ingredients, their participation in the bush foods industry is almost entirely as suppliers of raw products. There are a few exceptions, with some people who are value adding and manufacturing products for sale.

The emerging bush tomato industry faces many challenges. These include regularity of supply, food safety, appropriate nomenclature, correct identification of species, domestication, cultivation, quality assurance and traceability.

In many cases the cultivation and harvest of native foods is an even greater constraint to the industry than creating product demand

and awareness. Little is known about the agronomy of many species compared to exotic horticultural crops (Miers 2004). This is partially because some are still being domesticated, and also because the climatic and soil conditions of the area in which these plants are naturally found are quite different from the more traditionally agricultural areas of Australia.

Many of the techniques used in traditional temperate zone horticulture and/or agriculture are not applicable to horticulture in the desert, are restrictively expensive or are as yet untested. Available technologies for the harvest and post-harvest treatment and handling of many bush foods is either modified from machines designed for other crops or currently non-existent, forcing many bush food enterprises to hand harvest, sort and pack, which substantially increases input costs and reduces profit margins.

The Bush Tomato Handbook has been produced by the Desert Knowledge Cooperative Research Centre (DKCRC) in an effort to identify, collect, synthesise and present all of the information relevant to the horticultural production of *Solanum centrale* (bush tomato) that is currently available. These sources include our own experience of working with and undertaking research on the plant and its usage and the work of others who grow, harvest and/or study this plant. Our purpose is to support the establishment of bush food enterprises across desert Australia by making this information available and accessible to all.

The family Solanaceae includes some of the world's major food crops: potato, tomato, capsicum, eggplant and chilli. Some species have a high alkaloid content and are poisonous; some are used medicinally (e.g. *Atropa belladonna*, deadly nightshade) or as recreational narcotics (e.g. tobacco and *Datura* (Purdie et al. 1982). There are 132 endemic and 66 naturalised *Solanum* species in Australia (Purdie et al. 1982); a number of these species are or were an important staple food to central Australia's Aboriginal peoples (Latz 1995). Of the 18 species occurring across central Australia, nine are edible: *S. centrale*, *S. chippendalei*, *S. cleistogamum*, *S. coactiliferum*, *S. diversiflorum*, *S. ellipticum*, *S. esuriale*, *S. gilesii* and *S. orbiculatum* (Latz 1995, Johnson & Ahmed 2005).

The bush tomato is widespread in arid areas of Western Australia, the Northern Territory and northern South Australia (Purdie et al. 1982). It is an often sprawling clonal, perennial herb or undershrub to 45 cm, with a dense hairy covering usually of star-shaped hairs. The detail of the hairs can be seen with a hand lens. The frilled flowers are mostly in clusters. They are often purple and have yellow anthers projecting from the centre of each flower (Urban 1990) with yellow globular fruit 10–15 mm in diameter, which dry to a brown colour on the plant to resemble a raisin (Purdie et al. 1982).



The fruit is an important staple of past and present diets of some Aboriginal communities (O'Connell et al. 1983). The plant also has spiritual significance, featuring in many Dreamtime stories and increase ceremonies, which are carried out to ensure the food supply continues (Latz 1995).

Bush tomatoes are becoming commercially significant in the bush food industry. The fruit have a strong 'sun-dried tomato' flavour, often with a solanine aftertaste, and the dried, ground fruit is most often used as a flavouring or spice.

Solanum centrale JM Black (desert raisin, bush tomato) is a small clonal undershrub about 30 cm high with purple flowers and rather soft mid-green leaves. The fruit is round to pear shaped, 5–25 mm across and changes from green to yellow when ripe. The dried fruit is wrinkled and its colour is light to dark brown. As the fruit of this plant is widely sold and commercially recognised as bush tomato (Robins & Ryder 2004), this handbook will refer to *S. centrale* as bush tomato, even though its correct botanical common name is *desert raisin* (Latz 1995). It is possible that this species is andromonoecious (has both bisexual and male viable flowers, with sterile female flowers on the same plant), or exhibits varying degrees of andromonoecy depending on the environmental conditions. All members of the *S. maccoorai* group (to which *S. centrale* belongs) are apparently andromonoecious (Whalen 1984).



Solanum chippendalei Symon (bush tomato) is a shrub 0.8–1.5 m high with grey-green leaves, pale purple flowers and covered in prickles 2–6 mm long. The fruit is usually globular, and is green or



Photo courtesy AR Bean

green with purplish streaks to pale yellow when ripe. Fruit size is 2–3 cm in diameter. Only the thick outer rind is eaten; the black seeds and the thin inner part of the fruit are very bitter and inedible. The fruit is split open and the inedible portions are scraped out. The rind is relatively high in vitamin C and has quite low protein and fat values. It has a rather bland taste with a slight rockmelon flavour and has exceptional keeping qualities (Latz 1995).



Solanum cleistogamum Symon (Sly nightshade) is a low spreading shrub to about 25 cm high with soft, greyish to bluish-green leaves and rather insignificant pale purple or white flowers. The ripe fruit is pale yellow and is the sweetest of all *Solanum* fruits, often with a banana-like taste. The nutritional value of the fruit is quite high but the fruit spoils quickly and harvesters face strong competition from dingoes and other animals (Latz 1995).

Solanum coactiliferum JM Black (Western nightshade) is a grey or silvery plant to 35 cm high which usually has prickles on the stems. The leaves are narrow-oblong and slightly recurved. The flowers have four petals rather than the five more commonly found in *Solanum* species. The yellow fruits are in groups of three and have a somewhat bone-like texture when dry. Pintupi, Pitjantjatjara and Western Arrernte people use the fruit of this species. It is one of the few central Australian plant foods that is treated before consumption. The fruit is pounded between stones and the bitter juice squeezed out. Water is sometimes added and the process repeated. The resulting paste is cooked before being eaten, although sometimes children eat it raw (Latz 1995).

Solanum diversiflorum This species is similar to (and often confused with) *S. chippendalei*, but it has deeply lobed leaves. It grows only in the far north-west of central Australia (Tanami). An important food plant in its restricted area, it is used in the same way as *S. chippendalei* (Latz 1995).

Solanum ellipticum R. Br. (Native tomato, Potato bush) is a spreading, clonal sub-shrub to 30 cm high with velvety grey or bluish-green leaves. Purple flowers give way to green fruit with purple stripes which ripen to pale yellow. Often considered very bitter by non-Aboriginal people, this is a traditional staple food throughout the area (Latz 1995).



Solanum esuriale Lindl (Quena, tomato plant) has a grey or silvery hairy covering and no prickles. The young leaves are lobed but the adult leaves are not. The pale yellow mature fruit is edible, although it has a rather rubbery texture. The fruit has good keeping qualities and is available late in the season. *S. esuriale* occurs only east of Alice Springs and is a rare plant (Latz 1995).



Photos courtesy: D. Albrecht,
Alice Springs Herbarium



Solanum gilesii Symon (Wild tomato) is an erect shrub to about 30 cm high with soft orange-tinted leaves from a covering of rust coloured hairs.

The flowers are purple and the fruit is enclosed in a spiny papery calyx. The plant occurs only in the extreme north-west of central Australia, and the fruit are eaten by the Pintupi and Warlpiri people (Latz 1995).

Solanum quadriloculatum

F Muell (Wild tomato) is a semi-erect shrub to 40 cm high with soft grey-green leaves which dry to a yellowish colour. The fruit is angular and is spongy when green, hard when ripe. It dries to a bone-like texture. It grows among edible species and is often mistaken for *S. ellipticum* (Latz 1995).

The fruit of this very common plant is very poisonous and should be avoided at all costs.



Bush tomatoes, the dried fruit of *Solanum centrale*, botanically known as desert raisin, are one of the major desert-originated bush food resources that present an opportunity for enterprise development in Australia's arid zone.

Wild harvest of bush tomato for financial return (mostly by Aboriginal women) in central Australia began in the early to mid-1980s. To date the majority of this product has been sourced from wild-harvest activities undertaken in central Australia.

In the wild, bush tomatoes are quite erratic, only producing good crops once every few years. In some years, crops of bush tomatoes are outstanding. In 2001, the best year since 1993, wild harvesters in the region north and north-east of Alice Springs gathered more than eight tonnes of high quality fruit between August and December (Morse 2005).

During 2007–08 the demand for dried bush tomatoes outstripped available supply. This was due to unfavourable climatic conditions across most of central Australia. Supply from wild harvest during 2007–08 to one local wholesaler fell from a yearly average of 3–5 tonnes to less than a tonne. This scarcity of fruit pushed the average wholesale price from \$10.00/kg in 2005 to highs of up to \$50.00/kg during 2008 and 2009.

The apparent rise in demand and record wholesale prices have led to an increased interest in the horticultural production of the bush tomato since 2008.

Some manufacturers, trying to guarantee a reliable future source of product, have approached communities and/or individuals asking them to grow bush tomatoes under contract. Other communities and/or individuals are considering horticultural projects that include a bush food component as a potential income source.

While these opportunities may appear to generate possibilities for training, jobs and income for individuals or communities, it is very important to fully understand the risks that are associated with any horticultural venture. Particularly when attempting production from a

non-domesticated plant (most bush food plants), these risks increase substantially.

It is very unlikely that the 2008 high wholesale price for bush tomatoes will be sustained for any substantial period of time. The shortage of supply has been a result of conditions which can (and do) change very quickly; that is, an increase in rainfall will bring an increase of product available to be wild harvested, lessening the shortage and leading to an industry-wide drop in wholesale prices paid for the dried fruit.

From all available information to date, it appears to be extremely difficult for larger growers of bush tomatoes to make any substantial profit when all real costs are included in an input/output analysis. This means that it usually costs more to grow the plants and harvest the fruit than can be made from the sale of the fruit during the first few years of production.

The buy-back period for the initial capital investment will depend entirely on the amount of fruit produced and sold. This will in turn, depend on the average yield per plant (how much fruit a plant produces in its growing season) achieved across the whole plot during the growing season. Recent research indicates that yields from seed-raised plants are, on average, very low. The four main factors currently affecting the profitability of bush tomatoes as a broadacre crop are:

1. The low germination rate, high variability and low yield of seed-raised plants
2. The cost and difficulty of producing large numbers of plants from selected plants by cuttings and/or tissue culture for large-scale field plantings
3. The lack of purpose-built harvest and post-harvest technologies
4. The high costs and difficulty of retaining a labour force for hand harvest.

Site selection is the process of identifying areas of land capable of sustainable economic crop production. It involves two aspects:

1. site productivity (or site quality)
2. site suitability.

Site *productivity* is a measure of the relative productive capacity of a site for specified crops. It is dependent largely on inherent soil and climatic features such as temperature, rainfall, availability of groundwater, soil depth, drainage conditions and nutrient status. Site *suitability* is defined as the fitness of a given type of land for perennial horticultural crops, and it takes account of management constraints and land degradation hazards as well as site productivity.

As a general rule, horticultural plots should be situated on a flat or gently sloping plain with deep sandy soils to provide good drainage. An important step in the establishment of any horticultural venture is to identify, understand and manage the soil types in your area. Soil types can change widely across a region but can also change dramatically across smaller areas.

Soil with high water-holding capacity, ample soil depth, effective infiltration and drainage will reduce the need for watering and maximise the soil's ability to absorb and utilise any rainfall. The concept of dry land farming is well known in Australian agriculture. The key elements are:

1. maximising the water holding capacity of the soil by improving its suitability to support root growth
2. collecting and storing rainfall within the soil profile by improving infiltration and drainage while minimising runoff.

It is essential to ascertain the soil type and character of potential sites before taking any final decisions about where to establish the venture. The easiest way to do this is to send soil samples to a registered testing laboratory. Most labs will supply a testing kit and instructions on how to take the samples. If you advise the lab of the crops you propose to grow and what kind of testing you need, most labs will be able to run a full range of tests from basic garden soil tests, through standard soil tests with full reports to residue tests and water tests.

The report from the lab should include a standard report (see Figure 1) outlining the results from the test sites and (if a full report is ordered) an interpretation of the test results showing a step-by-step program to allow your soil to reach its ideal potential. In other words, the lab will tell you what is wrong with the soil and how to fix it.

The quality and amount of irrigation-standard water available to the site will be essential to the success of the venture. Water quality can affect plants,

Very fresh	<500 mg/litre Suitable for most uses
Fresh	500–1500 mg/litre Suitable for most uses
Brackish	1500–3000 mg/litre Unsuitable for human consumption; suitable for only limited irrigations
Saline	> 3000 mg/litre Suitable for limited stock and industrial uses

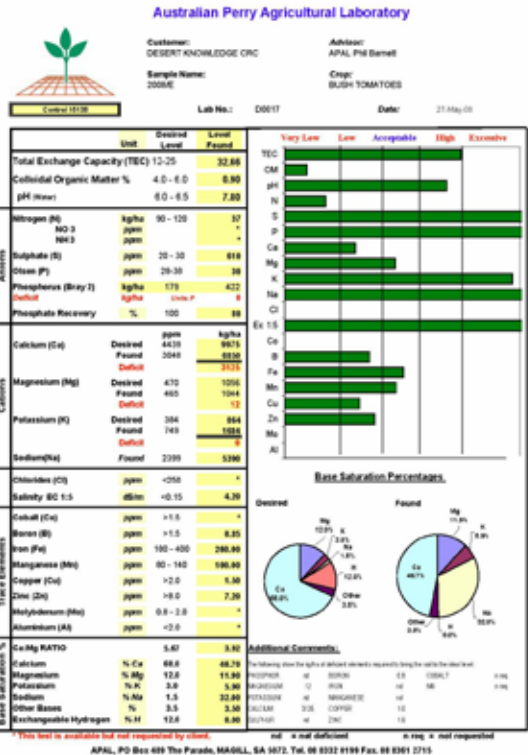


Figure 1: Example of an APAL Standard test report

soils, irrigation equipment and general farm activities. Some water problems affect a whole range of uses, while others are restricted to more specific uses. It is advisable to get as complete a picture as possible of the local water available for irrigation purposes.

Any water used for irrigation should be tested by an accredited laboratory. The quality of irrigation water should be regularly monitored because it can change over time and fluctuate with seasonal conditions (especially during a drought). There are a number of factors

that affect water quality and these can be detrimental to plant growth and development.

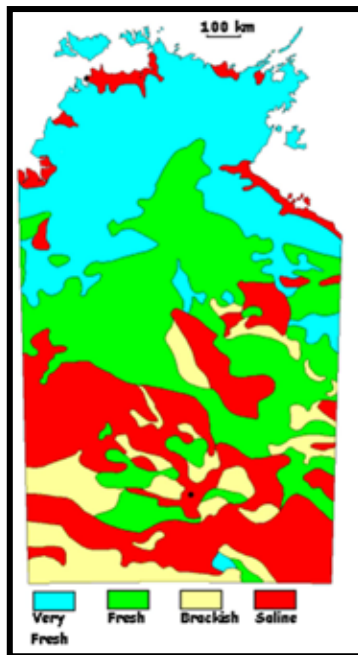
Most underground water in central Australia is suitable for irrigation, but some areas do have salinity problems. Although bush tomatoes exhibit considerable natural salinity tolerance (Johnson & Ahmed 2005), better growth and yield results will be achieved with good horticultural quality water.

Once the amount and quality of available water is known, planning and design of the components and the layout of the irrigation systems can begin. Inexperienced people are advised to seek professional advice on all technical details. It is very important that all systems and infrastructure for the plot be designed as an interactive system from the beginning. Understanding the site and how all parts of the plan work together will reduce the likelihood of system clashes or catastrophic failures later.

Desert plants such as bush tomatoes are designed to cope with their natural environment. They will respond quite well to basic horticultural interventions such as increasing the organic content of the soil and the application of appropriate fertilisers.

Although obtaining quality composted material in central Australia can be difficult and expensive, it is beneficial to add well-rotted compost/animal manure into the soil at 2 kg/m² or more, well in advance of planting.

Chemical control of all weed species on the site should be undertaken prior to the physical removal of all vegetation (10 days knockdown with Roundup). Any large trees or shrubs will need to be removed from the growing area.



Generalised zones of groundwater salinity in the NT

If the soil is hard and compacted, ripping or ploughing is recommended, and any organic materials or fertiliser should be incorporated at this stage. Increasing the organic matter will improve the soil structure and water holding capacity; it adds micronutrients to the soil and generally makes the soil and crops healthier. The site should then be levelled as much as possible to remove any disturbance from ripping or ploughing. It is advisable to roll the site to reduce subsidence in disturbed areas after irrigation. Some producers insist that planting on mounds or in furrows will give better results, although to date this has not been proven experimentally. A flat, level site is far easier to manage in terms of access, weeding, irrigation repair, pest control and harvest.

A fertiliser application schedule should be based on the results of a complete soil analysis taken six to eight weeks before planting. The pre-planting fertiliser application developed from the test results should be incorporated into the soil about 10 days prior to planting. The soil analysis will also indicate if anything needs to be added to increase or decrease the soil pH to the optimum of between 6 and 6.5. These products should be applied at least four weeks before the crop is planted.

Understanding soil pH: pH is a measure of the acidity and alkalinity of the soil using a scale from 1 to 14, where 7 is neutral, less than 7 is acid and greater than 7 is alkaline. pH is a logarithmic scale: the difference between pH 7 and pH 6 is ten times the acidity; between 7 and 5 is a 100 times the acidity; and between 7 and 4 is a 1000 times the acidity. pH is used as an indicator of the availability of nutrients in the soil, but only hydrogen ions are actually measured.

Acid soils with a pH of less than 6 commonly have deficiencies in calcium, magnesium, phosphorus, potassium and molybdenum.

Acid soils with a pH of less than 4 commonly have toxic amounts of aluminium and manganese.

In alkaline soils with a pH of more than 7, the following nutrients may be unavailable: iron, manganese, zinc, copper and boron.

The addition of agricultural lime (calcium carbonate) or dolomite (magnesium carbonate and calcium carbonate) will increase the pH of the soil. Agricultural lime is generally cheaper than dolomite. The application of dolomite is only recommended if the soil is deficient in magnesium; if acid soils are already too high in magnesium, adding more will cause the ratio of calcium to magnesium to be out of balance.

Sulphates of iron and ammonium, elemental sulphur and organic matter are used to lower the pH of the soil. Gypsum (calcium sulphate) does not alter the pH of the soil but can improve aeration and reduce compaction in a clay soil.

The texture of the soil and the amount of organic matter present will affect the quantity of material needed to alter the pH. Clay soils need a much greater amount of lime to shift the pH than sandy soils. The addition of organic matter is always beneficial to the soil whether added as manure, compost or by green manuring. Organic matter will generally 'buffer' plants against the impact of acidity so that a soil with a lower pH range will still successfully grow plants.

Plants vary in their desired pH range and this is due to the pH of the soil type they evolved in. The following table sets out the amount of lime needed to raise the pH of different types of soils (from Bolton 1969):

Soil texture	pH 4.5–5.5	pH 5.5–6.5
Sandy, loamy sand	85 g/m ²	110 g/m ²
Sandy loam	130 g/m ²	195 g/m ²
Loam	195 g/m ²	240 g/m ²
Silty loam	280 g/m ²	320 g/m ²
Clay loam	320 g/m ²	410 g/m ²

If the soil is low in phosphorus, a basal fertiliser that contains 40–60 kg/ha of nitrogen, 60–70 kg/ha of phosphorus and 50–60 kg/ha of potassium is commonly used. On soils high in phosphorus 40–60 kg/ha of nitrogen, 10–30 kg/ha of phosphorus and 50–60 kg/ha of potassium may be required. This should be tilled into the soil seven to 10 days before planting.

Or a complete fertiliser mix containing calcium and medium amounts of nitrogen and potassium, but which is high in phosphorus (i.e. 14N:14P:10K) should be used as the base pre-planting fertiliser at the rate of 15–20 g/m².

Once the crop is growing, sap testing is used to indicate how much nitrogen fertiliser should be applied. Sap testing is carried out with a portable specific ion electrode, which provides the ability to quantitatively determine the concentration of NO₃-N and K⁺ in expressed plant sap under field conditions. This facilitates a real-time diagnosis of nutrient requirements and leads to improved fertiliser management.

Site selection and preparation

Fencing the site will be necessary if cattle, horses, camels and/or donkeys are present, or if security may be an issue. The type of fence chosen will depend on what threat you are trying to keep out. It appears from our observations that kangaroos and rabbits do little damage, so fencing to exclude these animals may not give a value return for dollars spent.

Some thought should be given to access to the site; storage of equipment; materials and tools for day-to-day maintenance of the site; facilities for activities, including post-harvest treatments such as sun-drying yellow fruit, washing and re-drying fruit; facilities and equipment for packaging the final product for transportation and/or sale; and any value-adding activities (i.e. grinding) that are to be undertaken. The secure storage of products and equipment is also an important consideration at this stage of project development.



Growing crops outside the frost zone increases available growing time, negates the winter frost burn-off of plants and may allow for more than one annual harvest if fertiliser and irrigation are applied appropriately. It is possible that two growth/harvest cycles could be generated within each 12-month period by planting in winter (July), allowing growth for several months (September–November), drought for one month to reduce crop bulk (December), harvest in January; then growth for several months (February–May), drought for one month (June) and harvest end of June. Observed responses during the DKCRC trials have supported this theory, and Dennett (2006) agrees.



The ability of bush tomatoes to sucker and resprout from roots should make *S. centrale* highly productive over time. It is possible to use root fragments from selected plants rather than seed to establish crops, given that low germination is a major problem in commercial production (Stefanski 1998, Ahmed et al. 2006). Slashing or burning the above-ground growth can induce fruit production within weeks, if irrigated. Mechanical harvesting should trigger the same resprouting and may prove highly feasible if the fruit can be separated from crop bulk by mechanical harvesting (Dennett 2006).

Available water is the most important element in the development of a horticultural block. There is no point in planting anything unless you can generate enough good quality water to grow your chosen crop through to harvest. Before any decision to plant takes place, the amount and quality of water available should be determined.

The most common water quality issues affecting irrigation are pH and salinity. The pH balance of a water supply describes how acidic or alkaline it is. The acidity (or alkalinity) of a water supply can affect plant growth, irrigation equipment, and herbicide and pesticide efficiency. The balance of positive hydrogen ions (H⁺) and negative hydroxide ions (OH⁻) in water determines its pH level. The pH scale goes from 0 to 14, and a pH of 7 is neutral. Water with a pH below 7 is acid and water with a pH above 7 is alkaline. Most natural waters are between pH 5 and 8. The generally accepted pH for irrigation water is between 5.5 and 8.5.

Salinity is one of the greatest water quality concerns, as it can affect crop performance in several ways:

- dissolved salts in the root zone can strongly affect water availability (salt outcompetes roots for moisture)
- dissolved salts reduce shoot growth and yield (normally reduce fruit number)
- the presence of certain elements such as chloride, sodium or boron can cause toxic effects.

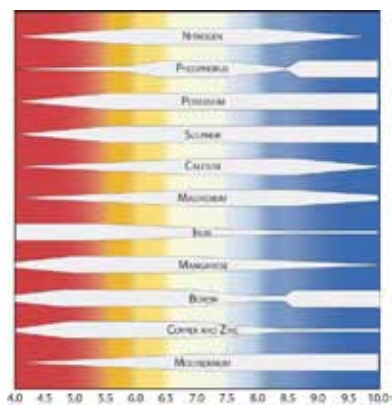
During a drought the salinity of the water usually increases. In conditions of low humidity the effects of salinity can also be intensified. Testing the water will indicate if it is suitable for irrigation. Salinity measurements of water are referred to as the electrical conductivity (EC) of the water.

Electrical conductivity (EC) is a measure of the level of combined salts present in water at the irrigation source. EC measures the extent to which water conducts an electrical current: the higher the salt load, the higher the conductivity. EC is generally expressed in microsiemens per centimetre (uS/cm), as millisiemens per

centimetre (mS/cm) or as decisiemens per metre (dS/m). Water with an EC of less than 0.6 dS/m is generally deemed as suitable for horticultural production. However, the EC does not indicate whether these dissolved salts are present as 'friendly' nutrients, damaging substances (such as chloride, sodium, bicarbonate) or as toxic amounts of iron, zinc, copper, boron, fluoride, etc.

The salinity threshold of a crop is the point at which the EC (average root zone salinity) reaches the level (threshold) at which it causes yield reductions in the crop growing in sand, loam and clay. The thresholds are different for each of the three soil types. The salinity thresholds are not currently known for *S. centrale*, but it will tolerate high levels of salinity: we have observed continued growth and fruiting when irrigated with water which has an EC of 2.4 dS/m. We do not know what the reduction in yield is which resulted from this level of salinity; we do, however, know the effects of salinity on other *Solanum* species.

The salinity threshold for eggplant (*Solanum melongena*) and potato (*Solanum tuberosum*) is 3.2 dS/m (sand), 1.8 dS/m (loam) and 1.1 dS/m (clay). It is estimated that water at an EC of 1.6 dS/m would result in a 10% reduction in yield for these species. Other factors, such as the soil's ability to drain, the method of irrigation, the level of rainfall and the variety of the potato or eggplant also affect the ability of plants to cope with salinity when wetting of the foliage is avoided.



pH: Water with a pH reading between 5.5 and 8.5 is generally suitable for irrigation. Highly alkaline water with high carbonate and bicarbonate levels can affect plant uptake of calcium, magnesium and some trace elements. It also tends to precipitate calcium carbonate, which can cause blockages in pipes. Carbonate and bicarbonate levels of up to 150 mg/L are acceptable, while 350 mg/L would be cause for concern.

Sodicity: The concentration of sodium ions (Na^+), or sodicity of the water, is also important. The sodium adsorption ratio (SAR) is a measure of the imbalance of sodium ions relative to calcium and magnesium ions in the water. High SAR levels cause poor water penetration through the soil, poor drainage, low aeration levels and poor soil structure. Soils affected often have a hard, blocky structure and surface crusting. High sodium levels in soils can be treated with gypsum.

The **calcium carbonate saturation index** gives the relationship between pH, salinity, alkalinity and hardness. It is used to assess the scaling (encrustation) or the corrosive potential of water. Most water-testing services present the calcium carbonate saturation index in positive and negative units. Positive (+) index figures refer to scaling potential and negative (-) index values refer to corrosion potential.

The index is divided into three ranges:

1. No scaling or corrosion (between -0.5 and +0.5):

If the index is between -0.5 and +0.5, there is little likelihood of either scaling or corrosion of pipes and fittings.

2. Scaling risk (less than -0.5 or greater than +0.5):

If the index is more than +0.5 there is a risk of precipitating calcium and magnesium salts. When these salts precipitate and settle they form a scale on the inside of pipes and fittings or on the outside of heating elements.

This is important in irrigation systems that use small emitter or pipe diameters, such as drip and micro-irrigation systems. In these systems the drippers, microjets, microtubes and small lateral pipes can block, reducing flow rates and affecting water distribution patterns. In automated irrigation systems, the tubes serving solenoids can also block, and the valves will not operate properly. The effect on heating elements creates maintenance problems and shortens element life. Scaling can also impede the operation of float valves on tanks and troughs.

3. Strong scaling risk and corrosion risk (less than -1.5 or greater than +1.5):

When the index exceeds 1.5, the risk of scaling is very strong and the water should not be used without prior treatment. If the index is less than -0.5 the water may be corrosive. Values below -1.5 indicate that the water is highly corrosive and corrosion-resistant pipes and fittings may be necessary.

Drip irrigation is the most effective way to apply water and nutrients directly to plants. It conserves water and can increase the yield of vegetable crops (Tiwari et al. 1998, Al-Omran et al. 2005). Ayars et al. (2001) reported from their studies of subsurface drip irrigation and furrow irrigation in the presence of shallow saline ground water that the overall yield of tomato (*Solanum lycopersicum*) was greater under drip irrigation than under furrow irrigation. Phene et al. (1991) reported that subsurface drip irrigation improved the water-use efficiency of tomato plants. Irrigation by a drip system will provide an advantage when using saline water for irrigation. More frequent long watering will induce a high soil matric, leading to a low salt concentration in the root zone.

The irrigation system should be designed by a professional. It should include the water-source interface between bore pump and system or between tank and system. The design should consider the soil type, quality and quantity of water available, the size and slope of the planting area, the number and type of plants to be grown, their optimal water requirements over time, ease or complexity of use and possible future needs. One hectare of bush tomatoes (20,000 plants) will require up to 80,000 litres per week during the hot summer period.

The controller should be the most basic model capable of doing the job and should be battery operated rather than a more expensive electronic or hydraulic system. The number of stations necessary will be indicated by the size of the plot, the number of plants, the planting intervals and the pressure of water delivery. Several battery-operated small, single-station controllers may be better than a larger, more complex multiple-station system.

DKCRC Bush Tomato Trial – Irrigation:



The study site is situated on the Frank McEllister Horticulture Block at the Arid Zone Research Institute, just south of Alice Springs. The site consists of two plots: A1 (70 m wide by 50 m deep) and A2 (40 m wide by 50 m deep). The plots are oriented east–west, with the rows running from south to north; the two plots are separated by a permanent bed of irrigated asparagus approximately 4 m away.

Water quality and irrigation

Non-pressure compensated 17 mm inline drip irrigation lines were installed 30 cm below the soil surface in rows 1.5 m apart. To examine the effect of different irrigation rates, three types of line were used (in a randomised block design) to deliver water to plants at different rates.

The lines used were:

- Netafim Typhoon Super 80, drip spacing 30 cm, delivering 1 L/hr
- Netafim Dripline 2000, drip spacing 30 cm, delivering 2 L/hr
- Netafim Dripline 2000, drip spacing 30 cm, delivering 3 L/hr

Napperby seedlings were planted by hand in April 2007 above each irrigation line at 300 mm intervals in a zigzag pattern either side of the buried drip line to increase plant density. The irrigation was a closed loop design to ensure adequate pressure and ran from three separate stations on an automated controller at a different time for each station. The plants were watered on the following schedule:

- March: twice weekly, for two hours each time
- April–May: once per week, for two hours
- June–July: not irrigated
- August–September: once per week, for two hours
- October: twice weekly, for two hours each time.

Table 1: Yield data by block from A1

	1 L/hr	2 L/hr	3 L/hr
Block			
1	1991	1849	4461
2	4080	3629	3280
3	4391	4813	5122
4	9646	4737	10887
5	2955	11303	17571
Total	23063	26331	41321

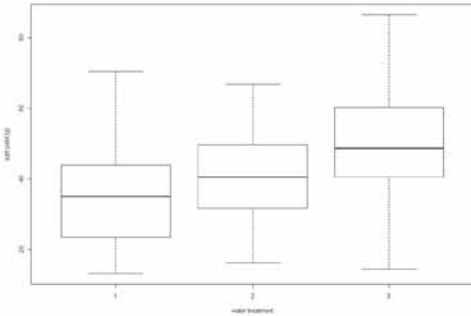


Figure 3: Yield data by block from A1

However, not every row or block reflected the trend shown by the total: an analysis of variation (ANOVA) of this data shows that while the graph (Figure 3) suggests 50% higher mean yield in the 3 L/hr treatment compared with the 1 L/hr treatment, there is very large between-row variability and so the overall effect is statistically weak.

Bush tomato plants respond to a level of irrigation which, in conjunction with soil type and climate, allows the root system to remain moist without either drying out or becoming water-logged. Drip irrigation, compared with other types of irrigation, allows irrigation with water of a higher salt content, as evaporation losses are minimal. Drip irrigation can reduce the effects of salinity by maintaining a continuously moist soil around the roots and providing steady leaching of salts to the edge of the wetted zone. Under furrow irrigation, salts accumulate at the top of the mounds. Sprinkler-irrigated crops are potentially subject to additional damage caused by foliar salt uptake and leaf burn from spray contact.

The area designated as A1 (Rows 1–46) was divided into five blocks of nine rows with irrigation lines laid in units of three and randomly assigned to each of the blocks. Row 1 was designated as a buffer row and has not been included in any calculations.

Yield data (in grams) was collected from this area (A1) from 21 November 2007 to 13 October 2008. Block totals are shown in Table 1. From the raw data it appears that the use of 3 L/hr drip line has resulted in substantially higher yield than the 1 L/hr irrigation.

Irrigation water management requires timely applications of the right amounts of water. Water shortages, high pumping costs and environmental concerns are ensuring that good water management is now essential. Good management of irrigation water combines a method of measuring soil moisture with appropriate irrigation scheduling (Werner 2002).

Methods of measuring soil moisture

Soil moisture can be measured or estimated in a variety of ways. For most irrigation water management applications, one of the several resistance-block models or tensiometers is recommended.

Electrical resistance blocks

A meter is used to read the electrical resistance of moisture blocks installed in the ground at various depths. The blocks generally comprise two electrodes embedded in a gypsum block. Meters or data collectors are portable and are intended for use in reading a large number of blocks throughout one or more fields.

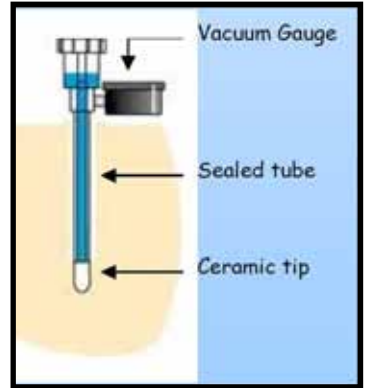
The water available in the soil moves in and out of the block in equilibrium with the soil moisture. Meter readings change as the levels of moisture in the blocks change; this is an indication of the amount of water in the soil. Devices such as G-Bugs are usually supplied with calibration guides to enable conversion of meter readings to soil tension. Proper installation is important for reliable readings, and good soil contact with each block is essential. The blocks will deteriorate over time, and it may be best to use them for only one season. Problems can occur when used in highly acid or highly saline soils.

Tensiometers

A tensiometer is a relatively cheap instrument that measures how hard the plant is working to extract water from the soil, which indicates the availability of soil moisture. Installation of these instruments will allow a high degree of control of soil moisture content. A tensiometer consists of a sealed tube filled with water, a porous ceramic tip and a vacuum gauge.

Installation:

1. Fill the tube with water and soak the ceramic tip in water the day before installation.
2. Make a hole at the site selected for the tensiometer to the width of the tensiometer tube. This is achieved by either driving a hole with a pipe or using an auger.
3. Correct depth of the hole is essential: the ceramic tip must be at the depth of soil that is to be monitored. Make up a slurry of dirt (screened to remove lumps, organic matter and stones) and water.
4. Pour slurry into the hole and immediately insert the tensiometer to the desired depth. If it is a tight fit there may be no need for the slurry, but the ceramic tip must have good soil contact to work properly.



Source: <http://www.greenharvest.com.au>

Tensiometers come in a wide range of tube lengths. Two units installed at different depths are often used in irrigation scheduling. One tip is located at the middle of the effective rooting depth to indicate when to turn on the irrigation, and another is placed just below the root zone to indicate when the water has passed the root zone and the irrigation can be turned off.

As the soil dries out, water is sucked out of the tensiometer through the porous ceramic tip. This creates a partial vacuum in the tube, which registers as an increase on the vacuum gauge. Conversely, if irrigation or rainfall occurs and the soil becomes wet, water is sucked into the tube, the vacuum is reduced and the reading on the gauge decreases.

Readings should be taken at the same time of day, where possible, 2–3 times per week during summer. The following table is a guide only; closely monitor crop growth in relationship with the readings in order to fine tune the setting that best suits your soil and crop type.

Reading	Soil Condition	Irrigate	Notes
0	Saturation	No	Zero readings can be expected after heavy rain
0-10	Surplus water	No	Water held by the soil in this range drains off within a few days
10-20	Field capacity	Maybe	Best conditions for soil moisture and crop growth; irrigation may need to be started in coarse sandy soils with water sensitive plants
20-40	Available moisture for plant growth	Yes	Irrigation started for coarser sands in the 20-30 range and for finer sandy soils in the 30-40 range
50-80	Dry to very dry	Yes	Yields will be affected

Feel method

A soil probe is used to sample the soil profile and the moisture content is evaluated by feeling the soil; a chart is used to judge relative moisture levels. This method is only an estimate; accurate measurement is not possible.

Portable measuring devices

Most portable measuring devices have electronic meters and use either resistance or capacitance technology to estimate soil moisture. Some use the same principle as a tensiometer. They are most useful in providing relative readings of moisture within or between fields, rather than providing an accurate measurement of soil moisture.

Other ways to measure soil moisture

Other available methods of measuring soil moisture are not in widespread use by irrigators, largely because of cost or inconvenience.

Sampling and drying involves collecting soil samples from various depths and locations in the field. Weights of the wet samples are recorded, the samples are oven dried, and dry weights are recorded. This provides values of total soil moisture. Available soil moisture and soil tension can be determined if moisture release information and bulk density are known for the soil. This method gives an accurate measurement of soil moisture and is the basis by which all other methods are calibrated.

The *neutron probe* is an electronic instrument with a radioactive source that is lowered into the soil through an access tube. The neutron probe detects hydrogen levels in soil water. This number is then used to calculate the moisture content. Neutron probes require special licensing and training. The equipment is also expensive, and installation of access tubes can be labour intensive. With good calibration, the method is quite accurate and is accepted for most research work.

Time domain reflectometry (TDR) is a technology based on sensing the dielectric constant of the soil, which is dependent on the soil moisture. An electronic meter is connected to two rods placed into the ground, then an electrical signal is sent through the soil from one rod to the other rod. These units are expensive.

The *capacitance probe* is a non-radioactive probe that is lowered into an access tube; an electronic meter senses the amount of moisture in the soil based on its electrical properties. This method is as expensive as a neutron probe, but special licensing is not required.



Research undertaken by the DKCRC and James Cook University shows that morphological variation in general vegetative characters of *S. centrale* indicate high levels of plasticity, including traits such as hair colour, leaf shape and size and general plant erectness. Based on a small sample size, there is good evidence that fruit size at least in part correlates as a genetic trait (pers. comm. M. Waycott 2009).

Yield is a critical factor in the horticultural production of bush tomatoes for financial profit. When bush tomatoes are propagated from seed, they produce plants with a very wide range of yield difference within that population. This means that even if seed from the best yielding plant is propagated, it is very unlikely that many of the seedlings will have the same yield as the parent plant.

The DKCRC study of 10,000 seed-raised plants grown with minimal horticultural intervention and irrigated with water with an EC of 2.4 dS/m showed the average yield to be approximately 17 grams per plant, a total yield across the plot of less than 200 kilograms. Twenty-four plants (from the 10,000) produced more than 300 grams per plant. Four plants (less than 0.05% of the total) produced more than 500 grams. Obviously a plot filled with higher yielding plants will generate much more income for effort than those plants which produce less. It is probable that intensive horticultural practice may be used to increase the average yield of seed-raised *S. centrale*.

The growth in horticultural production of *S. centrale* is limited by four main factors:

- the low germination rate, high variability and low yield of seed-raised plants
- the cost and difficulty of producing large numbers of plants from selected plants by cuttings and/or tissue culture for large-scale field plantings
- the lack of purpose-built harvest and post-harvest technologies
- the high costs and difficulty of retaining a labour force for hand harvest.

The seed of some species of *Solanum* is dormant when fresh. Many local nurseries have been propagating a range of endemic *Solanum* species from seed and cuttings for many years. However, the common low germination rate of seedlings and low strike rate of cuttings has meant that many seeds need to be planted and many cuttings struck to make up for expected losses. One of the main obstacles to the horticultural production of *S. centrale* is the low germination rate of the seed (Johnson & Ahmed 2005). In the wild, *S. centrale* germinates from seed produced on plants that develop following fire and/or sufficient rain. These seeds have extremely low germination (typically less than 5%) (Ahmed et al. 2006).

DKCRC *S. centrale* seed germination trial: As part of the DKCRC Bush Foods Project, the Alice Springs Desert Park (ASDP) nursery was supplied with dried fruit of *S. centrale* from three different geographic regions and asked to test the various local anecdotal seed pre-treatment methods. The effectiveness of the different pre-treatment techniques to increase the germination rate was directly compared to each other treatment. The most successful treatments were then tested on three other local species (*S. cleistogamum*, *S. chippendalei* and *S. quadriloculatum*) to ascertain its efficacy across a wider selection of *Solanum* species.

Table 2: Summary of fruit and seed weights

Provenance	Dry fruit	Dry seed	100 seeds	Total # of seeds
Anmatyere	250 gms	40.7 gms	0.265 gm	~15,000
Utopia	528 gms	47.5 gms	0.190 gm	~24,000
Napperby	Not weighed	25.5 gms	0.223 gm	~11,000



Plant selection

The treatments trialed are listed below:

- Control: (demineralised water 24 hours)
- Smokewater (10%) 24 hours
- Smokewater (10%) 48 hours
- Smokewater (10%) 72 hours
- Gibberellic acid (500 mg/L) 24 hours
- KNO₃ (potassium nitrate) (0.1%) 24 hours
- Fire on top of punnet (Alice Springs Desert Park nursery)
- Fire on top of punnet (Greening Australia nursery)
- Fire on top of punnet (Tangentyere nursery)

'Fire on top of punnet' technique

Three different local nurseries that use this technique kindly demonstrated their methods as a part of this research.

Solanum seeds were sown into standard plastic nursery punnets (140 mm x 85 mm x 50 mm) in a seed raising media of 2:1 sand:coco peat. Sown seeds were covered with seed raising media to 1 mm (ASDP) or with a layer of vermiculite to 5 mm (Tangentyere and Greening Australia Nurseries). A range of flammable organic materials (grass, leaves and paper) were placed on top of the punnets and ignited. Some care was taken to ensure that the small fires burnt well. After the fires extinguished themselves, the punnets were immediately watered and transferred to the glasshouse (irrigated by intermittent misting). Germination data was scored by counting the hypocotyls of seedlings.

Table 3: Summary of 'Fire on top of punnet' techniques

Nursery	Flammable material	Time (in mins)	Notes
ASDP Nursery	Buffel grass, mulga leaves	2	Flames fanned to promote an even burn: fully combusted
Greening Australia Nursery	Ironwood leaves	3	Incomplete combustion: charred leaves remaining
Tangentyere Nursery	Shredded office paper, river red gum leaves.	Variable: 1-3	Turned punnets to promote a more even burn: incomplete combustion, charred leaves remaining

S. centrale seeds from Napperby and Anmatyere treated with 500 mg/L GA generated the highest germination (66% and 35%). The potassium nitrate and water treatments had minimal effect (less than 2%) on breaking any *S. centrale* seed dormancy.

The 'Fire on top of punnet' technique produced variable results due to the nature of the materials used. This technique produced the highest germination rate for seed from Utopia (18%) of all treatments. While this technique did produce a positive germination response in both the Anmatyere and Napperby varieties, both were 50% less than the GA rate.

Additional tests of the treatments were undertaken on *S. cleistogamum* (GA and Smokewater), *S. quadriloculatum* (GA and Smokewater); and *S. chippendalei* (GA) seeds to indicate if the results shown in the *S. centrale* trial would be transferable to different *Solanum* species. The results indicate that GA has a much stronger effect on germination than the other treatments when used on *S. cleistogamum* and *S. quadriloculatum*, and that GA can raise the germination rate of *S. chippendalei* by 500%.

The highest germination of *S. centrale* occurred with the Napperby seeds treated with 500 mg/L Gibberellic acid (GA). Smokewater and fire treatments also showed a positive influence, and the potassium nitrate (KNO₃) and water treatments had low to zero effect in breaking seed dormancy.

Smokewater and GA were tested on *S. cleistogamum* and *S. quadriloculatum* to determine whether the results shown in the *S. centrale* trial could be reproduced on different species. The germination percentages indicate that GA has a stronger effect than smokewater or no treatment (control) on *S. cleistogamum* and *S. quadriloculatum*. GA is shown to break the dormancy of *S. chippendalei* seed, even at 22 years old.

The fire on top of punnet technique produced variable results for the different provenances and nursery propagators. It is likely that slight variation in technique and materials used, as well as the difficulty in standardising the quantity and quality of fuels, account for the

difference in germination rates. Other factors such as materials and wind speed could affect the production of heat and smoke from the fires. The main drawbacks to this technique are fire risk, scorch risk to seed and general mess created during the process.

Temperatures within the normal seasonal range for this species had no significant effect on the speed of germination or final germination percentages, which indicates that this species will germinate year round, probably in response to moisture cues (Johnson & Ahmed 2005).

Table 4: Seed pre-treatment test results for *S. centrale*

Percentage Germination	Control	SW 24	SW 48hr	SW 72hr	GA 24hr	KNO3 24hr	Fire 1	Fire 2	Fire 3
Anmatyere	0%	3%	3%	2%	35%	2%	7%	15%	19%
Napperby	0%	8%	7%	12%	66%	1%	21%	15%	28%
Utopia	1%	15%	11%	8%	16%	1%	14%	12%	18%

Research on re-drying potato seeds after soaking in GA indicates that this technique may also be possible with commercial batches of *S. centrale* seed, although to date this has not been scientifically tested. Soaking true seeds of potato species in GA solution prior to sowing enhances germination. The germination of botanical seeds of potato is often enhanced by soaking in 2,000 ppm GA solution for approximately 24 hours prior to sowing (Spicer & Dionne 1961). If seeds could be re-dried without loss of the GA germination-enhancing effect or without

otherwise losing ability to germinate, potato gene-banks could distribute pre-treated seed lots, ready to sow (Bramberg 2000).

Model seed lots were selected which had very high germination when soaked in GA



Plant selection

and very low without it (i.e. very dependent on GA). These were assumed to provide a sensitive test for germination decline when GA-treated seeds were re-dried. Re-drying and storage for one week had little effect on the final percentage germination and no effect on the efficacy of GA for enhancing that germination. There appears to be little risk in applying this technique whenever it makes seed sowing more convenient (Bramberg 2000).

In the glasshouse, seedlings (grown from seed) declined in vigour after about six months, even when watered and fertilised. Shoots had a very high rate of leaf turnover, and after the initial growth burst branches produced fewer new leaves and eventually dried out. In contrast to field observations, branches grew so long that they could not support themselves. This suggests the low light intensity of the glasshouse relative to central Australian daylight levels caused shoot elongation (Dennett 2006).

These seedlings responded well to pruning, with new shoots emerging from stems which had been cut right back to ground level. New growth from shoots was stimulated by the application of water. One seedling reshot after remaining dormant for the two months that water was withheld. Plants that had been pruned back grew rapidly and the new growth produced flowers within a month (Dennett 2006).

One of the main difficulties in growing a new generation of tomatoes from the seed of fruit grown the previous season is the low germination rate of this seed. One home gardener method for smaller numbers of seedlings is to squash an amount of fresh or dried fruit to expose the seeds. Put these into a container, then add a small amount of water to just cover and leave for about four or five days so that the mixture begins to ferment. The fermenting bush tomato pulp releases acids and enzymes that break the seed dormancy.

Wash under running water in a sieve, rubbing the seeds until all are washed clean. Spread them on paper towel to dry: the seeded towel sections can be stored until needed and whole or parts of the seeded paper towel can be planted. The paper towel dissolves or rots away as the seedlings grow.

Propagation from cuttings is a vegetative method (i.e. not from seed) and as such each plant produced is genetically identical to the parent plant. The three main types of cutting are:



- **Softwood or tip**

cuttings, taken in spring

to summer when the plants are actively growing. The cutting (50–75 mm) is taken from the tip of the stem cutting just below a bud, and leaves are removed from the bottom half of the cutting. These cuttings need a lot of care and should be grown in a propagation box or glasshouse with a regular misting of water.

- **Semi-hardwood cuttings**, taken from slightly mature wood, usually around late spring to early autumn. Cuttings look much the same as tip cuttings except the soft tip is pinched out, and the leaves are removed from the bottom half of the cutting, leaving 1–3 nodes with leaves at the top.

- **Hardwood cuttings** are prepared from mature wood in late autumn and winter. The mature stems are cut into lengths of 100–250 mm, depending on the species. Cut a slight sloping cut at the top just above a bud and a flat cut at the bottom just below a bud. The base is sometimes wounded (slice of bark removed) to further encourage root growth.

Clone solution and rooting hormone are used together in propagating cuttings. Cuttings are dipped in clone solution before rooting hormone is applied. Clone solution is super-concentrated, containing minerals, vitamins, wetting agents and root-promoting hormones. It encourages rapid and profuse root development to protect young plants against fungal disease.

Rooting hormone is a complex blend of hormones, vitamins, nutrients and fungicides to initiate root development. Rooting hormone comes as a whitish powder or in three different coloured gels:

- Red: for hard wood cuttings

- Green: for soft wood/tip cuttings
- Purple: for medium wood cuttings.

The gel ensures consistent results by eliminating the entry of air into the cuttings and sealing the cut tissue to eliminate the risk of infection.

Propagation of *S. centrale* from vegetative material has proved difficult, with damping off a major problem (Miers 2004). Several attempts to propagate bush tomatoes from cuttings of selected plants collected from the field during the DKCRC trial failed to produce satisfactory survival rates. However, Collins (2002) reports that rooted cuttings of *S. centrale* with at least 90% survival rate were achieved with plant hormone IBA (Indole-3-butyric acid) at 3,000 and 8,000 ppm.



Plant selection

Field studies of the underground structures of *S. centrale* have confirmed that this species forms clonal communities. These communities have been observed in both natural and cultivated conditions. The underground lateral connections (roots) were found to possess root rather than stem anatomy (Dennett 2006).

The lateral roots of *S. centrale* form shoots and fine roots along the axis, a feature common to rhizomes (Jackson 1900). They also store large amounts of starch (Berry & Jackson 1976) and retain meristematic cells, which allow for rapid shoot formation (Guerrero-Campo et al. 2006). The function of the lateral roots of the bush tomato is similar to rhizomes in that they are underground organs for vegetative reproduction, and the storage of non-structural carbohydrates. In *S. centrale* the carbohydrate reserves probably enable the plant to re-sprout from roots, while still connected to the plant and from root fragments resulting from damage to the plant (Dennett 2006).

The ability to re-sprout from both roots and shoots, then to rapidly produce fruit, may make a colony/plantation of bush tomatoes highly productive. There is considerable potential to use root fragments or sections rather than seed or stem cuttings to establish crops from high yielding selected plants.

Dennett, in her work on underground structures of *S. centrale*, reported that all fragments of collected lateral roots that had been stored wrapped in damp paper had re-sprouted when replanted and watered, more than a week later. Some laterals re-sprouted while still wrapped in damp paper two weeks after excavation, but when replanted, shoot growth was very rapid and flowers formed within 12 weeks. Root fragments as small as 10 cm in length produced healthy shoots. Even laterals that were excavated from dry soil & wrapped and stored for three weeks in dry paper re-sprouted when planted and watered.

This ability to re-sprout from roots and shoots and for new plants to rapidly produce fruit, should make a colony/plantation of bush tomatoes highly productive. Given that vegetative reproduction from traditional cuttings is difficult, there is considerable potential to use root fragments or sections rather than seed or stem cuttings to establish crops from high yielding selected plants.



Tissue culture is increasingly used for commercial propagation of plants, especially in species where seed germination is difficult or where uniform features or disease-free stock is required. Tissue culture (micro-propagation) is a way to produce large numbers of 'clones' from a small number of selected specimens. Tissue culture protocols have been developed for only a few Australian native edible plants.

Very small cuttings (micro-cuttings) of the plant are taken and grown in a sterile medium in tubes in a laboratory. Although this is an extremely expensive way of producing plants, it produces large numbers of healthy replicates of the original selected plants. Plant material sourced from wild populations or from plants grown in any open air context is extremely difficult to sterilise prior to the establishment of aseptic cultures (pers. comm. D. Ormandy 2008¹). Most tissue culture is undertaken with material from plants that have been pre-conditioned, or grown in a very clean and controlled environment for several months prior to explants being taken.

Tissue culture protocols for *S. centrale* have been developed by Johnson and Ahmed. Ten-week-old seedlings of *S. centrale* were potted up (potting mix pH 6.6) and preconditioned in a glasshouse for a further two months prior to culture initiation. Cuttings 2 cm long were excised from the plants and, after a thorough wash under running water with soap, were sterilised by immersion in 0.5–1.0% (v/v) sodium hypochlorite solution for 15–20 minutes. The cuttings were then rinsed three times in sterile distilled water (Johnson & Ahmed 2005).



1 Don Ormandy is MD of CleanGrow.

Tissue culture trials using the Johnson and Ahmed protocols on field-collected material undertaken by DKCRC and Alice Springs Desert Park failed. This was due to the damage caused to the plant material during the sterilisation procedures, especially those carried out on very spiny and hairy material. This initial damage to the plant material led to the eventual failure of all subsequent micro-cuttings. In all subjects, the damage to soft tissue of the apical shoots resulted in no production of plantlets, or the failure to sterilise the plant material led to an inability to establish aseptic cultures (pers. obs. A Vincent, 14 November 2008).

Low-cost succession planning to increase yield and fruit size

A low cost way of increasing the yield and fruit size in a small plot is to continually introduce better yielding plants and remove those that are inferior. This can take place throughout the life of a small plot and will help to increase the longevity of the plot as well as production from it. Over the life of the plot:

- monitor yields of individual plants for the first few years
- take root cuttings from those with high yields
- strike and grow in tubes over winter
- allow suckering of higher yielding plants
- weed out low yielding plants
- replace dead and low yielding plants and/or enlarge planting with new 'selected' plants
- continue this practice over several years, replacing less productive plants with those grown from cuttings from the most productive plants.

Plot yield will increase incrementally each year.



Transplant seedlings or cuttings on a cool cloudy day after the danger of frost has passed and temperatures have risen to about 18°C. Water the seedlings well an hour beforehand to make it easier to remove them from the containers. Run the irrigation system for several days prior to planting to ensure that the seedlings are planted into moist soil, thus reducing stress. The spacing should be 30–50 cm between plants, with 1.5 m between rows. It will be beneficial to water the seedlings after transplanting with one of the water soluble trace element mixes on the market.

Dig a hole slightly larger than the tube-stock, remove the seedlings from the tubes, being careful not to damage the roots, and place in the hole, so that the base of the seedlings is just below the surface. Place the soil back around the hole and firm down.

There are various mechanical tree planters that can be used when planting tube stock. The most common manual planter is the Hamilton Planter. Planters remove a core of soil the same shape but slightly deeper than the seedling pot; the seedlings are then dropped into the holes and backfilled.

The 'Pottipuki' planter can also be used. This implement makes a hole for the plant and has a chute that the seedlings are dropped into, going straight into the hole. The seedlings are then backfilled.

Two fit and experienced people can plant up to 500 seedlings per full day if using a Hamilton Planter or pottipuki. However, where inexperienced people such as volunteers or school children are involved, it will take at least six people to plant 500 seedlings per day.

In recent years mechanical tractor-drawn planters have been developed for cell tray stock and forest tubes. These automated machines dig a hole for each seedling, plant it and firm the soil around it. Some machines can also water the seedlings in. This method requires two



Photo from forestrytools.com.au.

Planting out

people (a driver and someone to feed seedlings through the planter), and can plant several thousand seedlings every day.

Tomatoes (*S. lycopersicum*) are grown with a three-phase fertiliser program. The first and second phases encourage strong early growth and the third phase is to ensure good fruit development:

- Phase 1: 10 days prior to planting (14 kg N, 40 kg P, 48 kg K) at 15–20 g/m² of row
- Phase 2: At planting: (25 kg N, 5 kg P, 18 kg K) per hectare per week for early growth
- Phase 3: At flowering: (12 kg N, 5 kg P, 18 kg K, 10 kg Ca) per hectare per week from fruit set onwards.

Excessive use of nitrogen will result in bushy plants with few fruits. Our research suggests that a similar three-phase fertiliser program will suit *S. centrale*.

When planting out seedlings, make sure to acclimatise them to direct sun and weather conditions (harden off) before planting. Always plant seedlings in cool weather if possible.

A traditional method of planting tomatoes (*S. lycopersicum*) is trenching, which encourages greater water and nutrient uptake, as well as enlarging the area of root growth and encouraging more rapid growth if planting in cold areas.

The horizontal trench method is where a trench is dug for each plant, about 15 cm deep and long enough to lay down each seedling from the roots to the first true leaves. Any yellow lower leaves are pinched off the stem and the top of the plant is gently turned up (not too far) and supported with a little soil. It will naturally grow in the right direction. These methods also work well with *S. centrale*.

The vertical trenching method is where a deep hole is prepared for each of the tomato plants. Pinch off any



yellowing lower leaves and plant the seedlings 20–35 mm deeper than the original tube soil level. Leggy seedlings gain the most advantage from deep, vertical planting once the soil temperature reaches 18°C. If mulching, keep the mulch at least 75 mm from the stem of the plant.

Water the plants in after planting and keep well watered until they have established. Many factors, such as temperature, humidity and wind, determine the amount of water a plant needs. If the area around the root zone is kept moist, the plant should be getting adequate water. This can be measured by using instruments such as tensiometers or G-Bugs. Regular watering in the late afternoon is recommended. Drip irrigation is the most effective and economical means of watering.

The use of composted mulch can reduce evaporation from the soil surface, thereby reducing irrigation water requirements and maintaining soil moisture levels, reducing crop stress and stimulating plant growth. Composted mulch also reduces weeds and erosion, supplies nutrients and improves soil structure, improving water infiltration and drainage. These benefits can increase productivity and revenue, reduce farm inputs and associated management costs, and increase the sustainability of farms (Campbell & Sharma 2003).



The use of various mulching materials has long been understood to provide many benefits, and as such should be readily transferable across all horticultural ventures, including bush food plants. However, obtaining large quantities of organic mulch material in central Australia can be both difficult and expensive.

In central Australia, melon producers use black plastic mulch painted white along the growing mounds prior to planting. The plastic is painted white to try to reduce soil temperature increase. The plastic mulch has the added benefits of suppressing weed growth on the mounds and channelling any rainwater to the base of the growing mounds. This plastic mulch is replaced every year just

prior to the new melon plants being planted. The use of plastic mulch on mounds can be counterproductive if planning to harvest mechanically as the crop lifters will tear the plastic, often lifting it into the cutter blades and fouling them.

Some thought needs to be given to the use of any mulch in the horticultural production of bush tomatoes, as this may reduce the amount of natural suckering from each plant. In an unmulched plantation, natural suckering will increase biomass (the number of plants) by at least 30–40% per year, thus increasing possible yield (pers. obs. A Vincent 16 October 2008). Consideration should be given to all possible costs and/or benefits of all actions before making any final decisions. Compare the cost of purchase, installation and replacement of mulch materials against other weed control costs. Compare also the possible increased yields through improved soil condition from the addition of organic material, the water savings and reductions in crop stress against the loss of yield increase from natural suckering.



Planting out



Good management of the crop throughout the growing season will guarantee the continued vigour of the plants, ensure that any problems are noticed and dealt with immediately and will promote optimal plant health and good yields.

Irrigation: Newly planted seedlings should be well watered-in and kept well watered until they are established and able to cope with the conditions present. If the root zone is kept moist, the plants should be getting adequate water. Regular watering in the late afternoon is recommended.

When flowering begins it is best to irrigate under the plants, using drip or micro-irrigation methods, rather than by overhead sprinkler. This is because there are several leaf disorders common to *Solanum* species that are better controlled if the foliage is kept dry. Watering from above washes fungicides and insecticides from the foliage, promotes cracking of the skin of the fruit, flattens seedlings, kicks mud splatters onto plants and increases humidity, increasing the likelihood of bacterial or fungal infection.

Frequency of watering is governed by climatic and soil conditions. It is important to maintain a constant moisture content in the soil, as the greater the variation the more chance there is of disease or deficiency developing. Soil moisture content in the field should be monitored using tensiometers or capacitance meters such as EnviroScan, tensiometers, G-Bugs or Gopher.



It is reasonable to assume that plants will do better with more water and fertiliser than with less, but bush tomatoes are tough desert plants. The results of trials carried out at the ASDP by students from JCU to test

response to different water and fertiliser applications indicate that *S. centrale* will respond favourably to traditional horticultural treatments (fertiliser and irrigation) for other *Solanum* such as *S. lycopersicum*.

Tomato plants require frequent watering to establish good growth and fruit set. Stress from lack of water will reduce the quality and yield, and ultimately shorten the life of the plant. In mild, dry conditions, a deep watering of 40–50 mm every week will sustain the plants and encourage good root growth. In warmer weather, this may be needed every 2–3 days. Plants grown in a clay soil need less water than those in a sandy soil.

Weather conditions greatly affect the amount of water that crops use. Consider temperature, wind speed and humidity carefully when deciding how much water to apply during irrigation. Although watering by sprinkler is not advised, if it must occur allow for some being lost through evaporation before it reaches the root zone.

Calculate the output of the irrigation system before deciding the irrigation time for the crop. For 'butterfly' sprinklers in good condition and at 6 x 6 m spacing, the output is about 20 mm per hour. 'Knocker' or impact sprinklers on a 12 x 12 m spacing apply about 10 mm per hour. For example, if the evaporation from a free water surface is 12.5 mm per day, then running 'butterfly' sprinklers for about 38–40 minutes per day will adequately irrigate the crop.

$$\begin{aligned}\text{Watering time} &= \text{evaporation (ml/day)} \times 60 \div \text{output (ml/hr)} \\ &= 12.5 \times 60 \div 20 \\ &= 37.5 \text{ minutes}\end{aligned}$$

To calculate the flow rate needed to operate a drip system, multiply the flow rate of one emitter by the number of emitters in that block.

Where plastic mulch is used, water loss is 40–60% less than that from a free water surface, and adjustments in calculations should be made accordingly.

Drip irrigation can help you use water efficiently. A well-designed drip irrigation system loses practically no water to runoff, deep percolation or evaporation. Drip irrigation reduces water contact with crop leaves,

stems and fruit, making conditions less favorable for the onset of diseases. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

Fertiliser: Tomatoes (*S. lycopersicum*) are grown with a three-phase fertiliser program. The first and second phases encourage strong early growth and the third phase is to ensure good fruit development:

- 10 days prior to planting (14N:14P:10K) at 15–20 g/m² of row
- At planting: (25 kg N, 5 kg P, 18 kg K) per hectare per week for early growth.
- At flowering: (12 kg N, 5 kg P, 18 kg K, 10 kg Ca) per hectare per week from fruit set onwards.

Nitrogen is good for initial growth, but if used too strongly will deny good fruit set. A fertiliser higher in potassium encourages fruiting. Plants lacking in calcium (often due to inadequate watering or too much nitrogen) are susceptible to getting blossom end rot. Although there is usually plenty of calcium in the water in the Alice Springs area, it is not always effectively taken up or used by the plant. Many of the commercially available liquid tomato foods (such as Phostragen) contain added calcium. Alternatively, gypsum can be added to the soil around the plant as this will add calcium to the soil without increasing the pH. The plants should be fed at least 2–3 times per growing season to ensure adequate growth and development (Poffley & McMahon 2006).

DKCRC examined the effects on *S. centrale* of different nutrient regimes on morphology and growth characteristics during the early developmental stages as measured by total plant growth with three different nutrient treatments, with water levels remaining constant, where the treatments included no added nutrients, standard commercial nutrient loading and double loading.

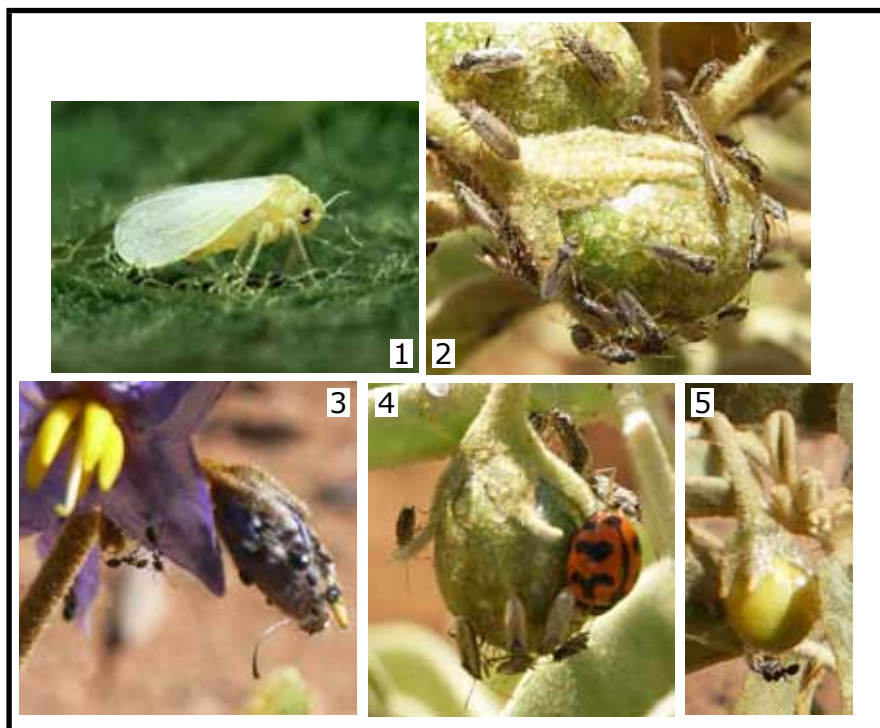
Significant differences in overall plant biomass were detected between any nutrient addition and the control (zero nutrient addition). Fruit size had limited influence on total plant weight although small-fruited plants differed from medium-fruited plants overall (irrespective of nutrient addition). There was no interaction between fruit size and nutrient treatment (Waycott forthcoming).

Pests and disease: Routinely check all of the plants for signs of pests, disease and deficiency symptoms.

Identified insect pests observed on *S. centrale* during the DKCRC trials:

1. Silverleaf whitefly¹ – *Bemisia tabaci*
2. Rutherglen bug² – *Nysius vinitor*
3. Cowpea aphid³ – *Aphis craccivora*

Other insects observed were lady bugs⁴, native bees and ants⁵. Ants were present in large numbers and appeared to be attracted to a clear, sticky exudate that formed on some fruits. Pollination of *S. centrale* is usually by hover flies or native bees (Symon 1981).



Whitefly and mites are able to build up a resistance to most chemical pesticides and should not be treated with these. Spraying with chemicals also destroys natural enemies or biological control agents that occur naturally. Potassium soap such as Natrasoap or Neemtech potassium soap with added spray oil may assist in managing

populations on host plants (note that other potassium soap products may also be effective).

Examples of spray oils include Eco oil, DC tron plus, Spraytech oil, Synertrol Hort oil or any other suitable horticultural spray oil. For smaller situations, cooking oils such as canola oil or a vegetable oil are also suitable. It is important to spray both sides of the leaves and spray to runoff and repeat every three days (until controlled). This spray solution may cause leaf burn to sensitive plants. The best time to apply sprays is in the late afternoon. Suggested spray rates are Natrasoap 20 ml/L + spray oil 2 ml/L or Neemtech 30 ml/L + spray oil 2 ml/L. (The recommended rate of spray oil listed is for canola oil and vegetable cooking oil. For horticultural spray oil, use the rate shown on the product label.)

Sucking insects such as aphids, white flies, mites and thrips can be a problem, and soap sprays can be used to control these pests in low numbers (Poffley & McMahon 2006).

Rutherglen bug (*Nysius vinitor*), or RGB, is a native species that can migrate into crops in very large numbers in favourable seasons and is a pest of many crops across Australia. This species breeds on a wide range of native and weed hosts, building up to large numbers in inland areas when winter and spring rainfall allows the growth of native herbs and weeds. In spring, as the hosts start to dry off, large numbers of adult bugs will move into the eastern cropping areas, migrating on the winds associated with storm fronts.



Adults are 3–4 mm long, mottled grey-brown-black, and have clear wings folded flat over the back. Nymphs are wingless, with a reddish-brown, pear-shaped body. *N. clevelandensis* and *N. vinitor* (Grey Cluster Bug) can be distinguished from each other with a hand lens or microscope. *N. vinitor* looks smooth, while *N. clevelandensis* is hairy.



RGB has eight generations a year. In spring and summer, development from egg to adult takes 3–4 weeks. Adults will live up to four weeks, and females will lay up to 400 eggs in this period. Adults will overwinter, moving to available weeds and crops in spring and starting to breed. Heavy infestations during budding may cause flowerheads to wilt and distort. RGB impact is greater in moisture-stressed crops.

The major pests of tomatoes (*S. lycopersicum*) are cutworms, budworms and mites. In many cases, early control is possible by hand-picking the pest from the plant. Remember that regular monitoring of the crop is necessary and correct diagnosis is important. The following descriptions are basic and are not intended to be used as the sole means for identifying pests (Marte 1998).

Cutworms: Seedlings will be cut off at or near ground level. Small worm-like caterpillars may be found just under the soil surface; they usually feed at night. Control these pests by putting a paper or cardboard collar around the base of plants when they are seedlings. Push it into the soil. Chemical control is possible during periods of serious infestation with chemicals such as Supracide and Suprathion. A word of warning: to date no testing has been carried out to ascertain if these chemicals are absorbed by fruit that has dried on the plants.

Budworms: Most damage will be seen on the fruit as the larvae burrow into the developing tomatoes, leaving holes. Budworms can be controlled by picking them off by hand or by applying a spray. Insecticides recommended for control are *Bacillus thuringiensis* (Bt). Bt is a biological insecticide and is most effective in controlling young grubs. Therefore early detection is important. Sprays should be applied when the grubs are first noticed, and then repeated if necessary.

Mites: Damage caused by mites is usually first seen on the leaves. They will start to curl downwards and turn silvery, eventually turning a bronze colour, wilting and dying. Damage may also be seen on the stems and fruits. Control is difficult because mites become resistant to chemicals very quickly. There are a few natural predators of mites

but they are usually not in sufficient numbers to significantly reduce populations. Insecticidal soap applied to both sides of the leaves should prove effective as a control. Spray late in the afternoon to avoid burning the foliage.

Nematodes: There are a number of different types of nematodes, the most common in tomatoes is the root-knot nematode. a microscopic worm that invades roots and inhibits water and nutrient uptake. Roots will have galls if this pest is present, which will give them a knotted appearance. The best control is prevention. Plant cultivars that show some resistance to nematodes and make sure seedlings are free from the pest before planting. Marigolds (*Calendula* spp.) are said to repel nematodes and can be used as a border to keep an area free of the pest.

Always follow manufacturer's recommendations when using any pesticide.

No disease symptoms were identified in plants on the DKCRC plot during the trial, but it is likely that *S. centrale* will be susceptible to diseases that affect other *Solanum*. Most Solanaceae family members are prone to fungal disease such as blight. Many of the vegetables are susceptible to soil-borne fungal disease such as Phytophthora, Verticillium or Fusarium. For this reason it is important to rotate crops. Also, many Solanaceae are susceptible to viruses, such as tobacco mosaic virus. These can be easily spread via weed species of the family.

Big bud is a minor disease in tomatoes and is spread by leaf-hoppers. The top of the tomato plant becomes stiff and upright and the flower buds are greatly elongated. Leaves become small and distorted. A natural control is to keep the area in and around the tomatoes free from weeds, which are a host for leaf-hoppers. As the weather becomes drier and the weed source dies, the insects move onto the tomato crop.

Bush tomatoes can suffer from a calcium deficiency resulting in blossom end rot. As the fruit begins to grow, this will show up as a brown spot on the blossom end of the fruit. Although there is

usually plenty of calcium in the water in the Alice Springs area, it is not always effectively taken up or used by the plant. To remedy this situation, irrigate regularly to maintain soil moisture around the plant roots. Add gypsum to the soil around the plant to add calcium to the soil without increasing the pH (Poffley & McMahon 2006). A grower in South Australia controls blossom end rot in bush tomatoes by applying calcium nitrate via their centre pivot irrigation system.

DKCRC weed trial: 12 rows to the east of area A2, designated as A2b (140 plants per row), were divided at the mid-point (east-west) across the rows with the northern section designated as 'unweeded' (with no weeding activity for six months) and the southern end as 'weeded' (weeds removed continually for six months). The irrigation lines (1 L/hr, 2 L/hr and 3 L/hr) were laid in blocks of two and randomly assigned between the 12 rows.



Row 65 B (north): unweeded



Row 65 A (south): weeded

As can be seen from the photos above, failure to reduce weed competition resulted in an initial loss of 85% of the plants in the unweeded area compared with a more normal mortality rate of 4.7% in the weeded area. The loss of plants resulted in a corresponding reduction in yield. Several months after the trial ended and the area was fully weeded, the mortality rates were recorded at 78% of total

plants in the formerly unweeded area and 3% in the weeded area. The change in mortality is due to the underground root systems of some of the 'dead' plants reshooting once the competition had been removed.

Care must be taken when weeding using either manual, chemical or mechanical means, as the removal of suckering growth around the plants will reduce possible overall yield. Good weed control reduces the amount of unnecessary vegetative material that a mechanical harvester will have to cope with, thus reducing post-harvest cleaning. It also expedites hand harvest and reduces the possibility of pest infestation.

* * * * *

Bush tomatoes will flower under a wide range of conditions. For satisfactory fruit setting, warm conditions are desirable. Factors that cause poor fruit setting are:

- excessive nitrogen levels, which result in heavy foliage growth, proliferation of side shoots and flower shedding
- inadequate, uneven or patchy irrigation
- less than six hours of direct sunlight per day
- damage to flowers by insects such as thrips, which cause imperfect pollination, fruit setting and fruit shape
- high humidity.

Fruit ripening: In general, plant tissues communicate using classes of compounds called hormones: substances produced in one location that have an effect on target cells in a non-adjacent location. In plants, germination, growth, development, reproduction and environmental response are all coordinated through hormones. Although most of the main plant hormones are transported in the vascular system of the plant, one class of hormones is transferred in gaseous phase. This class includes the plant hormone ethylene.

Ethylene is manufactured and released by rapidly growing tissues in roots, senescing flowers and ripening fruit. It has many effects on plants, including being responsible for the stunting of plants in high winds or when repeatedly touched. In addition, ethylene promotes fruit ripening. Like many hormones, it does so at very low

concentrations. Apple growers take advantage of this by picking fruit when it is not ripe, holding it in enclosed conditions without ethylene, and exposing it to ethylene just before sale (Graham 2005).

When the seeds of most commercially grown fruit are ripe and ready for dispersal, the fruit converts stored starch into sugar, creating a 'reward' for animal seed dispersers. This sweetness is what makes the fruit attractive to humans and therefore commercially viable. The hormone ethylene initiates the metabolic pathways that lead to this conversion (BSA 2001).

Mature green fruit may be artificially ripened by spraying with an ethylene-releasing chemical, Ethrel®. Use 200 ml of Ethrel® to 100 L of water, and spray to cover all fruit required for ripening. For best results on tomatoes (*S. lycopersicum*), moderate to high temperatures and humidity are desirable; temperatures higher than 18°C are best. Harvest 10–14 days after application.

S. centrale is a hardy, fast-growing species. Planted as a seedling in early spring at a spacing of around 0.3–0.5 m, the plant usually produces a small crop for harvest the following autumn. The longevity of aerial stems of *S. centrale* is unknown. Severe frosts will kill shoots

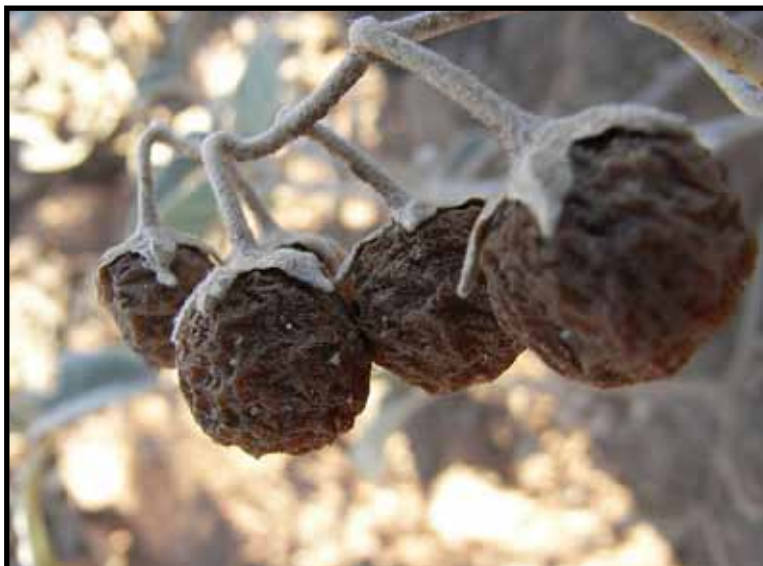


of *S. centrale*. It appears that over time the shoots will lose vigour and after a few years following a disturbance there may be no shoots remaining (Dennett 2006).

The second season will see plant growth and yield increase, with interplant areas beginning to be colonised by suckers. It is unclear how many years an individual plant will continue to regenerate from the original rootstock, or how long an agricultural planting will remain economically viable. Experience to date suggests around 3–4 years (Hele 2006).

S. carolinense, *S. elaeagnifolium* are vigorous weeds in cropping regions. Colonies are very difficult to eradicate as the viability of roots is not affected by cultivation and most herbicides. In fact, cultivation stimulates sprouting from root fragments (Klimesova & Martinkova 2004, Urakawa & Koide 2004).

The difficulty in eradicating colonies or preventing colony expansion has been noted in *S. centrale* (pers. comm. T Collins). This will create challenges when using *S. centrale* as a crop; it will be difficult, for example, to rotate the field with other crop species, or even to sow new varieties, because of the difficulty in totally removing the *S. centrale* colony.



New flowers and fruit are produced along the branches of *S. centrale* in sequence, most plants producing small bunches or trusses. Inflorescences consist of 1–6 flowers and vary in colour from bright purple to a soft mauve. Approximately 0.01% of bush tomato plants produced white flowers in the DKCRC plot; plants with white flowers produce little or no fruit (pers. obs. A Vincent 06 June 2008). Production and ripening of fruit is sequential, not synchronous. The first green fruit appear approximately three weeks after the first flowers.

Fruit size, shape and colour vary substantially within and between varieties. Sizes range from 5 mm to 20 mm. Fruit shape ranges from spherical to obovoid and some have a pointed end, like small chillies (acuminate). When ripe and edible, fruit colour ranges from bright sunshine yellow to an opaque cream. Fruit shape and colour is consistent for individual plants. All fruit turns an ochre colour when dry, but older dry fruit that has been on the plant for some time can be quite dark, almost black. This may be the result of re-wetting after rain. Green fruit that has dried on the plant is a shiny black or wrinkled grey colour.

CAUTION: Unripe fruits contain the toxin solanine (which is also present in green potatoes) and must be fully ripened before consumption.

It is common to find plants with dried fruit, yellow ripe fruit, green fruit, flowers and flower buds present at the same time. Trusses are produced throughout the growing season in response to water availability. In a horticultural situation this can mean that plants will produce fruit from November through to the first frost of winter. In areas outside the frost zone, or during mild winters, flowering and fruiting can continue through winter.



The majority of plants in the DKCRC trial exhibited a semi-prostrate to prostrate habit, although some were upright and quite woody. Prostrate or sprawling plants tended to produce higher yields. The majority of plants, regardless of phenotype, exhibited a strong indehiscence, with the fruit staying attached to the plant for long periods of time. Ripening is dependent on weather conditions and starts at the bottom (first fruit) of the truss.

Hand harvest of bush tomatoes produces a very high quality product with minimal yield loss, foreign material or damage. Some of the smaller, family-based Aboriginal growers have chosen to hand pick their fruit. This choice has been made for several reasons:

- Smaller horticultural enterprises cannot afford the outlay for large machinery
- The labour of family members is seen as the input necessary for individuals to obtain a share in the income generated by the business and is not costed as an expense to the business
- Crops are planted on mound and furrow, making mechanical harvest difficult
- Cleaning and sorting occurs during picking, resulting in a higher quality product.

Most growers who choose to continually hand pick, pick ripe fruit throughout the season. The harvesters pick the ripe (yellow) fleshy fruit as it ripens and do not leave fruit to dry on the plants. As there is currently no market for the product in the undried state, fruit must be dried prior to sale (see post-harvest handling). Periodic hand harvest (as opposed to continual), results in the pickers harvesting both dry and ripe fruit. These should be separated from each other, as drying already dry fruit can 'over dry' the product, resulting in a reduction in weight and loss of quality.

It is likely that continual hand harvest may increase overall yield; as with conventional tomatoes, when fruit is picked as it ripens it encourages the development of new flowers.

Hand harvest can be expensive, if costed realistically. An experienced harvester is capable of picking approximately 1.5 kilograms of ripe

fruit or 1 kilogram of dried fruit every two hours. Inexperienced pickers may take three hours to pick a kilogram of dried fruit. Using the national minimum wage rate of \$14.31 per hour this would equate to hand harvest costing around \$28.00 per kilogram, substantially reducing profitability.

Harvest

Hand harvest is quite unpleasant work. The plants are low to the ground (even harvesting while sitting on low crates is back-breaking); many of the plants are covered in spines which are very painful and irritate the hands; the plants are often covered in biting ants that swarm up arms and legs to attack; the plants exude a strong solanine smell that can bring on headaches; and even when picking in the early morning, it can be hot and very tedious work. For these reasons, it is often extremely difficult to attract and keep an adequate labour force. The quality of the hand harvested fruit is, however, of a higher quality than that which has been machine harvested.



Machine harvest of bush tomatoes: Machine harvest of any crop results in some percentage of crop yield loss. As this percentage is usually known for most crops and in the range of 2–5%, it is considered an acceptable exchange for the time and labour savings made with the use of mechanical harvesters. Since large-scale agricultural production of bush tomatoes began in the early 1990s, several individual growers have modified existing cereal harvesters to mechanically harvest bush tomatoes.

Cereal harvesters work by cutting the plant material just under the fruiting bodies, as cereal crops have the grain located at the very top of the plants. This material is then carried up a conveyer belt to the thresher where all material enters the space between a revolving drum and a concave screen (thresher). Then the materials pass across walkers which shake and separate the threshed material over a series of sieves to separate the grain from the chaff.

Unfortunately, this is not usually possible with bush tomatoes, as a large percentage of seed-raised plants are prostrate to semi-prostrate. It has also been observed that some plants become more so with the weight of fruit borne on softwood stems. Capturing as much product as possible necessitates harvest of almost the entire above-ground portion of the plants, thus substantially increasing the amount of harvest bulk that the machine has to cope with.

DKCRC machine harvest trial: Trials carried out with a Hege 125 plot combine harvester (1972) illustrate the main issues currently affecting efficient machine harvest of bush tomatoes. The Hege was modified to harvest bush tomatoes by an experienced broadscale bush tomato grower from South Australia. Modifications included installing a 'concave' with a mesh size of 25 mm, opening the space between the drum and the concave to 15–20 mm and fitting or adjusting sieves to 25 mm apertures. Crop lifters were fitted to the machine by research staff after the first pass failed to capture all plant material.

Several rows were harvested in June 2008, with a purpose-built shade-cloth bag fixed to the waste chute to enable the collection and measurement of waste material. Hopper bins were emptied

and measured after each row to establish amounts of fruit and waste material, and to establish damage and loss rates. All materials from waste chute and hopper buckets were hand sorted and measured. Fruit was also collected from along harvested rows to ascertain the percentage left behind by the harvester.



It immediately became apparent that harvesting healthy, growing bush tomato plants was difficult because the machine was unable to handle the large amounts of green, moist vegetative material. The feeder tube to the hopper and the hopper itself quickly and consistently became clogged with soggy, chewed-up leaves and stem material, which had to be manually removed after each row was harvested. The amount of vegetative waste material mixed with the fruit in the hopper bins was more than 50%, and therefore unacceptable.

Peter Hoffman, who has several years' experience in using cereal harvesters on bush tomatoes, emphasises slow groundspeed and thresher drum speed to avoid damaging the fruit. Raising the blade to take first the top of the plants, and then the rest at successive passes reduces bulk moving through the machine and helps to avoid damaging fruit and improves the separation process. Peter also indicated that a high fan speed setting helps separate the fruit from leaf material (Desart 2008).

There are a number of important variables that influence how any crop is harvested using a cereal harvester. These are the bulk of the



crop, the ability of the bulk to travel through the machine without clogging it, the height of the crop being cut, the size of the product being separated, the fragility of the product being separated, and the fraction of the waste material in the hopper that is difficult to separate from the desired product.

Fortunately, a cereal harvester may be adjusted to reduce harvesting problems caused by variations in these parameters. Other problems can be overcome by pre-harvest

management of the crop, but there are some problems that need to be addressed by modifying the machine beyond manufacturer specification to obtain the best harvest result.

Harvest bulk refers to the volume of plant material that enters the machine at any given time. The more bulk going into the harvester, the harder it has to work to separate out the desired product from the rubbish. As a rule, the greater the bulk going into the machine, the slower the ground speed of the machine needs to be.

Attempting to push through too much bulk will result



in greater wastage out the back of the machine as it struggles to process it. Excessive bulk will also increase the chances of the machine clogging up in the field. Unfortunately, the bulk percentage in a bush tomato crop is very high as the fruit is distributed in a way that requires processing the entire plant. This is different from cereal crops where all the grain is located at the very top of the plant and can be selectively cut off.



Crop bulk associated with leaf material can be reduced prior to harvest by spraying the crop with a desiccant which uses the active ingredients Paraquat and Diquat. This is a technique used to improve the harvest qualities of crops such as field peas and potatoes. Chemicals other than Paraquat or Diquat herbicides can be used; however, they are more likely to cause permanent damage to plants

(Desart 2008). Testing to see if these chemicals will be absorbed by the dry fruit on plants needs to be undertaken prior to their use.



Several harvested rows after two opposite directional cuts

An alternative method is to mimic the natural growth cycle of the plant and reduce crop bulk by droughting, that is, to turn off the irrigation for a period long enough to



desiccate the majority of leaf and stem material present on the plants.

In the DKCRC trial, the irrigation was turned off for a period of one month prior to harvest in June 2008; however, heavy rain at the end of that month effectively negated any desired effects. To counter this, irrigation to the area

was disabled for a further month. The resulting desiccation of leaf material reduced machine clogging substantially. Depending on the length of droughting, this may also lead to small yield losses from increased fruit drop and fruit discolouration (where the fruit is very dark) due to the extended length of time the fruit is on the plant and to rain events, where dry fruit is saturated and redried.

It is difficult to establish an accurate percentage of probable yield loss from machine harvest of bush tomatoes. Estimates from the DKCRC trial suggest that it may be as much as 20% if the machine has not been set for optimal operation.

Losses from unharvested material left on the ground after a single pass was 7.6% per row; this was reduced to less than 2% with the introduction of a second harvest pass in the opposite direction per row. Fruit lost out



the back of the machine was measured at 3.4% of total yield per row. The highest losses observed were those attributed to incorrect adjustment of the distance between thresher and concave screen or to excessive ground speed and/or thresher drum speed damaging fruit. The extent of the loss is difficult to calculate but is obviously substantial as can be seen by the amount of damaged fruit in the hopper material.

It is important that fresh green or dried green (black) berries not be included in the final harvested product, as these contain high levels of solanine. The finished product must be as free as possible from all leaf, stem, calyx and foreign materials.

When bush tomato plants on the side of local roads are removed by a grader, and there is a rain event soon after, the plants respond strongly by reshooting, flowering and fruiting, in a very short time. It may be possible – with the use of a mechanical cereal harvester, appropriate timing and irrigation – to manipulate the plants to produce two scheduled crops per year. It is unclear, however, if this would produce a greater yield from the plot than a single harvest per year and requires further investigation.



Excessive waste material in the hopper due to incorrect ground and drum speed, incorrect concave settings on harvester and too much fresh green leaf and stem material on plants being harvested.

The difference between hand-harvested and machine-harvested bush tomato fruit is evident even after the machine-harvested fruit has been cleaned further in a Zig Zag Aspirator and then picked over by hand (see below). The removal of non-fruit material from machine-harvested product will potentially negate some of the cost and time savings accrued from mechanical harvest. Post-harvest mechanical separation methods are necessary to ensure improved product quality and good cost/benefit ratios.



Post-harvest handling

Of considerable concern is if machine-harvested product with a relatively small percent of leaf, stem and calyx material ($\leq 10\%$) present is ground for consumption; the amount of solanine is increased, which alters the palatability of the finished product (pers comm. J. Robins 12 May 2009¹).

A grower in South Australia who uses a modified PTO harvester puts the material back through the stationary harvester for re-threshing after the harvest is complete, and he has dried the material on racks to reduce the amount of harvest bulk. Reportedly, this will substantially reduce the amount of leaf and stem material transferred to the hopper (Desart 2008).

Additional DKCRC trial material harvested in 2009 by the 1992 Kingaroy Engineering Works Trial Plot Harvester was cleaned using a Zig-Zag Seed Aspirator at the Alice Springs Desert Park. The seed aspirator used was designed for small sample sizes (≤ 500 g); and as such was time consuming and inefficient. Although larger capacity machines are available, the dried fruit are very often of similar weight

¹ Robins is the Director of Robins Foods

to the materials we are trying to remove. The other issue is that calyx and stem materials still attached to fruit and larger pieces of stem are not removed using this method. Some form of cleaning and de-stemming machinery is required to handle observed levels of waste in the harvested product, but such a product is currently unknown to the author.

Number of fruit	139
Weight range of fruit	0.4 grams
Weight range of fruit	3.0 grams
Total Wet weight	135.0 grams
Total hours on drying rack	116
Average RH - 9am	19%
- 3pm	9.2%
Average Evaporation Rate	12.44 mm
Sundried weight	55.0 grams
Weight at 0% Moisture (solids)	48.77 grams
Moisture by weight	86.23 grams
Total moisture loss (sun)	92.775%
Total moisture content (Sun)	7.225%
Total % weight loss (Sun)	40.74%

Drying fruit: Sun/air drying is the most cost effective way to reduce the ripe yellow fruit to the wrinkled brown dried product. After hand picking the fruit should be hand cleaned to remove any foreign material. It is then washed (agitated) in warm to hot water for several minutes to remove the sticky residue and any ants or dirt attached to the fruit. The fruit is drained and spread onto mesh racks to dry. These racks can be constructed from timber or metal and wire mesh (≤ 5 mm) or shade cloth and should be in an area where air can travel freely around the racks and in filtered sunshine (under shade cloth). Periodically raking through the drying fruit will speed up the drying process.

An average 40% weight loss occurs during the drying process from ripe, yellow fruit to dry, caramel-brown fruit. The dry fruit should be firm and not squishy when squeezed between the forefinger and thumb. Drying to the required dryness can take several days on the racks, depending on the weather, but care should be taken not to over-dry the fruit by leaving them on the racks for longer than necessary.

Fruit that has too high a moisture content will not be accepted by buyers and may spoil during storage. As mentioned above, it is also

important not to over-dry the fruit as this can affect the flavour, and will reduce the overall weight of the product. For example, 100 kg of fresh fruit dries to 55–60 kg at optimum moisture levels, but will dry to just 48.7 kg if over-dried, thus losing \$X/kg for the over-dried product.

Research into the effect of post-harvest handling of wild-harvested product on the bioactive (nutritional components) content of *S. centrale* suggests that sun drying resulted in a greater loss of bioactive components but produced a better appearance. Hot air oven drying (2 hours at 70°C) produces a dark brown fruit with higher levels of bioactive compounds. The stability and retention of bioactive compounds is dependent on drying conditions and on the moisture content of the fruit (McDonald et al. 2006).

While a reduction in bioactive content may be an issue that needs further work, the greater immediate issue for the bush tomato industry is controlling the taste of the product. It is recognised by many manufacturers that the flavour profile of sun-dried fruit (controlled drying) is far better than that of oven-dried. Oven drying can produce a brittle, dark brown fruit with a noticeable bitterness and less attractive appearance when ground than the sun-dried product (pers. obs. A Vincent 12 December 2009).

* * * * *

Washing fruit: Fruit harvested by traditional Aboriginal wild harvesters is dried on tarps on the ground and then hand-rubbed in dry sand to clean it. There are some manufacturers who are concerned that traditional methods do not meet current Australian standards for food handling or batch control, and therefore products made from fruit produced from wild harvest may not meet export requirements.

Dried bush tomato fruit that has dried on the bush can be quite dirty due to the clear sugary exudates produced by ripening fruit. This substance is very sticky and various organic and inorganic waste materials adhere to it (pers. obs. A Vincent 23 November 2007).

The dried fruit should be very quickly washed (strongly agitated) in warm to hot water. The fruit must be in the water for less than 2–3 minutes, as the dried fruit very quickly rehydrates, taking up water and becoming soft. Fruit collected late in the season (especially after rain events) can have quite a large amount of dirt and other material adhered to it. Measurements during the DKCRC trials have shown that this can be as much as 1–2% of the total fruit weight prior to washing.

A chlorine wash may be used to minimise possible contamination by *E. coli* if prior harvest, handling and storage practice is questionable.

After washing, the fruit is immediately drained and spread onto mesh racks to dry. It will take several hours (depending on temperature and humidity) and several rotations of the fruit for it to re-dry to an acceptable moisture content.

After washing and re-drying, fruit should be stored in airtight containers below 4°C for short-term storage. Long-term storage will incur risks associated with insect infestation.



The continued expansion of the bush tomato industry brings with it the need to adopt quality control and assurance procedures for the post-harvest handling and storage of the dried product. Stored-product pests have a major economic impact on the food industry due to the costs associated with monitoring and treatment of infestations and the rejection and return of contaminated products (Campbell & Arbogast 2004). The market for post-harvest dried fruits and nuts has much lower tolerance for insect infestation than other markets, particularly when the product is destined for export.

Worldwide, the Indian meal moth, *Plodia interpunctella* (Hübner), is a major pest problem during processing and storage of dried fruit and nuts. Second in importance as a stored-product pest is the Rust red flour beetle, *Tribolium castaneum* (Herbst), followed by the Sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) and the Warehouse beetle, *Trogoderma variabile* (Everts) (de Sousa-Majer et al. 2009).

These pests are major or secondary pests that attack many products around the world. Post-harvest pests of dried fruit can be divided into two categories: those that infest products in the field and which are brought into storage; and those that infest products after they are stored (Throne et al. 2003). These insects are found anywhere cereal products and other dried foods are processed and stored. It is not a surprise that these stored-product pests are also 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 pests listed above in recent years (de Sousa-Majer et al. 2009).



The various developmental stages of the Indian meal moth.

Source: de Sousa Majer et al. 2009

The need to eliminate methyl bromide fumigation to control insects in stored commodities was addressed under the terms of the Montreal Protocol. Some storage facility managers have shown increased interest in the use of high temperature and/or vacuum treatment to control insects; this trend is being driven by an increased public awareness of the health benefits of fruit and vegetables, and increased interest in food without chemical residues (de Sousa-Majer et al. 2009).

One of the main assumptions about bush-food products is that they are 'clean and green' because they are from the 'bush'; this assumption persists even though much more bush food is being cultivated. Therefore the use of non-chemical control of pests of bush food products would increase their uptake by supermarkets and would promote wider acceptance by the international industrial food industry (de Sousa-Majer et al. 2009).

The two main methods of non-chemical control for stored product pests are:

1. high temperature treatment
 - a. ordinary heat: fluidised bed or spouted bed, conductive, convective or pneumatic conveying
 - b. radiative heat: infrared, microwave or radio frequency
2. vacuum low pressure treatment with temperature modification.

An investigation into the post-harvest storage of *S. centrale* and impact on produce quality was carried out by a DKCRC research team and reported in de Sousa-Majer et al. 2009. A précis of the research results follows.



Adult Sawtoothed grain beetle
Photo courtesy of Rob Emery & Rebecca Graham, DAFWA, in de Sousa Majer et al. 2009



Larva of the Warehouse beetle
Photo courtesy of Rob Emery & Rebecca Graham, DAFWA, in de Sousa Majer et al. 2009

Insects found and identified in stored *S. centrale* fruit samples from the NT and WA were Indian meal moth, *P. interpunctella*; Rust red flour beetle, *T. castaneum*; Saw-toothed grain beetle, *O. surinamensis*; and Warehouse beetle, *T. variabile*. Also, the Eggfruit caterpillar, *Scelioles cordalis* (Doubleday), was found in green *S. centrale* fruit grown in a field trial area in WA.

Samples of *S. centrale* fruit from NT and WA all showed considerable levels of infestation. The weight of 100 *S. centrale* fruit varied from 37.06 g to 87.84 g, and several of the samples showed damage and loss of integrity. 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, which attacks green fruit in the field. No stored-product insects were found in SA samples.

The impact of insect control treatments on product quality is very important. The effect of high temperature and low-pressure treatments on product quality 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 50°C or greater.

The recommended treatment is high temperature at $60 \pm 2^\circ\text{C}$ (interior batch temperature) with exposure time of 12 hours. The DKCRC study concluded that $60 \pm 2^\circ\text{C}$ for 12 hours was lethal for the four main storage pests and maintained *S. centrale* fruit quality.

After the above treatment, hygienic storage in sealed polyethylene bags or sealed airtight plastic containers is essential, to prevent reinfestation. The study recommends that fruit be stored at temperatures below 8°C in order to help preserve product quality (de Sousa-Majer et al. 2009).



Rust red flour beetle: larva and adult

Photo courtesy of Rob Emery & Rebecca Graham, DAFWA, in de Sousa Majer et al. 2009

There are four food safety standards contained in Chapter 3 of the Australia New Zealand Food Standards Code. These standards require Australian businesses to follow food safety practices and use food premises and food transport vehicles that meet specified requirements. The standards applicable to post-harvest handling of both wild harvest and cultivated bush foods are:

Standard 3.1.1 Interpretation and Application: Standard 3.1.1 is an introductory standard, which explains the main terms used within the Food Safety Standards, such as the meaning of 'safe and suitable food'. It also applies the other three standards to food businesses in Australia, with some exceptions. For example, there are exemptions from some of the provisions for charities and community groups and also for temporary premises and home-based food businesses. Note: If you are unsure about whether any of the standards apply to your food business, contact your State or Territory health department.

Standard 3.2.1 Food Safety Programs: Standard 3.2.1 is based on the internationally accepted principle that the best way to keep food safe is to control the hazards that can arise during the production, manufacturing and handling of food. To that end, Standard 3.2.1 supports Standard 3.2.2 Food Safety Practices and General Requirements and Standard 3.2.3 Food Premises and Equipment. Under Standard 3.2.1, a food business must be able to show that it complies with the other standards through an independent audit process.

Standard 3.2.2 Food Safety Practices and General Requirements: Standard 3.2.2 sets out specific food handling controls related to the receipt, storage, processing, display, packaging, transportation, disposal and recall of food. Other requirements relate to the skills and knowledge of food handlers and their supervisors, the health and hygiene of food handlers, and the cleaning, sanitising and maintenance of the food premises and equipment within the premises. If complied with, these requirements should ensure that food does not become unsafe or unsuitable.

Standard 3.2.3 Food Premises and Equipment: Standard 3.2.3 sets out the requirements for food premises, fixtures, fittings, equipment and food transport vehicles. If food businesses comply with these requirements, they will find it easier to meet the food safety requirements of Standard 3.2.2 (FSANZ 2008).

Supply and value chains are vertically integrated, strategic alliances between a series of independent businesses that have come together as a group to more efficiently capitalise on specific market opportunities (Cox 1999). The goal of a supply and value chains is to optimise performance in that industry using the combined expertise and abilities of the members of the chain. Successful chains depend on integration, coordination, communication and cooperation between partners with the traditional measure of success being the return on investment (Bryceson & Kandampully 2004).

All bush-food producers are part of what is known as a value chain, that is, the raw product grown on farms (or harvested from the wild) is transformed through the chain to a processed food product bought by consumers on the shelves of a retail outlet. With increasingly competitive and quality-conscious global marketplaces for food products, governments and agriculture industry chain members are beginning to recognise that food integrity and traceability is critical in answering consumer demand for safe, clean food with an emphasis on quality (USDA 2002).

Product tracking, or traceability, is the ability to backwards track, to their source, the inputs used to make a food product through different points in the supply chain. Traceability is established for an attribute when information about that particular attribute is systematically recorded from creation through to marketing. For example, for beef meat complete traceability would include the ability to identify the genetics (via DNA tracing), feed sources, animal husbandry techniques, method of slaughter, etc. Any number of attributes about a product can be recorded in this manner.

Traceability systems are about good record keeping and may be used either to segregate one crop or batch of ingredients from another, or as an Identity Preservation (IdP) system that identifies

the nature of the crop or ingredient. These IdP systems require strict documentation to guarantee that certain qualities or traits are maintained in the supply chain (Bryceson 2008).

In *Value chain analysis of bush tomato and wattle seed products* Bryceson (2008) states: That analysis shows that demand for bush food products has grown in the last two years, and that currently demand for bush tomato is higher than for wattle seed. It was also found that while a viable bush food industry exists, there are considerable challenges to developing a sustainable industry, both from a production and from a market perspective. These include:

Quality Assurance

- Supply issues need to be addressed, such as raw product availability, quality and consistency of raw product, effective grading of product and appropriate inventory management of all components in the chain to minimise fluctuating demand/supply flows. The question of sustainability and efficiency of wild-grown product and bush harvesting methods, and are unlikely to be plausible as the only source of product in a commercially driven environment. Cultivation of bush tomato in particular is being investigated in an effort to address this issue.
- Internal industry competition for raw material supply is fierce when supplies are poor. This is leading to monopolistic behaviours by some players, and these behaviours create a perception of a



lack of professionalism increasing the business risk of the bigger retail outlets which are dealing with the small producers that are coming into the industry.

- Food safety and traceability is a key area of concern. Poor food-hygiene practices at the production stages will result in variable raw material quality. Additionally, there is very little record keeping or traceability generally. This situation must be addressed in the current food business environment for product to be sold within current food safety guidelines.
- Consumers do not know what most of the current marketed bush food tastes like, so are not actively demanding the products. The questions arise as to how consumers differentiate bush products from all the similar products on the shelves, and do they want to?
- Business development and knowledge creation, transmission and operational training are lacking.

Donald et al. (2006) recommend the development and implementation of a Quality Assurance program for bush foods that would address:

1. correct botanical identification of raw material
2. identification of optimum storage and packaging to ensure product integrity
3. institution of a batch numbering system and analysis from point of harvest
4. identification of optimum post-harvest and pre-processing procedures
5. development of specifications for all bush food raw products
6. development and adoption of storage and handling protocols for raw products.



Alyawarr speakers from Ampilatwatja, Fiona Walsh and Josie Douglas.

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Desert Knowledge Cooperative Research Centre

Horticultural Production of Bush Tomato

This project has been funded by Desert Knowledge CRC to investigate the economics of growing Bush Tomato (*Solanum centrale*) as a commercial crop in Central Australia.

