Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Improving smallholder canarium nut production in Vanuatu

Liz Ota

lota@usc.edu.au

University of the Sunshine Coast (USC)

Elektra Grant

Queensland University of Technology

Dora Carias

University of the Sunshine Coast (USC)

Research Article

Keywords: Melanesia, galip nut, Small-Island Development States, small-scale forestry, agroforestry

Posted Date: June 1st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9623509/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Agroforestry Systems on September 15th, 2026. See the published version at https://doi.org/10.1007/s10457-026-01670-w.

Abstract

The diversification of sources of income can reduce the financial vulnerability and increase the resilience of rural household in developing countries. This paper aims to assess the potential of *Canarium indicum* L. plantations for smallholders in Vanuatu. We carried out a review of available literature on canarium nuts in Vanuatu and performed financial and sensitivity analyses of canarium tree plantations at the household level under four scenarios: sale of nut-in-shell, sale of kernel-in-testa, sale of dried kernel using solar dryer, and sale of dried kernel using electric dryer. The literature demonstrates great potential for the canarium nut industry, but also highlights its challenges, which were confirmed in the financial analysis. The financial returns for the different scenarios, the nature of labour provided, nut processing limitations, and potential market opportunities are discussed. Current prices do not pay off investment in canarium growing if labour is costed at the minimum wage of the country. However, smallholders might place a non-financial value to the activity. Prices paid for all canarium products must increase for a profitable investment. There is potential for value adding if infrastructure is available and if smallholders are interested. Challenges and opportunities for canarium nuts discussed in this manuscript are also relevant for other non-timber forest products in other remote locations in the tropics.

1. Introduction

The diversification of sources of income can reduce the financial vulnerability and increase the resilience of rural household in developing countries. Small-scale agriculture is the primary economic activity of about two thirds of the population in Vanuatu, where copra, cocoa, and kava are the dominant agricultural products (CIA, 2020). Despite the importance of agriculture, only one third of the total cultivable land of the country is being farmed and great potential exists in domestic and export markets of traditional and high-value agricultural commodities (Department of Agriculture and Rural Development, 2020). The need for optimisation of use of agricultural lands was also demonstrated by the long-lasting economic impacts of the 2015 Tropical Cyclone Pam. The production of canarium nuts is a potential complementary livelihood activity for ni-Vanuatu rural households, but challenges in the production system and the value chain for canarium products still constrain the benefits it can bring to smallholders.

The canarium tree (*Canarium indicum* L. of the family Burseraceae) or nangai, as it is named in Vanuatu, has been used and cultivated in Melanesia, where it has great cultural importance (Thomson & Evans, 2006) and may possibly be the oldest domesticated species (Yen, 1994). Its edible nuts, collected in an often-opportunistic manner, are part of the local diet in Vanuatu. Despite the high prices of up to USD 25,000 per tonne of processed canarium nut products, supply constrains the market that has unmet demands for all canarium products (Thomson & Evans, 2006, Wallace et al., 2012).

There is a high cost involved in harvesting canarium nuts from wild, scattered trees (Bunt & Leakey, 2008), and there is limited availability of wild resources (Crowley et al., 2001). Because of its long use, it is well adapted to local agricultural systems (Evans, 1994b). Canarium trees are grown in Vanuatu,

predominantly in the western provinces (Carter & Smith, 2016). Despite the progress in canarium plantation systems, the industry is still very limited and there is the need to educate more people about the economic value of canarium as a new crop and to discourage logging of its trees for timber (Nevenimo et al., 2007). A developed canarium industry in Melanesia would particularly benefit women, who are greatly involved in growing, processing, and marketing canarium products (Wallace et al., 2012).

This paper aims to assess the potential for canarium nut production systems by smallholders in Vanuatu. The specific objectives are to: i) carry out a review of available literature on Canarium nuts, with a special focus on Vanuatu; and ii) perform a financial analysis of Canarium tree plantations at the smallholder level. The combination of these two steps can assist identifying the gaps and strengths for the viability of this activity to smallholders. These are discussed in the final section of the paper.

2. Methods

For the literature review, a search was carried out in Web of Science using the search string *'Canarium indicum' OR 'canarium nut'* in topics in all years. In total, the search yielded 27 results. Six of them were not available in full text and four were not relevant for the review. The remaining 17 papers were read in full, as well as other five journal papers, three papers from conference proceedings, two online documents and four reports recommended by experts. Data were systematically extracted from these 31 documents under the following themes: Biology, Uses, Cultivation, Nut Production & Processing, and Markets & Supply Chains. Each theme is summarised separately in the results section.

Data from the literature review were also used in the financial analysis. Literature data were validated and complemented by interviews with experts in Vanuatu and Australia. Experts were growers, traders, researchers, and government officials. Cash flow analysis for four scenarios were developed: 1) sale of nut-in-shell, 2) sale of kernel-in-testa, 3) sale of dried kernel using solar dryer, and 4) sale of dried kernel using electric dryer. The financial analysis considered a 30-year project. The values for the parameters in the financial models can be found in the Supplementary Materials (Table Supplementary Material 1). Sensitivity analyses of discount rate, price of canarium products and labour costs were performed.

3. Literature review

Biology

The canarium tree can grow up to 40 m tall (Orwa et al., 2009), 30 m in crown diameter, and 1.5 m in diameter-at-breast-height (Thomson & Evans, 2006). The species is widely spread throughout Melanesia (Evans, 1994b) and is indigenous to Vanuatu, Papua New Guinea, the Solomon Islands and Indonesia (Nevenimo et al., 2007). In Vanuatu, canarium trees are polygamodioecious – i.e., trees bear hermaphrodite flowers plus male or female flowers (Walter & Sam, 1994). Flowering lasts less than two weeks, but gestation period lasts for about six to nine months (Evans, 1994b). Canarium occurs in both well and poorly drained soils, and thrives on a wide range of soil type and climatic conditions (Orwa et al., 2009). However, it does not tolerate shallow, infertile or saline soils, nor droughts longer than 3–4

months (Thomson & Evans, 2006). Its optimal growing conditions are deep, fertile, well-drained soils (Orwa et al., 2009) with neutral pH (Thomson & Evans, 2006).

Uses

Canarium nuts are oily and can be eaten raw or processed. Because of its high content of lipids and antioxidant activity, the nuts are a suitable source for edible oils (Djarkasi et al., 2011). Canarium nut food products include honey- and sugar-coated nuts, cookies, nut flakes, and nut meals (Bunt & Leakey, 2008). Canarium oil can also be used in cosmetics and its mesocarp can be eaten, or used as fertiliser or fodder (Evans, 1994b). Its hard shell can be used to produce high-grade charcoal, refined to activated charcoal for the pharmaceutical industry (Nevenimo et al., 2007), or be used for jewellery (Evans, 1994b). The wood has low density (500–650 kg m^{-3}) and is used for light construction, mouldings, house framing, interior finish, canoes construction, and fuel (Orwa et al., 2009). Canarium timber is likely to be sold only at local markets (Thomson & Evans, 2006). Its resin can be used as an ingredient in incense, plasters, ointments, for lighting, and to caulk boats, while its bark and young leaves have medicinal uses and its shoots can also be used in cooking (Orwa et al., 2009, Evans, 1994b).

Cultivation

Canarium trees are often cultivated in homegardens with other crops (Orwa et al., 2009). It is recommended to plant canarium trees along with crops that provide rapid returns (Thomson & Evans, 2006). It is a suitable shade tree for shade-tolerant crops like cocoa and also suitable for wind breaks since it is highly wind resistant (Orwa et al., 2009, Thomson & Evans, 2006). Bai et al. (2017b) studied canarium as a shading tree for cacao in 8-year-old plantations in Papua New Guinea, and concluded that canarium at a wider spacing of 8 m x 16 m is better than 8 m x 8 m, and that, regardless of the spacing, improved nutrient management practices are required to prevent nutrient impoverishment. Other planting spacings suggested for canarium plantations include of 9–10 m x 9–10 m, and 9–10 x 2 m, or 500–555 trees per hectare, thinned down to 100–150 trees per hectare between ages 3 and 6 for combined production of timber and nuts (Thomson & Evans, 2006).

Thomson and Evans (2006) described ideal planting practices. Seeds are recalcitrant and should be sown as soon as possible after their collection but should be soaked in water for 24 hours first, and those that do not sink completely should be discarded. In direct sowing, three or four seeds should be placed per hole, and in seedling planting, it is recommended two seedlings per hole. Young plants must be planted under shade, and, for that to be achieved, live posts species can be planted in the area six months prior to planting canarium seedlings. Even though canarium trees tolerate 25–70% of shade, maximum yield is achieved in close to full-sun conditions when mature.

Non-fruiting male trees are very rare in Vanuatu (Thomson & Evans, 2006), but should be removed as soon as they are identified, leaving about one male tree for each 20–25 female trees (Orwa et al., 2009). Monthly weeding may be needed in open conditions, especially in the presence of vines, and with good maintenance, seedling survival rates over 90–95% can be achieved (Thomson & Evans, 2006). Canarium

trees have intermediate self-pruning ability, but active pruning may be needed to stimulate lateral branching until the tree starts fruiting (Orwa et al., 2009, Thomson & Evans, 2006). Only a few pests and diseases have been reported to affect canarium trees. Anthracnose can affect young seedlings but can be controlled with fungicides, while *Amblypelta cocophaga*, a shooting-feeding bug, can cause severe damage to trees (Orwa et al., 2009).

Canarium tree growth rate is slow in the first year (0.6-2 m in height per year) but rapid thereafter (2.5-3 m in height per year) up to at least 15–20 years (Thomson & Evans, 2006). On the Salomon Islands, at a spacing of 9 m x 9 m, growth rates were of 2.8 m $year^{-1}$ in height and 3 cm $year^{-1}$ in diameter (Orwa et al., 2009). In a 27–30 year-old plantation in Papua New Guinea, a canarium tree can produce 3 m^3 of log for export or 2 m^3 of sawn timber (Vigus, 1997). From our interviews we estimate 2.5 to 3 m^3 of log at age 50, and 1.5 to 2 m^3 at age 30.

Nut Production & Processing

Production of canarium nuts can be discussed in terms of fruits, nut-in-shell, kernel-in-testa or kernel (Fig. 1). Fruits of canarium trees are harvested and depulped. Then the nut-in-shell is dried and cracked. Subsequently, the testa is removed, and the kernels are roasted, packaged, and stored. Fruiting starts around ages 5 and 7, with more heavy fruiting beginning at age 7–8 or later (Thomson & Evans, 2006). Maximum annual yields for trees under 30 years are around 50 kg (Evans, 1994b), although there are suggestions of yields up to 100 kg (Orwa et al., 2009).

In Vanuatu, fruiting occurs between October and January, with a pick in November, and fruits ripen between October and March (Orwa et al., 2009, Thomson & Evans, 2006). Fruit size is likely influenced by age, mature trees having larger fruits than young ones (Macdonell, 2017). Fruits are either picked from the tree or from the ground (Nevenimo et al., 2007). Fruits take over eight weeks to turn from green to purple, and the ones at the top of the tree appear to ripen more quickly than those at the bottom (Wallace et al., 2012). Harvesting by breaking off the fruiting branchlets has been found to encourage renewed growth and flowering (Nevenimo et al., 2007). When hand harvesting, only full- to half-purple fruits should be harvested to ensure kernels are mature with high oil content (Wallace et al., 2012). In a study in Papua New Guinea, Walton et al. (2014) found that fruit colour is a reliable indicator for kernel oil content. Ripe (purple- and half-purple) fruits had a mean oil content of about 76%. For immature green fruits, this value was of about 73% (Walton et al., 2014).

Nut-in-pulp should be processed as soon as possible within 24 hours of delivery (Wallace et al., 2012). Depulping usually involves rotting pulp leaving it to break down on the ground or soaking treatment (Macdonell, 2017) until the point the nut-in-pulp is fully purple and the pulp is soft enough for its removal (Wallace et al., 2012). In some instances, nut-in-shell is sold, and in others further processing occur before the sale. Placing nut-in-shell in water can be used in buying points to identify and discard low-quality nut-in-shell, which floats (Wallace et al., 2012). When nut-in-shell is commercialised, returns are much lower. There is a lack of infrastructure and technologies that enable nuts-in-shell to be cracked on

farm and sold as a higher-value, lower-volume kernel-in-testa product and to be readily transported to a central processing unit (Thomson & Evans, 2006). Selling kernels instead of nut-in-shell represents reduction in 83% of the weight to be transported, which is advantageous once there are high transportation costs and low transport availability (Bunt & Leakey, 2008).

Drying nut-in-shell on farm increases the level of preservation of kernels (Evans, 1994a). High quality nuts can be achieved by initially drying nut-in-shell below 40°C, producing whole kernels with good colour and little translucency. A stepwise drying regime comprising three days at 35°C followed by four days at 38°C reduces moisture from 24% to 6%, and dried nut-in-shell can be stored or transported without the need for immediate freezing (Wallace et al., 2012). Nut-in-shell dried to 6% at 25°C showed no deterioration signs after 6 months and nut-in-shell dried to 7% moisture can be stored for up to 11 months at low humidity without loss of quality (Wallace et al., 2012). Nuts have traditionally been sun dried or dried over fire, however, this results in a highly variable product, limiting marketing possibilities, whereas electric dryers require diesel to operate, making this option too onerous for producers (Curtis et al., 2015). Low-technology, efficient dryers have been proposed (Curtis et al., 2015, Wallace et al., 2012, Curtis et al., 2010). A low-profile solar tunnel dryer was proposed for small-scale drying of canarium nuts based on the following criteria: ease of operation and construction, use of local materials, low cost and efficacy of drying The dryers designed in the research of Curtis et al. (2015) have been used by the South Pacific Nuts in Port Vila. The prototype operated in temperatures between 50 and 60°C leading to a final kernel moisture content of 2.5–3.5%.

Nuts-in-shell are cracked for the kernels to be removed. Different morphotypes occur within *Canarium indicum* species and nuts are often variable within an individual tree. About 45% of the nuts in Vanuatu are broad, and few morphotypes are elongated, while up to 12% of nuts are sterile, and can be up to 34% after cyclones (Walter & Sam, 1994). While processors seek for large kernel sizes, the number of kernels per shell – which is usually one or two, and in a few cases three – is not a concern for farmers who get paid by weight of kernel-in-testa (Macdonell, 2017). In a study in PNG, Leakey et al. (2008) found that considerable improvement in kernel quality and uniformity could be achieved by selecting trees with mean kernel mass over 3 g. Seeds from selected trees in Vanuatu have a fresh weight of about 9–18 g (Thomson & Evans, 2006). Besides kernel mass, it is also important to take into consideration the kernel-to-nut-in-shell ratio when selecting superior trees. Higher market prices were achieved for larger and less damaged kernel with a ratio above 0.25 (Leakey et al., 2008). Other selection criteria can be used to target specific markets. For example, medicinal and nutritive properties such as oil content, variation in protein and carbohydrate can be identified (Leakey et al., 2008).

Poor and limited post-harvesting handling and processing methods limit offer of canarium products (Wallace et al., 2012). These include drying and cracking the nuts. Dryers and mechanical crackers can be too expansive for growers (Carter & Smith, 2016). This results in manual cracking, a more time-consuming procedure, and irregular drying process. Some canarium nut suppliers crack the nuts at the regional airport to be able to sell it within the 24 hours timeframe and avoid nut spoilage (Carter & Smith,

2016), resulting in a 90% acceptance level in Port Vila (Bunt & Leakey, 2008). If not processed in 48 hours, 50 to 60% of the kernels are unsuitable for use (Bunt & Leakey, 2008).

Mechanical cracking is much more efficient than manual cracking in terms of nuts cracked per time. However, the high heterogeneity of sizes reduces the percentage of whole kernels obtained from mechanical cracking (Thomson & Evans, 2006). Mechanical cracking causes a 65% damage, much higher than the 10% damage caused by manual cracking (Bunt & Leakey, 2008). When cracked, dried nuts cannot be sold. Mechanical cracking is, however, an option if the final product is nut additives or oil (Bunt & Leakey, 2008). A hand-powered mechanical cracker suitable for nuts with 20 mm to 35 mm diameter has been developed in 1994, with a potential commercial price of USD 500, which would be paid off after cracking only 4 tonnes of nut-in-shell (Gautz, 1994). However, in a workshop in Vanuatu 2009, stakeholders stated that crackers that have been proposed in the past had made no difference to local people (Wallace et al., 2012). The portable TJ's nutcracker developed for macadamia, which weighs only 1.3 kg and costs between AUD 50–70, is suitable to crack canarium nuts at small-scale and village level, works best with nut-in-shell moisture of 10% and has a recovery rate between 72–82% (Wallace et al., 2012). It is not understood why technologies like these have not been adopted, but from our interviews we suspect they are not easily available for purchase and that initial investment is too high.

After cracking, testa is removed. A way of removing the testa and sanitising kernels is blanching the nuts in hot water just below boiling for 90 seconds, which requires redrying of kernels after testa removal but does not require any sophisticated equipment and can be adopted in small-scale processing. Another option is treating it with steam for 2.5 minutes, which requires more equipment but may be more suitable for commercial purposes (Wallace et al., 2012). When testa is removed while still moist, there is no difficulty in the process (Macdonell, 2017).

Drying, smoking or roasting nuts allow for their storage for up to 3–12 months (Thomson & Evans, 2006). Bai et al. (2017a) concluded that roasting the kernels at 150°C for 10 min does not affect kernel chemical composition and oil oxidative stability and does not cause excessive colour development. The authors also found that testa provided additional protection to heat. Dehydrating kernels within 24 hours of cracking increases the shelf life (Bunt & Leakey, 2008). South Pacific Nuts store processed kernels at ambient in plastic bags (non-vacuum sealed) for three months and in glass jars for up to three years (Bunt & Leakey, 2008). Electrical dehydration for 48 hours with 30 kg of fresh kernels results in 22 kg of dried kernels (Bunt & Leakey, 2008). Even though electrical dehydration is the optimal method for drying kernels, solar dehydration can also be used (Bunt & Leakey, 2008). To ensure quality, roasting temperatures should not exceed 115°C (Wallace et al., 2012).

Packaging costs are high. South pacific labels costed USD 0.56 each, in 2008, ten times equivalent costs in Australia. Vacuum-sealed packaging can minimise oxidation and hold the delicate kernels together, but excessive vacuum appears to draw oil out of the kernels and vacuum packaging makes it difficult to read and unattractive (Evans, 1994a). Foil packaging is highly reliable as an oxygen and moisture barrier and has high commercial and storage potential, but the equipment is more expensive and there is the

need to purchase bags in bulks (Wallace et al., 2012). Vacuum packaging with plastic film is more economical (Wallace et al., 2012). Hermetically sealed glass jars preserve kernels as well as vacuum sealing, however, kernels can break apart moving inside jar and jars are expensive, heavy and breakable (Evans, 1994a). An alternative is reusable, light plastic jars that are able to withstand sterilisation and designed to reduce movement of kernels inside it (Evans, 1994a).

Nuts need to be stored in dry, cool, airtight conditions to avoid oxidation and rancidity (Thomson & Evans, 2006). Freshly harvested, vacuum-packed (using domestic vacuum sealer) kernels-in-testa can be stored for six months in temperatures between 22 and 31°C, and up to nine months in temperatures around 15°C without development of rancidity (Walton et al., 2017). Wallace et al. (2012) showed that vacuum packed kernels can be stored for nine months at 25°C and six months at 30°C. Canarium kernel oil can last up to two years in cool storage or six months in ambient temperatures (Nevenimo et al., 2007).

Markets & Supply Chains

The export of value-added products is limited due to quarantine reasons (Bunt & Leakey, 2008). There is the need to develop products complying with production standards such as food safety to ensure the product is marketable, domestically or for export, and to increase quality control in the production process. Good practices to reduce risk of contamination of nuts by human pathogens and aflatoxin include: maintaining all premises and equipment clean; good personal hygiene; minimising physical damage to nuts; separating nuts with mould or attacked by insects; drying nuts to 10% moisture content within nine days; and storing nuts under 75% relative humidity (Tungon et al., 2021). Thomson and Evans (2006) estimated that about 100 ha of plantation area, providing about 550 t of kernel-in-testa annually is enough to support commercial processing and export. High-value niche market could also be attained through organic certification (Crowley et al., 2001), promotion of the product as an exotic commodity and marketing through internet directly to consumers (Thomson & Evans, 2006). Macadamia nuts have a stable market and wholesale price of over USD 10 per kilogram, and with similar packaging and quality levels, canarium has the potential to achieve similar market conditions (Thomson & Evans, 2006).

Unlike PNG and the Solomon Islands, the Vanuatu nut industry has been driven by the private sector. In Vanuatu there were two companies purchasing nuts (Thomson & Evans, 2006), but the canarium industry has been driven mainly by South Pacific Nuts in Port Vila (Bunt & Leakey, 2008). To address the limited supply of canarium products, South Pacific Nuts has promoted canarium tree planting through radio and leaflets (Nevenimo et al., 2007). South Pacific Nuts also established post-harvest technologies and increased the quality control to achieve higher grade products (Bunt & Leakey, 2008).

The Kava Store in Port Vila sold 1.7 tonnes of canarium nut products in 1994 (Wah, 1994). In 2004, South Pacific Nuts processed 180 tonnes of canarium nuts, which returned 18 tonnes of kernels, representing only a third of the demand in Port Vila, most of which sold in small packs for a price per kilogram between USD 10 and 18 (Bunt & Leakey, 2008, Thomson & Evans, 2006). Globally, the market for

canarium nut is growing and in 2008 demand was higher than supply, and export offers with high prices of up to USD 50 kg^{-1} of kernels were rejected due to insufficient supply (Bunt & Leakey, 2008). To increase market confidence, surety of supply needs to be improved and a Melanesian Supply Chain has been recommended (Bunt & Leakey, 2008). A transnational coordination of canarium nuts has also been supported by Carter and Smith (2017). This would be achieved through a unified marketing network, to benefit from different fruiting season timing across countries in the region and avoid discontinuity of supply. In PNG nuts are harvested between April and June, on the Salomon Islands between June and October, and in Vanuatu between September and December (Bunt & Leakey, 2008).

In Vanuatu, farmers collect fruits for local consumption, for sales in urban or rural markets or for processing units that will then export or sell it in the domestic market (Pacific Agribusiness Research & Development Initiative, 2012). Wallace et al. (2012) compared three alternative business models for the processing of canarium nuts: i) centralised, ii) village cracking and iii) decentralised. The three alternatives represent a continuum of value-adding at the village, which go along higher returns per kilogram of nut-in-pulp collected, but also challenges in the processing and quality control.

Another alternative business model involves the processing company buying nut-in-shell from producers on different islands and selling them to women in Port Vila to carry out the cracking of the nuts, who could then sell it back to the company if favourable (Bunt & Leakey, 2008). Companies would benefit from a fresher product and the women would benefit from a higher income than they are able to earn from other activities. In 2007, crackers, who are often women, could buy 75 kg of nut-in-shell (the amount an experienced cracker can process in a day) for USD 22.44 (USD 0.3 kg^{-1}), resulting in the sale of about 15 kg of kernels at USD 2.99 kg^{-1} and a net income of USD 22.41 per day (Nevenimo et al., 2007).

4. Financial analysis

All four base-case scenarios for the sales of canarium nut products resulted in a negative NPV (Tables 1 to 3). Increasing maximum production per tree of these base-case scenarios with negative NPVs resulted in even more negative NPVs. All base-case scenarios remain negative even with lower discount rates (r). Scenario 1 with r = 8% is positive for nut-in-shell prices above USD 0.319 kg^{-1}, about 21% higher than the base price of USD 0.263 kg^{-1} (VUV 30 kg^{-1}). The price found by Tungon et al. (2021) of USD 0.35 kg^{-1} (VUV 40 kg^{-1}) brings a positive, despite not high, NPV of USD 1002. The sales of nut-in-shell can bring positive returns, however, this scenario with no value adding to the merchantable material limits the profitability to producers.

Table 1
Internal Rate of Return (IRR) and Net Present Value (NPV) for Scenario 1 (i.e., sale of nut-in-shell, NIS). In bold the input parameters for which the values were changed in the sensitivity analysis

Scenario 1	**Price NIS (VUV/kg)**	**Price NIS (USD/kg)**	**Labour cost (USD/hour)**	**IRR**	**NPV (USD)**		
					***r* = 8%**	***r* = 10%**	***r* = 12%**
Base-case	30	0.263	1.93	0	-1,767	-1,637	-1,500
Low labour cost	30	0.263	**0.58**	27	5,171	3,599	2,526
No labour cost	30	0.263	**0**	34	8,160	5,855	4,261
High NIS price	**40**	**0.35**	1.93	13	1,002	435	77
Very high NIS price	**50**	**0.439**	1.93	22	3,772	2,508	1,655

Scenarios 2, 3 and 4 count with labour for cracking the nuts. This highly time-consuming process has a significant impact on the quality of the product. Scenario 2, which assumes the sale of kernel-in-testa, is negative for all prices per kilogram below USD 6.18, considerably higher than the price of USD 2.19 kg^{-1} (VUV 250 kg^{-1}) found by Macdonell (2017). Despite the lack of profitability, this is the most frequently practiced scenario in Vanuatu. One of the reasons behind this might be that canarium nut producers place a very low (USD 0.58 $hour^{-1}$) or nil value to their labour opportunity cost. Also, adding value to canarium products, as in scenarios 3 and 4, is not paying off with the current technology and prices.

Table 2
Internal Rate of Return (IRR) and Net Present Value (NPV) for Scenario 2 (i.e. sale of fresh kernel in testa, KIT). In bold the input parameters for which the values were changed in the sensitivity analysis

Scenario 2	**Price KIT (VUV/kg)**	**Price KIT (USD/kg)**	**Labour cost (USD/hour)**	**IRR**	**NPV (USD)**		
					***r* = 8%**	***r* = 10%**	***r* = 12%**
Base-case	250	2.19	1.93	N/A	-18,434	-13,972	-10,788
Low labour cost	250	2.19	**0.58**	8	13	-262	-415
No labour cost	250	2.19	**0**	38	8,072	6,187	4,765
High KIT price	**350**	**3.07**	1.93	N/A	-14,368	-10,961	-8,519
Very high KIT price	**704**	**6.18**	1.93	8	25	-301	-486

Scenarios 3 and 4 consider the sale of canarium nuts at a step further in the value-adding course. While solar drying of kernels (Scenario 3) has lower upfront and running costs, the drying process takes longer than using an electrical dryer (Scenario 4). Maintaining the base value for the other parameters, a market price of about USD 8.50 kg^{-1} makes Scenarios 3 and 4 break even (Table 3). Although the breakeven price for Scenarios 3 and 4 is virtually the same, higher prices are likely to be achieved in Scenario 4, considering the higher homogeneity of electrically dried nuts.

Table 3
Internal Rate of Return (IRR) and Net Present Value (NPV) for Scenarios 3 (i.e. sale of dry kernel in testa, KIT, using solar dryer) and 4 (i.e. sale of dry kernel in testa, KIT, using electrical dryer)

Scenario		Price dry KIT		IRR	NPV (USD)		
		(vt/kg)	(USD/kg)		*r* = 8%	*r* = 10%	*r* = 12%
3) Solar dryer	base case	350	3.07	N/A	-18,679	-13,937	-10,591
	high price	700	6.14	N/A	-8.243	-6,208	-4,766
	very high price	1000	8.77	9%	701	417	226
4) Electrical dryer	base case	500	4.39	N/A	-14,330	-10,730	-8,186
	high price	900	7.89	N/A	-2,404	-1,897	-1,530
	very high price	1500	13.16	36%	15,486	11,354	8,454

The results of a sensitivity analysis with labour needs for nut processing (including sorting, desapping and cracking) halved in comparison to the base-case – assuming the use of improved technologies – are presented in Table 3. Even with this significant reduction in labour needs for processing, Scenarios 2, 3 and 4 remain negative. Improved processing efficiency in these scenarios needs to be accompanied by increased prices as well for a profitable investment.

Table 3
Internal Rate of Return (IRR), Net Present Value (NPV) and break-even price for canarium products for four different scenarios with labour needs for processing halved form base-case scenario

Scenario	**Base price (USD/kg)**	**IRR**	**NPV (USD)**	**Break-even price (USD/kg)**
1) Nut-in-shell	0.263	13%	1,279	0.22
2) Fresh kernels	2.19	N/A	-5,577	3.42
3) Dry kernels (solar)	3.07	N/A	-5,926	4.82
4) Dry kernels (electrical)	4.39	N/A	-1,577	4.85

5. Discussion and Conclusion

The literature on canarium nuts demonstrates great potential for the industry, but also highlights its bottlenecks, which were in conformity with our results from the financial analysis. Among the challenges for the development of the canarium nut industry in Vanuatu are unstable supply, small and dispersed volumes produced, low prices, inconsistent quality of products, low infrastructure and technology in remote areas, limited trust among stakeholders on their ability to deliver quality products, high transportation costs, low awareness, and informal nature of supply chain. These challenges are common to other industries of forest products in remote areas (e.g. Shanley et al., 2002). Brazil nuts is the only globally traded seed crop that is virtually completely reliant on wild resources collected by forest-based harvesters (Guariguata et al., 2017). Brazil nuts is likely the most similar forest product to canarium nuts in terms of supply chain. Therefore, here we draw some comparisons to Brazil nuts and use the experiences in the industry to discuss alternative paths to canarium nuts in Vanuatu.

The casual, inconsistent nature of the canarium nuts industry in Vanuatu can be seeing as a cause and a result of the opportunistic labour it relies on. The fact that the current labour opportunity cost is low to nil is a risk for the industry: any other new work opportunity might pose a threat to the viability of canarium nut production, which may lead to lack of stability of supply. This means this livelihood option is vulnerable to market trends and changes. And because the industry is still not developed enough to provide better returns, there is little motivation for people to engage in the harvesting and selling of nuts more regularly. Adding to that, canarium trees are more demanding in terms of soil fertility than other native forestry species (e.g. sandalwood) and it may compete with agricultural crops for land. Nevertheless, labour and land opportunity costs alone do not explain the limitations of the industry, and other important bottlenecks are discussed below.

Yields can be enhanced with the selection of superior planting material and the use of appropriate silvicultural techniques, but increased yields do not make the project balance positive unless inefficiencies in processing are addressed. Nut processing technologies are limited and often only present on the major islands. One of the main processors of canarium nuts in Vanuatu interviewed for this study expressed they would prefer to buy dry kernels to lower transportation cost and reduce the immediacy to transport the material to the processing unit. However, they fear the drying process on separate islands would not meet their quality standards. An alternative they presented was having an agent on each island that would be in charge of ensuring the quality of dry kernels transported to Port Villa. Having a central drying facility on each of the main canarium nut producing islands can be a big step for the industry, but it will need to be accompanied by protocols and standards. Cracking technologies also need larger reach. One of the limitations of cracking devices is that they are suitable for a small range of sizes. Brazil nut producers have been using machines to sort nuts by size (Coslovsky, 2014). This type of technology could potentially be adaptable to canarium nuts if there is a centralised processing unit. Sorted nuts would then be cracked using the mechanical cracker that matches the nut size.

Increasing the selling price of canarium nuts will increase the financial attractiveness for smallholders. Nevertheless, prices for canarium nuts are comparable to and even higher than prices of other nuts

produced in the tropics. The price of USD 0.263 kg^{-1} for nut-in-shell is higher to that of Brazil nuts. To ensure harvesters of non-timber forest products receive a fair price, a governmental body in Brazil defines annual minimum prices for a set of products considered important for its “sociobiodiversity” and subsidises the difference between price paid by buyer and minimum price. The minimum price set for Brazil nut-in-shell in 2019 was of BRL 0.89 kg^{-1} (CONAB, 2019), or USD 0.2225 kg^{-1} using the conversion rate from Dec 2019. In Kenya, macadamia kernels had a farm-gate price starting at USD 1.48 kg^{-1} in 2018 (Quiroz et al., 2019), also lower than the price of USD 2.19 kg^{-1} for canarium kernel-in-testa in Vanuatu. In Cote D’Ivoire, raw cashew nuts had a floor producer price of XOF 225 and 350 XOF kg^{-1} (USD 0.393 and 0.637 kg^{-1}) in 2015 and 2016, but high demand lifted the price of the product and in 2016 prices of XOF 550 kg^{-1} (USD 1 kg^{-1}) were achieved (Bassett et al., 2018).

There is a great untapped potential for reaching niche gourmet and health and wellness markets. Canarium nuts sold in top-end, niche markets can be traded with the added biodiversity and socioeconomic value. Despite claims that there is much higher demand than supply for canarium products, there are constraints preventing greater engagement and enthusiasm from producers. To reach these markets, a certain scale, level of quality and consistency of supply will be crucial.

Despite the potential to reach higher markets, processing canarium nuts to sell value-added products might not be the aspiration of canarium producers, financial investment for value-adding might be limiting, and small improvements in the current business model might suffice for them. Adding to that, the non-financial gains might make up for the challenges of selling fresh kernels as it is practiced currently. For instance, cracking the nuts might be a social activity, and women might benefit from extra cash that they would not have access to otherwise.

The industry can still move forward in Vanuatu, even if smallholders continue to supply material with low value adding. For that, collective action will be needed. We describe the Bolivian experience with Brazil nuts as an example. In the Brazil nut supply chain, harvesters sell nut-in-shell to intermediaries who bring the produce to the processing plants, where the raw material is sorted, cleaned, dried and sometime cracked, depending on whether the final product is the kernel or the nut-in-shell (Coslovsky, 2014). Coslovsky (2014) describes how the Bolivian Brazil nut industry gained space over supply from Brazil as a result of the development of a local body that provided quality control, issued export permits, and brought producers that were previously antagonists together. This was done as a response to quality requirements imposed by the European markets that treated the whole Brazil nut production of the country as a single venture, which meant that if contaminated shipments were found, all producers would be harmed, and not only the ones who supplied contaminated material. This aspect of the Bolivian experience can serve as a model for development of a stronger canarium nut industry and highlights the need for a peak industry body to coordinate quality, supply, and legal processes. The Brazil nut industry can provide further insights for the development of the canarium industry. Policies implemented in Peru and Bolivia to protect the resource had unexpected negative impacts. The requirement for annual management plans in Peru represents an administrative and financial burden for Brazil nut gatherers

with harvest contracts, and in Bolivia the delineation of “no-take” zones for conservation inspired in logging regulatory requirements added substantial opportunity cost to harvesters (Guariguata et al., 2017).

Despite the demonstrated potential for canarium nuts, there is the need for more research and development on its industrial uses, processing alternatives, potential institutional arrangements for more profitable business models, and policy to formalise the industry. Small improvements in infrastructure and technology can increase the profitability to smallholders, and canarium nuts can keep playing its socioeconomic role as an additional source income to smallholders. Challenges and opportunities for canarium nuts discussed in this manuscript are also relevant for other non-timber forest products in other Small Island Developing States and other remote locations the tropics.

Declarations

Funding statement:

This work was supported by the Australian Centre for International Agricultural Research under Enhancing returns from high-value agroforestry species in Vanuatu (FST/2016/154).

Author Contribution

L.O. and T.P. conceptualsied the manuscript and wrote the initial draft. All authors reviewed the manuscript.

Acknowledgement

This work was supported by the Australian Centre for International Agricultural Research under Enhancing returns from high-value agroforestry species in Vanuatu (FST/2016/154).

Data Availability

The primary data used in this manuscript are stored in the UniSC R drive as per Human Research Ethics guidelines.

References

1. Bai, S. H., Darby, I., Nevenimo, T., Hannet, G., Hannet, D., Poienou, M., Grant, E., Brooks, P., Walton, D., Randall, B. & Wallace, H. M. 2017a. Effects of roasting on kernel peroxide value, free fatty acid, fatty acid composition and crude protein content. *PLOS ONE*, 12, e0184279.

2. Bai, S. H., Trueman, S. J., Nevenimo, T., Hannet, G., Bapiwai, P., Poienou, M. & Wallace, H. M. 2017b. Effects of shade-tree species and spacing on soil and leaf nutrient concentrations in cocoa plantations at 8 years after establishment. *Agriculture, ecosystems & environment*, 246, 134–143.
3. Bassett, T. J., Koné, M. & Pavlovic, N. R. 2018. Power Relations and Upgrading in the Cashew Value Chain of Côte d'Ivoire. *Development and Change*, 49, 1223–1247.
4. Bunt, C. & Leakey, R. 2008. Domestication potential and marketing of Canarium indicum nuts in the Pacific: commercialization and market development. *Forests, Trees and Livelihoods*, 18, 271–289.
5. Carter, J. & Smith, E. F. 2016. Spatialising the Melanesian Canarium industry: Understanding economic upgrading in an emerging industry among three Pacific small island states. *Geoforum*, 75, 40–51.
6. Carter, J. & Smith, E. F. 2017. Benefits and risks for Melanesian households from commercialising Canarium indicum. *Asia Pacific Viewpoint*, 58, 388–395.
7. Central Intelligence Agency 2020. The World Factbook Archive - Vanuatu. 20 April 2020 ed. Washington, DC: Central Intelligence Agency.
8. Conab 2019. Politica de Garantia de Precos Minimos para Produtos da Sociobiodiversidade. 2019 ed. Brazilia, Brazil: Gerencia de Produtos da Sociobiodiversidade, Ministerio da Agricultura, Pecuaria e Abastecimento.
9. Coslovsky, S. V. 2014. Economic Development without Pre-Requisites: How Bolivian Producers Met Strict Food Safety Standards and Dominated the Global Brazil-Nut Market. *World Development*, 54, 32–45.
10. Crowley, P., Wright, A. & Foo, F. 2001. Vanuatu: Agriculture and Fisheries Sector Review 2000.
11. Curtis, T., Corkish, R., Fuller, R. & Sproul, A. A Mixed Mode Low Profile Solar Tunnel Dryer for Canarium Indicum Nuts. APSRC 2015: Proceedings of the Asia Pacific Solar Research Conference, 2015. Australian PV Institute, 1–14.
12. Curtis, T., Fuller, R. & Corkish, R. Solar thermal drying of canarium indicum nuts. Solar 2010: Proceedings of the 48th AuSES Annual Conference: Bringing business and research together for a better tomorrow, 2010. [AuSES], 1–10.
13. Department of Agriculture and Rural Development 2020. Background. Port Vila, Vanuatu: Ministry of Agriculture, Livestock, Forestry, Fisheries, Biosecurity of Vanuatu,.
14. Djarkasi, G., Nurali, E., Sumual, M. & Lalujan, L. 2011. Analysis of Bioactive Compound Canarium Nut (Canarium indicum L). *Skripsi, Universitas Sam Ratulangi in cooperation with USAID–Texas A&M University*.
15. Evans, B. What we don't know about indigenous nuts in Melanesia. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994a Port Vila, Vanuatu. ACIAR, 67–73.
16. Evans, B. R. Overview of Resource Potential for Indigenous Nut Production in South Pacific Indigenous Nuts. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994b Port Vila, Vanuatu. ACIAR, 10–35.

17. Gautz, L. Commercial manufacture and use of mechanical crackers of Canarium and related nuts in Vanuatu. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994 Port Vila, Vanuatu. ACIAR, 122.
18. Guariguata, M. R., Cronkleton, P., Duchelle, A. E. & Zuidema, P. A. 2017. Revisiting the 'cornerstone of Amazonian conservation': a socioecological assessment of Brazil nut exploitation. *Biodiversity and Conservation*, 26, 2007–2027.
19. Leakey, R., Fuller, S., Treloar, T., Stevenson, L., Hunter, D., Nevenimo, T., Binifa, J. & Moxon, J. 2008. Characterization of tree-to-tree variation in morphological, nutritional and medicinal properties of Canarium indicum nuts. *Agroforestry Systems*, 73, 77–87.
20. Macdonell, P. 2017. Field report: Canarium Natural Population Survey. *In*: Aciar (ed.) *Enhancing returns from high-value agroforestry species in Vanuatu.*
21. Nevenimo, T., Moxon, J., Wemin, J., Johnston, M., Bunt, C. & Leakey, R. R. B. 2007. Domestication potential and marketing of Canarium indicum nuts in the Pacific: 1. A literature review. *Agroforestry Systems*, 69, 117–134.
22. Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Anthony, S. 2009. *Agroforestree Database: a tree reference and selection guide version 4.0* [Online]. Available: http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp [Accessed 11 May 2020].
23. Pacific Agribusiness Research & Development Initiative 2012. Canarium Nut Value Chain Review. Australia: PARDI, ACIAR, University of the Sunshine Coast and University of Adelaide.
24. Quiroz, D., Kuepper, B., Wachira, J. & Emmott, A. 2019. Value Chain Analysis of Macadamia Nuts in Kenya Commissioned by The Centre for the Promotion of Imports from developing countries (CBI). *research commissioned by CBI.* 2019 ed. Amsterdam, Netherlands: Profundo.
25. Shanley, P., Luz, L. & Swingland, I. R. 2002. The faint promise of a distant market: a survey of Belém's trade in non-timber forest products. *Biodiversity & Conservation*, 11, 615–636.
26. Thomson, L. a. J. & Evans, B. 2006. Canarium indicum var. indicum and C. harveyi (canarium nut), ver 2.1. *In*: Elevitch, C. R. (ed.) *Species Profile for Pacific Island Agroforestry*. Holualoa, Hawaii: Permanent Agriculture Resources.
27. Tungon, J., Grant, E., Macdonell, P., Page, T., Wallace, H., Bai, S. H., Randall, B., Johns, C., Simos, T., Jones, K., Nevenimo, T., Hannet, D. & Hannett, G. 2021. Canarium Producers Manual. Tachnical Note TN/C-01, FST/2016/154 ed. Australia: ACIAR.
28. Vigus, T. 1997. Some silvicultural aspects of Canarium indicum. *In*: Kandrian Gloucester Integrated Development Project (ed.) *Workshop on Galip as a commercial industry in PNG.* Canberra, Australia: AusAID.
29. Wah, C. L. Marketing indigenous nuts in Vanuatu - a private enterprise perspective. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994 Port Vila, Vanuatu. ACIAR, 79.
30. Wallace, H., Carter, J., Austin, J., Poienou, M., Moxon, J., Walton, D., Randall, B. & Viji, I. 2012. Processing of Canarium indicum nuts: Adapting and refining techniques to benefit farmers in the

South Pacific (Final report). *In*: Australian Centre for International Agricultural Research (ed.). Canberra.

31. Walter, A. & Sam, C. Indigenous nut trees in Vanuatu: Ethnobotany and variability. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994 Port Vila, Vanuatu. ACIAR, 56–66.
32. Walton, D., Randall, B., Poienou, M., Moxon, J. & Wallace, H. Maturity indices of Canarium indicum (Burseraceae) nuts. XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1109, 2014. 17–22.
33. Walton, D. A., Randall, B. W., Poienou, M., Nevenimo, T., Moxon, J. & Wallace, H. M. 2017. Shelf life of tropical Canarium nut stored under ambient conditions. *Horticulturae*, 3, 24.
34. Yen, D. E. Melanesia arboriculture: Historical perspectives with emphasis on the genus Canarium. *In*: Steven, M. L., Bourke, R. M. & Evans, B. R., eds. South Pacific Indigenous Nuts, 1994 Port Vila, Vanuatu. ACIAR, 36–44.

Figures

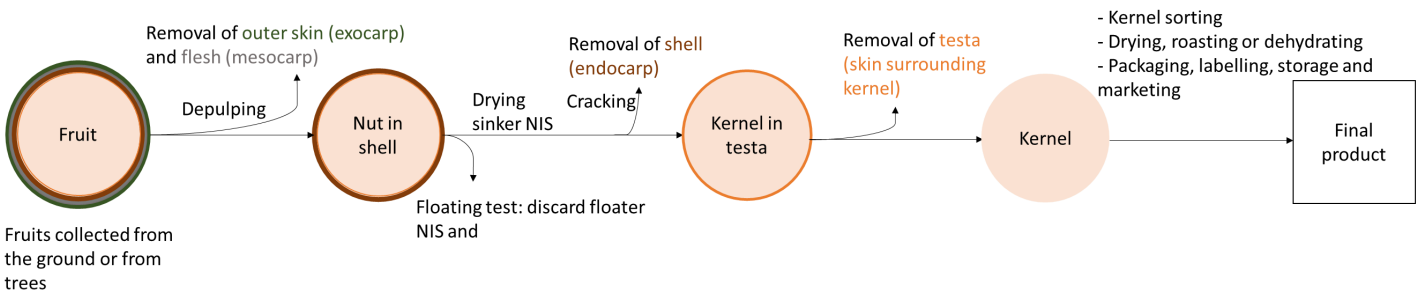

Figure 1

Basic processing of canarium nuts

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CanariummanuscriptSupplementaryMaterial.docx