Scale-up or continued stagnation?

An analysis into the opportunity for the commercial expansion of chestnut production in New Zealand

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For:

New Zealand Agricultural Greenhouse Gas Research Centre

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Executive summary

"Scale-up or continued stagnation?" is the second in a series of reports prepared for the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). These reports examine potentially viable diverse land uses in New Zealand that could provide alternatives to the largely monoculture and ruminant-dominated pastoral agriculture systems across our landscapes at a more expansive farm systems perspective.

This report builds on the recommendations derived from earlier work, on the potential for expanding the commercial production of chestnuts, which identified a number of potential supply chain challenges to this occurring. These were identified as increasing accessibility to suitable crumbing and drying facilities; overcoming the barriers to international consumer preferences and exploring opportunity for diversification of income from farm system integration, specifically carbon sequestration.

Expanding the commercial production of chestnuts in New Zealand has several potential benefits for farm businesses, including diversification of income from farm system integration, low intensity system for the environment and carbon sequestration from chestnut trees.

However, the chestnut industry continues to face a series of challenges with chestnut production being a viable land use in New Zealand.

While reported/projected status quo returns from chestnut production at $2,700/ha/year appear competitive with some other land uses, domestic demand for fresh chestnuts (on which these returns are based) seems unable to accommodate any significant increase in supply. Furthermore, the short two to three week shelf-life of the fresh chestnut prevents the export of the product in a fresh form to all but very close and very small Pacific Island markets. This makes the post-harvest processing of chestnuts all but a pre-requisite for any significant commercial expansion.

Unfortunately, the existing (but limited) processing infrastructure in New Zealand for peeling and processing is not well suited to the predominant varieties of chestnuts grown here, with their hard pellicle affecting the attributes of the processed chestnuts and limiting market demand.

The small seven to nine week window within which chestnuts must therefore be processed makes investment in processing equipment suitable for use by individual growers (behind the farm gate) almost impossible to justify. Larger scale, post-farm gate processing is certainly more capital efficient, but the amount of capital required to be invested in specialist machinery for such a short seasonal processing window erodes the available returns and ultimately requires a very high value product to justify. Development of a suitable co-operative with pooled capital or joint venture relationships could be a viable model for the industry to increase machinery utilisation and spread capital costs (and the low returns on this deployed capital).

At commercial planting densities chestnuts could be incorporated into an existing livestock system without the complete loss of pasture from those areas while still sequestering say 72.3 t CO_2 ha^{-1} over a 12 year period. If the eligibility of chestnut orchards for inclusion into the ETS was changed, then this carbon could have a cumulative value of between $5,400 and as much as $24,000 per hectare over their first 12 years of establishment at a $75/t NZU price, depending on how carbon volumes were assessed.

Despite this, expansion in the areas of chestnuts planted seems unlikely to occur at a sufficient scale to be able to have a regionally significant impact on land use change and greenhouse gas emissions reduction. Development of chestnut orchards targeting specialist markets could be significant for individual properties within a specifically located cluster, but once again seem likely to need sufficient scale to justify the required post-harvest processing and risks associated with a lag phase through to nut production.

To be sustain a viable export industry, it is concluded that the chestnut supply chain ideally needs:

- Improved scalable processing technology that aligns with New Zealand chestnut characteristics or to produce an alternative species of chestnut that is suited to both overseas consumer preferences and the existing processing technology. The development of innovative and low cost storage technology, that allows for extended processing or freight windows of the fresh nuts would probably be transformative.
- A market or, ideally, markets that are sufficiently stable and high value to justify the scale required and capital investment a chestnut farmer needs to make into the farm and equipment, either on farm or further along the supply chain, to support production.
- To explore production of high value-added chestnut products, particularly focusing on health products, which could provide better returns from the necessity of post-harvest processing and our distance to market.
- Recognition of the carbon sequestration potential of new chestnut orchards. While carbon revenue streams may not be reliable in the medium to longer term, they provide an opportunity to help with the transition to chestnuts as land use, either with on-farm investment, buffering uncertain chestnut revenue or helping fund the post-harvest processing that sector requires.

Potential production innovations that might accelerate early year yields or develop markets for by-products have potential value to the sector but will be irrelevant in the absence of a sustainable and profitable market for the chestnuts New Zealand currently produces, let alone additional production.

In summary, the observed supply chain challenges in the chestnut industry are not new and have plagued the scale-up of chestnuts in New Zealand for decades. The current environment for the industry is at a cross-roads. Stagnant and unchanging, left as is the industry will likely continue on its trajectory of decline with risk of fading out entirely. Sufficient investment and innovation would be required to shift the industry into the value-added product market for domestic and international production. Overcoming the current inability to reduce or eliminate the constrained processing window seems critical to future success, particularly with regards to improving capital efficiency and investment returns.

Ultimately identifying how the industry can ensure a reliable supply of chestnut products into the overseas market, considerate of export distance, seasonal supply and a perishable crop, will determine the fundamental future success, capacity for growth and ultimate longevity of the chestnut industry in New Zealand.

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1 Introduction

The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) has initiated and funded a Future Farm Systems Research Programme. It has two key parts – the first looking at case studies and co-designed solutions for the primary sector transitioning to a low emissions future [Part 1] and a second part envisioning what that low emissions future might look like [Part 2].

"Scale-up or continued stagnation?" is the second in a series of reports prepared for the NZAGRC programme. These reports examine potentially viable diverse land uses in New Zealand that could provide alternatives to the largely monoculture and ruminant-dominated pastoral agriculture systems across our landscapes at a more expansive farm systems perspective.

This report builds on recommendations derived from earlier work on the potential for expanding the commercial production of chestnuts, which identified a number of potential supply chain challenges to this occurring.

Expanding the commercial production of chestnuts in New Zealand has a number of potential benefits, including diversification of economies through farm scale integration, low intensity system for the environment and carbon sequestration from chestnut trees, although chestnut orchards are not currently eligible to be considered "forest" under the NZ Emissions Trading Scheme. Potential opportunities to grow chestnut production have been identified by experts and attempted by the industry in the past, however, the lack of domestic demand paired with the market challenges of exporting fresh chestnuts due to their short their shelf-life has resulted in a stagnant chestnut market today. Increasing access to suitable crumbing and drying facilities, understanding the requirements of potential new markets and the carbon sequestration potential are all factors that could impact the supply chain of chestnuts in New Zealand. Other opportunities to support industry expansion include access to trees with more suitable genetics; reducing the three to four year lag period for harvest yields, accessing value-added health product markets and agroforestry through farm-scale integration.

Worldwide demand for chestnuts exceeds that of walnuts or almonds (Davison *et al.*, 2021). Specific advantages for New Zealand currently include the absence of common chestnut diseases in the country (Klinac et al., 1999; Southland Regional Council, 2019). However, distance to market poses a challenge for exporting fresh chestnuts. Historically there have been some exports to New Caledonia (2018: 1.1 tonne, 2019: 0.4 tonne) and negligible exports to Cook Islands (2019: 0.03 tonnes) with no exports in 2020 (Horticultural Export Authority, 2021). The strong seasonal influences on demand in the potentially higher value markets in the Northern Hemisphere do not want chestnuts in New Zealand's peak harvest season because it is not the time of year tied to their traditional consumption of chestnuts. As a result New Zealand would have to store fresh chestnuts until the Northern Hemisphere chestnut season to achieve premium prices on fresh chestnuts. However, the shelf life of fresh chestnuts is only two to three weeks, which significantly restricts freight destinations. Even then, NZ chestnuts don't meet the expectations of European, Asian or American consumers in terms of taste and consumption (pers. comms David Klinac, 22 July 2022). Added to this is the complication that existing chestnut processing infrastructure in New Zealand is not suited to the hybrid chestnut varieties (*Castanea spp*.) grown in New Zealand due to their hard-shell characteristics. The machinery can be adapted for use with New Zealand varieties but has implications for the attributes of the processed product.

Access to the existing suitable crumbing and drying facilities is also a challenge. Different chestnut products require different infrastructure. Existing infrastructure in New Zealand include; crumbing machine, dehydration machine, freeze dryer or peeling machine. According to the New Zealand

Chestnut Council (NZCC), existing chestnut industry infrastructure is continuing to be sold outside of the industry for alternative uses -

Exploring alternative chestnut trees with more suitable genetics may be an opportunity to increase access to overseas markets and therefore the viability of domestic chestnut production expansion. The cost of importing a new species and the success of its growth could be considered. These genetics may enable easier processing, transport and shelf-life of chestnuts; however there may be biosecurity implications for production.

Exploring the potential of producing value-added chestnut products onshore for export would be a useful proposition for the industry. High in Vitamin C and low in fat, the chestnut "superfood" may be an attractive product for vegan or health food markets. Value-added products such as chestnut flour for specialty bakery products, puree, chestnut beer or milk may be suitable markets for the industry to explore. Existing supply chain opportunities from processing to market are outlined in Table 1 below.

Table 1: Current chestnut processing and supply chain opportunities in New Zealand

Processing	
Dehydration	Evaporation of water using heat
Freeze-drying	Low temperature dehydration by converting from ice to vapour
Osmotic dehydration	Placed in concentrated aqueous solution there will be a chemical potential driving force that extracts water from the chestnut to the aqueous solution
Crumbing	Broken down in crumbing machine
Peeling	Chestnut outer shell removed from chestnut
Storage	
Vacuum packed	Vacuum packed either whole or processed
Chiller	Chilled to be consumed in 1-2 weeks
Frozen	Frozen and stored for up to 12 months
Product	
Fresh	Whole chestnuts
Flour	Chestnuts dehydrated or freeze-dried
Puree	Chestnuts dehydrated or freeze-dried to form flour then processed further
Market	
Local	Year-round
National	Year-round
Japan	Autumn season
USA	Autumn season
Australia	March-July

2 Requirements for sustainable industry expansion

Current chestnut industry

Chestnuts are a small industry in New Zealand today and are not a common food product for New Zealand consumers. Demand for chestnut as a food source in New Zealand is low and are typically produced by small hobby farmers. With little local demand for chestnut products, the value proposition for changing land use to chestnuts would be largely for export to Japanese and USA markets (which have significant markets for chestnut products), particularly with increasing overseas demand and decreasing overseas production. Post-harvest processing is a requirement for meaningful production and sales, given the significant limitations to the export of fresh chestnuts (see Table 2 below). The supply chain challenges this report explores are the accessibility and viability of appropriate processing facilities, access to trees with quality genetics, and market access due to a short shelf-life and lack of demand. Demand for chestnut as a food source in New Zealand is low and are typically produced by small hobby farmers.

The New Zealand chestnut industry has approximately 100 growers and lacks a sustainable supply chain. Members of the Fagaceae botanical family, the national chestnut production as of 2016 was approximately 300-400 tonnes per annum, with only a small amount (i.e. <1 tonne) exported (Young & Kiwi-Knight, 2017). A three- to four-year-old tree is estimated to yield up to 50 kg of chestnuts annually over a four to six week period (Klinac et al., 1999). At a planting rate of 64 trees per hectare (12 m x 12 m spacings) on a 2–3 ha orchard, considered a minimum planting area for profitability (pers. comm. David Klinac, 22 July 2022)., chestnut yield could be up to 3.2 tonnes per hectare. Chestnut harvest is typically mid-March to mid-April. Chestnut trees reach maximum production at approximately 10 years, with a slow reduction in yield over the next 40+ years (pers.comms. David Klinac, 12 January 2023).

The New Zealand climate and environment is suitable for chestnuts and does not limit quantity or quantity of growth. Chestnuts require approximately five to seven megalitres of water per ha, essentially 500-700 mm rainfall per annum, throughout the growing season (Department of Primary Industries, 2016). Year-to-year tree performance is often varied across sites making it difficult to estimate grower returns and production levels per hectare (Renwick et al., 2021). The current chestnut industry faces several strengths, weaknesses, opportunities and threats (Table 2).

Table 2: Strengths, weaknesses, opportunities, and threats analysis for the development of a sustainable chestnut industry supply chain

Strengths: Climate Natural 'know-how' in growers Current organic status Able to supply health market at premium prices	**Weaknesses:** Current disease exposure No licensed exporters Small scale Storage facilities Methyl bromide requirements for export
Opportunities: Domestic marketing 'demand creation' Increasing restaurant interest Nutritional/health benefits Supply in off-season to Northern Hemisphere	**Threats:** Exposure to diseases Imported cheaper products Distance to market and rapidly perishable status of fresh chestnuts (which achieve highest value)

Growing and yield

A chestnut orchard costs approximately $5,000 per hectare to establish (64 stems/ha at $70/tree, plus planting), assuming a grower already owns land, with low maintenance except for some mowing and minimal input requirements. There is little to no requirement for fertiliser or agrichemical. The Euro-Japanese hybrids (*Castanea spp.*) that dominate New Zealand's chestnut plantings (Table 3) have unique fruiting characteristics and can produce a crop in low fertility, free draining soil and colder climates, offering opportunity to explore potential scale up of the permanent horticultural crop in New Zealand (AgFirst, 2020).

Table 3: Euro-Japanese hybrid chestnut varieties in New Zealand (Chestnut Traders, 2002)

Variety	Characteristics	Approx % of NZ crop
1002	Produces variable-sized nuts, late in the season. Some years produces high reject rate (splits). Nuts often fall in the burr. Strong tree form. Recommended primarily as a pollinator.	8
1005	Produces large to very large nuts, early in the season. Nut quality can be variable. Very strong tree form.	40
1015	Produces medium to large nuts, mid-season. Heaviest yielding and best keeping nut. Weak tree form, and susceptible to wind breakage.	48

Successfully grown in most areas of New Zealand, chestnuts have an ability to produce a crop in low fertility, free draining soil and colder climates. With existing production predominantly based in the Waikato, Bay of Plenty and Auckland regions, the expansion of chestnut production could see suitable areas such as Northland, Wairarapa, Horowhenua and Canterbury (Figure 1) establish greater chestnut plantings (New Zealand Export Authority, 2014). Despite these highly suitable growing conditions and a lack of common chestnut diseases, the chestnut domestic market in New Zealand is essentially non-existent, with no data available on the extent of domestic consumption or import of processed product.

At a price of $3.50/kg, chestnut growers producing for fresh local markets with a yield of 3.2 t/ha of fresh nuts can achieve an annual operating profit (earnings before interest, tax, rent and wages of management, EBITRm) of approximately $2,700 per hectare. The operating profit assumptions for fresh chestnut production for domestic consumption or third-party processing are presented in Table 4.

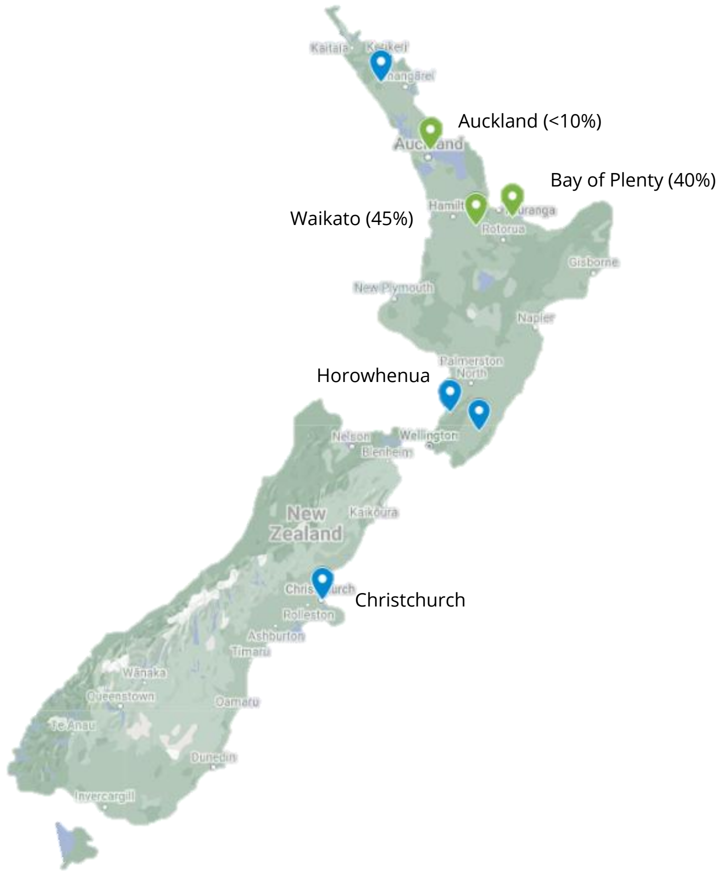
Table 4: Annual NZ chestnut orchard operating profit assumptions for supply to fresh local market

Crop	$/kg	$/ha	Notes and sources
Sold yield: 3,200 kg/ha			
Revenue			pers. comms. David Klinac, Chestnut Grower
Chestnut sales	$3.50	$11,200	pers. comms. David Klinac, Chestnut Grower
Expenses			Based on grower information from The Rotorua Land Use Directory (2022)
Fertiliser			Assume no fertiliser application as Chestnut tress don't require much of any. NZ soils are well suited to grow the crop.
Maintenance	$0.50	$1,600	pers. comms. David Klinac, Chestnut Grower
Harvesting	$1.00	$3,200	Chestnuts are often hand-picked, swept or vacuumed on small hobby farms in NZ (Great South, 2019)
Processing		0	
Packing	$1.00	$3,200	pers. comms. David Klinac, Chestnut Grower
Fixed costs	$0.16	$500	Allowance for rates and insurance
Total expenses	$2.66	$8,500	
Operating profit (EBITRm)	$0.84	$2,700	

While the return on a per hectare scale is reasonably high in comparison to the range in mean operating profit (as measured by EBITRm) of $256 to $661 per hectare for northern North Island hill country sheep and beef farms in 2020-21 (Beef+Lamb New Zealand, 2022), the lack of demand domestically results in an unsustainable market for growers with no guarantee of consistent returns. As such, these returns seem unlikely to be achievable at scale in the current market environment.

The processing technology available in New Zealand has been imported from Europe and Asia. The hybrid New Zealand chestnut varieties have a harder shell and pellicle (compared to non-hybridised European, Japanese, or American varieties), resulting in some pellicle remaining in chestnut products post-processing. Further processing is a viable solution, but adds to an already increasing supply chain length, risking further sharing of margins. Understanding the barriers to scaling up on a per hectare basis is beneficial. This may involve importing appropriate machinery suited to the New Zealand chestnut for processing of value-added products such as chestnut flour for baked goods.

Chestnuts in New Zealand



Existing chestnut producing regions

Potential chestnut producing regions

Figure 1: Existing and potential chestnut growing locations in New Zealand

Processing accessibility and viability

As stated above, fresh chestnuts require further processing for sale as an ingredient or value-added product for later use or for export. Furthermore, their high water content and lack of viable storage options necessitates processing of some kind to stabilise the product within two to three weeks of harvest.

To assist in assessing the viability of chestnut industry expansion, understanding the value-add and likely return from processing and potential markets for chestnuts is crucial.

Table 5 provides indicative margins along various current and potential supply chain options for chestnuts. For example, the grower returns, as measured by sales revenue/kg, for organically certified chestnuts sold direct to market is $9.50/kg, a margin 171% higher than the likely return from a joint venture where processing, distribution and sale to consumer occurs offshore. The return for chestnut producers supplying chestnut flour locally produced to domestic markets with a shorter supply chain will return a higher margin. However, the domestic market is not guaranteed, particularly if importing the same product can deliver a lower price-point to the purchaser. High capital costs for chestnut processing equipment and infrastructure may result in producers weighing up either supplying direct or engaging in a longer supply chain where margins are lost at multiple points.

Table 5: Comparison of current and potential supply chain returns to producer for fresh and processed chestnut products (pers. comms. David Klinac, 22 December 2022).

Supply chain returns for fresh chestnuts ($/kg)					
		Supply chain elements			
Supply chain type	**Cost to Consumer**	**Retailer [8]**	**Distributor**	**Processor**	**Producer**
Direct to market[1]	$3.50	-	-	-	$3.50
Local for local[2]	$3.50	$0.50	-	-	$3.00
Direct to market (organic certified)[3]	$9.50	-	-	-	$9.50
National for national[4]	$3.50	$0.50	$0.50	-	$2.50
Local for international[5]	$12.50	$1.50	$5.00	-	$6.00
National for international[6]	$12.50	$0.80	$5.00	$3.50	$3.20
Joint Venture[7]	$15.00	$1.30	$5.00	$3.50	$5.20
Supply chain returns for chestnut flour ($/kg)					
		Supply chain elements			
Supply chain	**Cost to Consumer**	**Retailer**	**Distributor**	**Processor**	**Producer**
Direct to market	$22.00	-	-	-	$22.00
Local for local	$22.00	-	-	$5.00	$17.00
National for national	$22.00	-	$1.00	$5.00	$16.00
Local for international	$36.00	$7.20	$5.00	$5.00	$18.80
National for international	$36.00	$7.20	$6.00	$5.00	$17.80
Joint Venture	$36.00	$7.20	$5.00	$5.00	$18.80

[1] Grower sells direct to local market
[2] Grower sells to local retailer to market
[3] Grower sells direct to market with organic certified status
[4] Grower sells to national market, contracts distribution and retail to market
[5] Grower sells to international market, contracts distribution and retail to market
[6] Grower sells to international market, contracts processing, distribution and retail to market
[7] Grower provides to international company for processing, distribution and sale
[8] Assumes retailer takes 20% of market price

Despite the obvious challenges of losing margins and increased opportunity for producer control to be lost in a longer supply chain, the market access that a joint venture can provide will likely return a higher number of product sales and an overall greater return. The challenge of processing machinery costs may be overcome by options such as co-operatives but there still needs to be strong demand at the right price point to ensure profitability for all actors along the supply chain.

Farm-level processing

There is limited chestnut processing facilities in New Zealand. Country Treats, a confectionary store in Levin was the only remaining certified existing processing facility in New Zealand for chestnuts. The facility was recently sold outside of the industry (pers. comms. Craig Cameron, 11 January 2023). Operating in the local market, the facility supplied ingredients such as freeze-dried chestnut flour for small scale chestnut processors and to retail outlets. To justify the cost given the short chestnut processing window and small product scale, the operator contract dried other meat, fruits and vegetables determined by a suitable food safety plan. The freeze-dried product is approximately two-thirds of the whole chestnut weight. Crumbing machines had previously been developed in and available in New Zealand, but the current commercial status of these is unknown.

New Zealand has access to other processing facilities used for other nut crops, however they are not fit for the production of value-added chestnut products such as chestnut flour.

In the absence of third-party processing, investment by growers in processing infrastructure behind the farm gate could be one option to expand market channels away from the essentially non-existent domestic fresh nut market. Freeze drying is a process that could be feasible for a grower. Given the three week fresh shelf life of the chestnuts, a 3 ha orchard would have approximately seven weeks to process the 9.6 t of fresh nuts produced in the annual four week harvest period. This would require the shelling and drying of approximately 275 kg of fresh nuts each day, five days per week, and could be met by a freeze dryer with a minimum daily capacity of 300 kg per 24 hour drying cycle. Understanding the relative return on investment estimated for chestnut processing infrastructure for a typical orchard yielding 3,200 kg/ha to an overseas market (e.g., freeze-dried flour to local consumers) at a price of $17.00/kg of processed flour helps indicate the viability of this kind of investment. The infrastructure required to allow this processing to occur would include a commercial shelling machine, a vacuum harvester, grading machine, freeze dryer, milling machine and vacuum packer

Table 6: Estimated capital costs of new chestnut harvesting and processing infrastructure on 3 ha orchard

Chestnut on farm harvesting and processing infrastructure for processed goods		
Item	**Cost/unit**	**Notes**
2-wheel Dr 50hp tractor[1]	$35,000	Based off hazelnut orchard (Miller et al., 2013)
Vacuum harvester	$30,000	Based off costs from Perna & Mortimer Machinery PTY
Grading machine	$8,000	Based off chestnut grading machine costs in USA
Shelling machine[2]	$15,000	
FD300GPC Freeze dryer[3]	$950,000	Based off costs from Cuddon Freeze Dry
Milling machine	$10,000	Based off costs from Chevpac Machinery Auckland
Vacuum packer	$2,000	Based off semi-commercial in-chamber vacuum sealer VS820 from Vacpack
Total	**$1,050,000**	

[1] A 50-horsepower 2-wheel driver tractor is used mainly at harvest to move and load totes for delivery to processors

[2] 150kg/hour small commercial chestnut sheller

[3] Freeze dryer able to process up to 300 kg whole peeled chestnuts per 24 hour cycle. Note this model is no longer produced.

We have estimated that a capital investment in the order of $1,050,000 would be required for grower to produce chestnut flour from a 3 ha orchard. The budget in Table 6 assumes the listed machinery and equipment below would complement any existing harvesting infrastructure and shift producers into a self-sufficient value-added chestnut production system.

A simple fifteen-year discounted cash flow analysis for the investment in a 3 ha chestnut orchard yielding 3.2 t/ha of fresh chestnuts and selling chestnut flour at the farm gate is presented in Appendix

2 and summarised in Table 7 below. It is assumed that after 10 years of consistent production the trees produce 10% less crop, annually, with no salvage value at year 15. The salvage value for the equipment, comprising harvesting, grading, shelling, drying, milling and packaging machinery, is based on it depreciating at a rate of 13% per annum (Lincoln University, 2018).

Table 7: Summary of the fifteen-year discounted cashflow analysis for a 3 ha chestnut orchard as presented in Appendix 2

Chestnut infrastructure cashflow analysis: 100% grower investment			
Year	**0**	**4**	**15**
Total Revenue $			
Flour income		$0	$31,801
Total Revenue:	**0**	**$0**	**$31,801**
Expenditure $			
Farm system expenses			
Capital: Trees	$13,440		
Capital: Tractor	$35,000		
Capital costs for processing			
Farm expenses	$1,500	$1,500	$1,500
Capital: Vacuum harvester		$30,000	-$6,484
Capital: Grading machine		$8,000	-$1,729
Capital: Shelling machine		$15,000	-$3,242
Capital: Freeze dryer		$950,000	-$205,322
Capital: Milling machine		$10,000	-$2,161
Capital: Vacuum packer		$2,000	-$432
Harvesting and packing costs		$0	$29,775
Total Expenditure:	**$49,940**	**$1,016,500**	**-$188,095**
Annual Cashflow:	**-$49,940**	**-$1,016,500**	**$219,897**
Net present value (at 5% discount rate)	**-$667,019**		
Internal rate of return (IRR)	**-11%**		

As reported in the fifteen-year discounted cash flow analysis summary (Table 7), the capital investment in harvesting and freeze drying processing infrastructure is unrealistic for a famer with a typical 3 ha chestnut orchard over a 15 year time horizon, with an internal rate of return of -11%. High capital infrastructure costs for small growers could potentially be eased by pooling resources between producers or purchasing second hand equipment. However, the need to process (in this case freeze dry) the chestnuts within three weeks of harvest is a significant impediment to this. The required freeze dryer (FD300GPC) would need to run almost at capacity during this time to process the crop from a single 3 ha orchard.

There would be scope to increase throughput (a further 2.97 t of chestnuts, effectively a further hectare of production) and capital efficiency if the dryer ran 7 days per week and at its maximum volume of 300 kg/day. This would improve the internal rate of return of the investment for a 4 ha orchard, albeit marginally, to -10% (see Appendix 3: Discounted cash flow analysis for a 4 ha chestnut orchard) – still insufficient to entice most growers to make the investment.

The FD300GPC dryer has 3.75 times more capacity than an FD80GPC dryer (with a cost of $300,000), but for only 3.16 times the price. The marginal reduction in the price of capacity as the equipment scales up is typical of most industrial machinery, but significant scale is often required before the investment can be commercially justified. This is amplified when utilisation of equipment is low (say for only 6 weeks a year). Ultimately, in such situations co-operative ownership of assets at large scale is often a necessity.

Post-farm gate/commercial scale processing

Given the clear economic challenges with individual growers investing in farm-scale drying machinery, processing at scale would be an alternative option, notwithstanding the fact that the post-harvest processing has to occur in an extremely condensed seasonal window. While freeze drying is suitable for small volumes of product, post-farm gate processing at scale would realistically require access to suitable crumbing and large scale drying machinery. Crumbing machines can process chestnuts with the pellicle on and expels a by-product made up of pellicle which can be used for stock food.

Labour is continually a risk for processing and manufacturing in New Zealand. The investment in automated machines, where efficiencies are gained through needing less staff is well worth investing in but still requires a consumer demand to justify the investment. The crumbing machines currently available in New Zealand have the capacity to process 2-3 tonnes of chestnuts per day (say the annual production from approximately 40 hectares of chestnuts. However not all cater to the food industry due to cross contamination and compliance restrictions.

Dried crumb would be easier to handle, store and transport than fresh chestnuts (about half the weight) but requires special dehumidifying drying facilities (Drying Solutions, 2022). Accessibility to these facilities in New Zealand has been reasonable, however facilities are being continually sold due to lack of use for chestnut production and re-purposed. Another challenge with drying facilities is that not all drying machinery works well on chestnuts; just adding heat, as most commercial dryers do, will just encourage fungal rots and spoilage as chestnuts are of high water content and high sugar content. Correia et al. (2009) found that the higher the drying temperature, the higher the reducing of sugar content and lower the starch content. Chestnuts cannot be air-dried at temperatures above 30 degrees Celsius without significant damage occurring. Drying is not required for all products and does add to the cost of processing at $1.50/kg. The dried crumb could also be incorporated into value-added products such as a dry stuffing mix, puree or chips and slices and exported that way.

Alternative processing technologies

Osmotic dehydration is an alternative to air-drying for reducing moisture content of freshly harvested nuts. Placed in a concentrated aqueous solution there will be a chemical potential driving force that extracts water from the chestnut to the aqueous solution (note this doesn't appear to impact on an organic status of a product, though this is not confirmed). Chenlo et al. (2006) conducted a study on Spanish chestnuts of different glucose concentrations and a range of temperatures and found that the lowest moisture content was achieved with the most concentrated glucose solution. The validity of using osmotic dehydration for bulk-packed New Zealand chestnuts is undetermined to date (Pontawe et al., 2016).

The justification for osmotic dehydration is difficult given the high operating costs, however these may reduce if done under ambient conditions where energy demands are lower than for air-drying. These will of course need to be offset by the cost of the solute needed for the dehydration solutions (Pontawe et al., 2016). The processing method could be an affordable option for growers unable to access the larger commercial drying facilities, however the need for this in New Zealand at a commercial scale still requires an increase in demand. Despite immersion in $CaCl_2$ solutions offering the greatest reduction in moisture content (Chenlo et al., 2006), the significant softening and darkening of the nuts would not be saleable in any of New Zealand's chestnut market.

Another emerging post-harvest technology that is being explored as a potential opportunity for the chestnut industry is ohmic heating (OH). With a short processing time and offering potential for decarbonising industrial processes, ohmic heating applies a voltage on two electrodes at extremities of the container resulting in internal heat generation. Under 55 degrees Celsius, combined with storage of 5 degrees Celsius, the study found that chestnut's shelf-life could be extended for 60 days without substantial changes in colour or texture. High investment costs and lack of regulatory framework have delayed the use on an industrial scale; however it is commercially available (Pereira & Vicente, 2010). With the primary purpose of controlling or preventing mould and larvae growth, the viability of employing this post-harvest technology for the chestnut industry in New Zealand is worth exploring.

Extension of the nut crops shelf-life has been explored by a variety of methods. In the past, fumigation with methyl bromide (MeBr) has been successful at extending a nut's shelf-life (ability to be exported fresh to more distant markets), however its production and use were banned worldwide after the Montreal Protocol of which New Zealand is a signatory to (UNEP, 2014). Other methods such as immersion in cold water, hydrothermal processes and freeze-drying for storage have all been explored. Increasing requirements for high-quality food, shelf-stable life of products and food preservation remain drawbacks for processing in the chestnut industry (Pino-Hernández., 2021).

Industry structure as a mechanism for expansion

A shift in consumer preferences for value-added chestnut products would need to occur for a grower to be sure there is a viable (size and price) market to enter given the cost of establishment is a large investment to a business. As discussed above, these considerable investments in processing potentially require pooled capital and supply to both fund investment and deliver the necessary scale to make the investment profitable. Growers could form syndicates or a co-operative to spread capital costs of machinery and increase efficiency in machinery utilisation. Syndicates may support the enablement of diverse ownership for new growers without the same extent of capital required. There is historical precedent for this – the chestnut industry in the 1970's established co-operatives in Ōtaki and Cambridge. Reliant on volunteers, the co-operatives fell over due to differences in understanding of suitable product quality among growers. Picking frequencies varied from daily to weekly and when combined, rotten chestnuts spoiled the whole production. As a result, international markets were unsatisfied, and the export opportunity was lost (pers. comms. Craig Cameron, 11 January 2023).

Understanding the value-add opportunity that a co-operative for chestnuts growers in New Zealand might be able to support is important. The product itself may be extremely viable, however if the supply chain is long and has several touch points where margins are lost to others, the value add may be small, if not less than a product direct to market that has little to no post-harvest processing. In addition, just adding value to a product through further processing does not guarantee that there will be additional buyers and an associated increase in demand. Agribusiness co-operatives in New Zealand have been reasonably successful. Fonterra, Ravensdown and the Dairy Goat Co-operative (DGC) are a demonstration of the critical success factors of a co-operative for successful international growth. Table 8 below highlights the critical success factors of an agribusiness co-operative in New Zealand and considers these for chestnuts.

The chestnut industry in New Zealand has several challenges that are either innate to the product or derived from the operating environment. As presented in Table 8 a chestnut production co-operative could adequately resolve the challenges of access to appropriate processing infrastructure, new market streams and high processing costs. The nature of the product and its lack of domestic demand, paired with the limitation to niche markets remain significant challenges for the nut crop despite a functioning co-operative.

Table 8: Summary of critical success factors of three agribusiness co-operatives in New Zealand. Adapted from Macdonald, and Rowarth, (2013)

Critical success factor	**Definition**	**Fonterra**	**Dairy Goat Co-op**	**Ravensdown**	**Applicability to New Zealand chestnut sector**
Value -add strategy		Progressing	Core strategy	Capture value chain	Not established
Control	Ensuring suitable measures of control over capital, infrastructure and product within the foreign market is critical to returning a profit for the co-operative with a demand driven supply chain	Fonterra control all offshore investments with staff and offices. Fonterra's global presence is well managed within the organisation's structure.	The DGC control input, processing, and output of the formula process. They use market relationships to control the supply of formula to market with little capital investment.	Controlled the initial investment by offering, i) equity as payment ii) Below market value Same management teams for both markets. Investment in international supply chain	Little to no control of the chestnut product within foreign market. Limited levers to pull with small market and specific consumer demands.
Sufficient access to capital	A capital structure used to generate sufficient pools of capital available for scale-up	High level of available capital. Introduction of trading among farmers enables greater working capital	Capital base growing with the co-op. Ability to raise sufficient capital growing significantly	Capital for going global provided by foreign member/farmers under co-operative agreement.	Low level of capital available. No incentive for growers in declining industry with unclear longevity of supply or certainty of market. Importance of bringing new growers into the fold.
Value chain management	Value chain management refers to the integration of communication and organisational capability up and down the entire supply chain	Being refreshed New high value product lines	High quality = High value 100% of strategy	Supply chain infrastructure to capture more value for farmers	Some innovative products being produced at small scale. Domestic awareness of the nut crop and its characteristics is limited.
Relationship markets	Development and management of specific customer relationships to allow for improved profit margins and less fluctuation in price	Slowly increasing, Branding refresh to improve customer interfacing.	Increasing Good branding, Good quality commitment	Strong Direct to customer	Limited international relationships exist. Opportunity to leverage consumer preferences and New Zealand brand through unique marketing strategies.

Sustainable point of difference	Sustainable competitive advantage to differentiate the co-operative in the global market	Technical processing ability, Scale	Market leaders Pasture fed quality	Cooperative structure	Adoption of "brand New Zealand" may offer a competitive advantage paired with niche product development for key markets. Opportunity exists in the food technology realm with chestnuts as a superfood.
Governance	Suitable governance and corporate structure to increase effectiveness of co-operative to deliver in line with co-operative purpose	Broad & complex. Independents with international experience.	Limited pool of governance within smaller shareholder base. High performance track record.	Broad – farmer owners Two Independents Australian represented	The NZCC and Horticultural Export Authority (HEA) are the current governance authorities in New Zealand. Communications internally may be effective, however independent representation and diversity may support chestnut industry expansion.
Going global		Multi-national, start-up ventures, partnerships and exports. Limited farmer involvement	Export based 20 countries Asian focus Farmers not involved	Australian only, International sourcing Australia pre-approved by board	No existing international market Opportunity to explore Japan and USA markets

Markets and supply chain

A key value-added opportunity identified for New Zealand is to grow and process chestnuts in New Zealand to export to high value markets in the Northern Hemisphere, such as the USA and Japan (pers. comms David Klinac, 18 July 2022). Some examples of products made from chestnuts include:

- Flour, bread and bakery items
- Puree and paste
- Stuffing
- Chips/slices

For these products to result in a viable chestnut industry in New Zealand they need to be large enough in size and margin to be profitable (when considering both prices paid and costs to grow and process).

Production of value-added products for international markets is likely more viable than producing for an already small domestic market in New Zealand. In 2020, the global world trade value was approximately $307 million (OEC, n.d.).

One example is VV Mylk, a supplier of alternative nut butters, is producing chestnut milk from freeze-dried flour. One of the challenges of the chestnut, different to oily nuts such as almond and cashew is the lack of oil in the nut to be used in value-added products. Chestnut beer has been produced by the Nuts Brewing Co in Canterbury offering a gluten-free beer for coeliacs. The chestnut nutritional profile contains a high percentage of restricted starch and a low glycemic index which offer additional health benefits (Mujic, 2016).

Requirements of the Japanese market

Accessibility to overseas markets is largely driven by the consumer and our ability to meet their requirements. It has been identified by some chestnut growers in New Zealand that the largest export markets exist in Japan and USA for several reasons, the primary being the prevalence of chestnut in cultural dishes and experiences (pers. comms. David Klinac, 9 December 2022). According to Fang et al. (2019) and similar studies, quality, freshness, production region, and nutrition are important features for consumer demand. Consumer demand for chestnut products exist in Japanese markets, however specific challenges related to product type, seasonality, taste and processing has hindered increasing volumes of chestnut export in the past. Dependent on product details, trade of chestnuts to Japan has a tariff rate of between 2.60% and 9.60% until 2025 (New Zealand Ministry of Foreign Affairs & Trade, 2023).

The Japanese chestnut has been cultivated since the 11th century. This market is expected to have good demand for two reasons; consumer preference of high food safety standards for the New Zealand chestnut, as well as reduced crop production in chestnut producing regions in Japan following the Fukushima nuclear disaster (Nakanishi, 2016). Processing methods to enter this market prove to be challenging with Japanese consumers preferring a slow manual peeling method initially influenced by the nature of the pollen parent resulting in easy peel pellicles, later became a marketing point of difference. Ultimately, this kind of processing method is inefficient for the chestnut industry in New Zealand. This method would require approximately 500 staff peeling 20 kilograms of chestnut per day, five days per week for six weeks from mid-March to process the 350 tonnes produced in New Zealand annually. This excludes the time cost of collecting, packaging and exporting the product.

New Zealand chestnuts have been exported frozen to Japan in the past. However, freezing is expensive and decreases the functional value of the chestnut. Frozen chestnuts are only suitable for puree because the freezing process destabilizes proteins turning the chestnut to mush. The Japanese are highly interested in New Zealand chestnuts, due to the compatibility of taste for consumers and production practices in New Zealand. Japanese chestnut production is in decline because of competition for land uses reduction in chestnut area. Opportunity lies in value added chestnut processing in New Zealand, with export of goods, such as chestnut puree to Japan.

It has been suggested that Japan would buy all the chestnut flour that New Zealand can produce from existing orchards (pers. comms. David Klinac, 9 December 2022). Supply chain challenges exist however in the requirement of pure-white coloured flour that New Zealand processing machinery cannot guarantee without fit for purpose machinery or bleaching with the now illegal sulphuric acid. Paired with the preference for a large "traditional" hand-peeling operation at a likely low labour cost under Japanese supervision, the Japanese consumer preferences are at odds with the attributes of the New Zealand chestnut industry. Adapting the chestnut processing system for one specific market raises concerns for supply chain sustainability if preferences or exporting requirements change. Offering a key market opportunity, a joint venture with Japan where a partnership of New Zealand supply met with joint ownership of processing facilities. Advantages such as shared cost, risk and access to new markets and distribution networks would likely provide New Zealand with a viable product to explore, however the extended supply chain and resulting margins for growers may remain a barrier. Consumer preferences and their related challenges and potential opportunities can be found in Table 9 below.

Table 9: Japanese consumer preference challenge and opportunities

Consumer preferences	Challenge for New Zealand	Possible opportunity
Hand-peeled	Lack of resource	
Pure-white coloured flour	Chestnut processing machinery grinds to a flour, however parts of the pellicle on the chestnut discolour the flour to a cream colour. Adding sulphuric acid to flour to bleach, now banned in NZ.	Export chestnut flour to Japanese partner company for bleaching there. Lower value product.
Fresh chestnuts	Chestnut season is mid-March to mid-May in New Zealand, whereas chestnuts are typically consumed September-October.	Freezing chestnuts, cannot be used whole after, as there is a nut composition change.

Requirements of the USA market

Like the Japanese market, the USA has its own set of consumer preferences. The chestnut is celebrated seasonally in Autumn, the chestnut being a staple ingredient in turkey stuffing for Thanksgiving. New Zealand is not currently exporting chestnuts to this market. The constant challenge of production of the chestnut six months ahead of the Northern hemisphere demand plagues market expansion. With a shelf-life of just two to three weeks and 50% water content, fresh chestnuts provide significant challenge for succeeding into overseas markets. An innovative opportunity the New Zealand market could explore may be vacuum packing and freezing peeled chestnuts. A co-operative in Europe is successfully shipping frozen peeled chestnuts on dry ice to chefs across America to compete in this market (Kane, 2007).

Chestnut as a superfood

Another avenue for the chestnut industry in New Zealand to explore might be health and food technology products. The Good Mood Food initiative developed by Hort Innovation Australia is re-defining how we create value chains and customer demand through education and awareness of products in the horticulture sector (Hort Innovation, 2021). A chestnut marketing program in 2020/21 to generate awareness around Australian chestnut products and tap into the opportunity to increase market demand, particularly in the vegan and gluten-free market (Hort Innovation, 2021). This campaign is focusing on using chestnuts fresh, frozen, flour or puree. Given the lack of requirement for fertiliser or agrichemicals, New Zealand can employ an 'organic' status for chestnuts, opening opportunity or expansion diversification into health products on both a local and international scale.

High in Vitamin C and low in fat, the chestnut has the potential to be marketed and sold as a 'superfood' similar to freeze-dried berries popular in the vegan and gluten free markets. The food value of chestnut products and other superfoods can be found in Table 10 below. It should be noted that it is the micronutrients such as vitamins and minerals in these products that make them 'super'.

Table 10: Food value comparison of chestnut products and other superfoods produced in New Zealand

Food value of superfoods				
Form	**Water (%)**	**Protein (%)**	**Fat (%)**	**Carbohydrates (%)**
Fresh chestnuts	44	4	1	49
Dried chestnut	9	7	2	80
Freeze-dried blackcurrant		7.67	0.74	54.7
Freeze-dried blueberries		7	6	87

A case study: The Australian chestnut market

A commercial chestnut industry has been operating in Australia since the 1970's. Producing approximately 1,250 tonnes annually, the Australian chestnut industry has a small export market (mostly to China) and a production period of March to June, similar to the New Zealand chestnut industry. The farm gate value of production in 2016 was valued at $12.5 million AUD. The greatest challenge that the Australian chestnut sector is productivity compromised by chestnut rot caused by the fungal pathogen *Gnomoniopsis smithogilvyi* (Silva-Campos, 2022). Growing five different varieties, the chestnut industry in Australia is largely producing ready to use peeled and frozen chestnuts, cooked and peeled, fresh, chestnut flour and puree.

There are currently three chestnut processors that service the Australian market. All three processors are located offshore in China. The existing supply chain for chestnuts produced in Australia are picked, transported to China (this transport enabled by their much closer geographic location) for processing in a commercial peeling machine to then be frozen or further processed in a crumbing and drying machine to produce chestnut flour. Processed chestnut products are transported back to Australia to be sold on the domestic market. Given the increasing overseas demand, Australia would likely benefit from mechanising production to compete on price in overseas and domestic markets (Hort Innovation, 2017).

For small producers, there is a need for value-added chestnut products, however challenges mimic that of New Zealand in the lack of established demand and the cost of production to be economically feasible (Hort Innovation, 2021). With over 70% of the total Australian crop grown in the north-east of Victoria, there is potential for chestnuts to become a focused regional food (Casey, 2009).

The Australian Hort Innovation, a grower-owned, not-for-profit research and development corporation for Australia's horticultural sector has established a Chestnut Fund to support productivity, profitability, and demand for chestnut growers. Driven by the Chestnut Strategic Investment Plan, Australia is seeking to grow the chestnut industry by focusing on reducing crop losses through the implementation of sustainable pest and disease management practices, as well as developing the demand for Australian chestnuts (Hort Innovation, 2021). Given New Zealand is void of common diseases, yet facing the same domestic demand issue as Australia, competition with the Australian market for export seems a viable opportunity to explore. However, the non-tariff barrier Australia introduced that required methyl bromide fumigation of imported nuts rules out New Zealand chestnut export to Australia, given New Zealand's discontinued use of this chemical treatment.

The Australian domestic market for chestnuts is small. The industry identified the need for demand creation to drive volume growth. A chestnut marketing program was designed to generate consumer awareness through promotional communication content on social media such as recipe development, events, e-newsletters and brochures. The Good Mood Food domestic marketing across-horticulture campaign (see Figure 2 for an example) was developed to encourage behaviour-change through messaging to motivate Australians to eat more fruit, vegetables and nuts. Seeking to encourage people to eat on the 'bright side' the campaign reached 98% of Australians through a range of channels, educating consumers about their high nutritional value and other dietary properties, however there is no indication provided of whether this resulted in consumers including chestnut products as a staple ingredient in the home. The opportunity in the vegan and gluten-free market was highlighted as a potential market for significant growth.

The New Zealand chestnut industry is probably slightly poorer placed than with that of Australia. Experiencing similar challenges of domestic and market demand, the New Zealand chestnut is void of the chestnut diseases that the Australian sector faces but is significantly further away from potential markets or places to outsource cost-effective processing. The marketing angle that Australia have explored through the Good Mood Food campaign and creating demand through awareness is an opportunity New Zealand could explore. With increasing interest in health and superfoods, the chestnut offers desirable properties, low in fat and high in vitamin C, the micronutrients of vitamins and minerals in the chestnut are desirable for this evolving market.

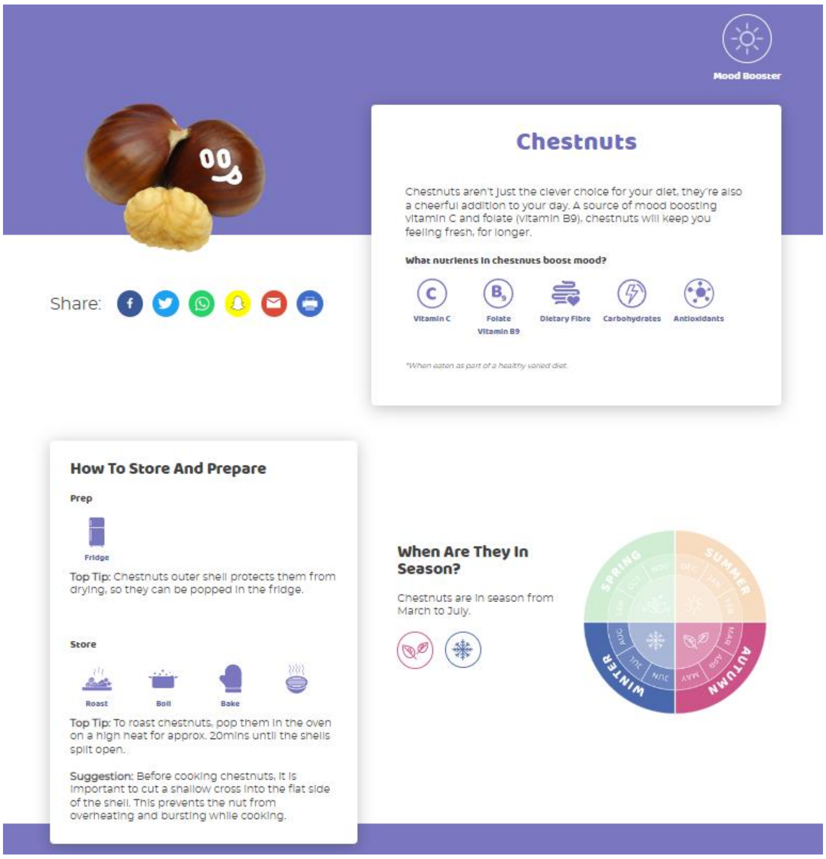


Figure 2: The Good Mood Food Tool (Hort Innovation, 2021)

Farm-level opportunities

At a farm level, one of the major supply chain challenges for the commercial expansion of chestnuts are access to trees with quality genetics. The most commonly planted varieties are the European/Japanese hybrids characterised by rapid vegetative growth when young and early bearing (Young & Kiwi-Knight, 2017). New Zealand chestnuts (*Castanea spp.*) are unique in that the trees are void of common chestnut diseases in overseas cultivars such as chestnut blight, gall wasp or chestnut weevil that have plagued traditional chestnut-growing areas. New Zealand's natural advantage in this areas could potentially be leveraged through its ability to more easily supply organic chestnuts, more reliable production and perhaps the avoidance of non-tariff barriers; however this doesn't appear to have happened to any significant extent to date.

Management techniques

The value proposition for land use change to chestnut production is impacted by the three to four year lag period while the tree is growing. While other horticultural crops also have a lag between establishment and full production, the value proposition for chestnut trees from an economic perspective is significantly lower than that of say a kiwifruit or blueberry orchard investment. The kiwifruit industry in New Zealand has 2,792 growers and was worth $2.967 billion in gross sales in the 2019/2020 season (New Zealand Horticultural Export Authority, n.d.). With an export value of $670 million to Japan alone in 2020, there is limited concern about whether the lag period from establishment to first crop will pay off for a kiwifruit investment if grower can afford the initial capital costs.

Overplanting and then thinning of chestnut trees may be one management technique the chestnut industry could explore. A chestnut grower in Horowhenua employs this technique by mass planting chestnut trees for quicker returns. More trees producing yield at first year of production will result in more yield per hectare, however thinning is required to prevent trees from crowding out and production only occurring at the top of the trees. As the trees mature, every second tree in the 6 m x 6 m spacing orchard is thinned once a full canopy cover is reached (pers. comms. Craig Cameron, 11 January 2023).

Access to trees with more suitable genetics

Chestnut trees are reproduced using seedlings or vegetative propagation, namely rooted cuttings (Song et al., 2021). An existing chestnut tree nursery in Hastings has been exploring the survivability of Asian, Japanese and European chestnut breeds in New Zealand, which could be better suited to market tastes and available processing equipment. Growing conditions have proven difficult for these breeds to thrive to the same degree of the Euro-Japanese hybrids. Other challenges such as the potential biosecurity implications of importing new breeds is another risk to consider. Grafted chestnut stems can be purchased for $70, excluding transportation costs to orchard. The survivability to producing age at 4 to 5 years is approximately 80%.

Agroforestry and intercropping

One opportunity at a farm scale is agroforestry. A traditional method that has growing interest, agroforestry describes the "land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence" (FAO, 2015). Research suggests that agroforestry systems *can* contribute to potential ecosystem and socio-economic benefits. The Spanish Dehesa method (Nature Scotland, 2022) is an agroforestry tool where the spacing of trees is strategically planned to minimise the loss of pasture production, or erosion. Other agroforestry tools for possible integration with chestnuts are outlined in Table 11 below.

Table 11: Agroforestry system as a supply chain opportunity in New Zealand (United States Department of Agriculture, n.d)

Agroforestry system	Function	Benefits
Alley cropping	Planting of rows of trees/shrubs to create alleys within which agricultural or horticultural crops are produced	Multiple crops for whole-farm yield Improved crop production Microclimate benefits to manage risks
Forest farming	Cultivation of high-value crops under the protection of managed tree canopy	Intentional use of vertical space Benefits from the interaction of the plants and microclimate
Silvopasture	The deliberate integration of trees and grazing livestock operations on the same land	Provide short and long-term income sources Trees can supply to grazing livestock as another food source Forage protects soil from water and wind erosion, adding organic matter to improve soil properties and protect water quality Reduced heat stress for livestock, improving animal performance and well-being
Windbreak	Linear plating of trees and shrubs to provide economic, environmental and community benefits	Additional income source Potential timber source Storage of carbon Indirect economic benefit through soil erosion control, livestock protection, wind protection

While tree and pasture integration is not commonplace in New Zealand outside of intermittent space-planted trees for erosion control, a sheep and beef farm near Pukeokahu (Mangarara Station) has diversified into an intensified diverse farm system with the incorporation of both tourism activities and agroforestry by planting chestnut trees like that of the Spanish dehesa system. Co-benefits of the agroforestry system included nitrogen fixing, carbon sequestration and enhanced biodiversity, alongside a potentially additional income stream (Tschora and Cherubini, 2020). Alternative drivers such as biodiversity, emissions and water quality drivers are valuable. However, the extent to which chestnuts planted within an agroforestry system can deliver a sufficient economic return from the harvest and sale of their nut crop has not been determined, but seems likely to be low. Table 12 below outlines some of the benefits of planting trees to mitigate, or at least alleviate some the environmental impacts of a ruminant livestock production.

Table 12: Environmental impacts of ruminant livestock production and how agroforestry could potentially mitigate these impacts. Adapted from Jordan et al. (2020).

Environmental Indicators	Ruminant Action	Details of negative environmental impact caused by ruminants	Ecosystem services provided by trees to mitigate this impact	Natural capital assets affected	Societal outcome affected
Greenhouse gas emissions and carbon	Eructation, urination, and defecation (i.e., manure production)	Emissions: Methane from eructation and manure Nitrous oxide from manure and fertiliser applications Carbon dioxide from machinery and embedded in animal feed production	Carbon sequestration in above and below ground tree biomass and soil	Air and soil	Stable climate
Air quality		Emissions from air pollutants	Particulate capture by tree leaves	Air	Clean air
Water quality		Nutrient loss in run-off from fields into groundwater and watercourses	Nutrient capture by tree roots	Water	Clean water
Water quantity	Trampling and grazing pressure	Reduced water infiltration caused by soil compaction leading to increased water runoff from fields	Increased water infiltration into soil facilitated by tree roots and increased transpiration rate of trees	Soil and water	Flood hazard protection
Soil erosion		Soil erosion	Slope stabilisation and sediment capture by tree roots		Sustained basis for food production

Impact of intercropping chestnut with livestock system on pasture production

Grazing under chestnuts is a common practice in the chestnut industry (pers. comms. David Klinac, 9 December 2022). There is limited literature on the impact of grazing on pasture production under chestnut trees. For the purpose of this report, the impact of pasture production under space-planted poplars is assumed to be similar to chestnut trees. Space-planted poplars reduce pasture production of a full canopy system due to the interception of light and moisture (Wall et al., 2006). Pasture production declines to approximately 50% of that of open grassland as canopy closure approaches 80%.

For safe grazing with livestock, trees need to be 3 - 3.5 metres in height, equating to approximately a 4 year old chestnut tree. Grazing during years 1-4 may be appropriate with sheep assuming sleeves are used around trees. Stock also need to be excluded ahead of nut harvest period mid-March to mid-April to enable deposited manure to dry to facilitate easy picking and avoid affecting the nut quality. Research from a walnut farm (Hodge, 2001) found that grazed trees experiences approximately 20 – 25% diameter growth suppression. It is assumed that growth suppression of a tree will likely result in a reduced optimal yield. This wasn't apparent from the literature reviewed, nor is it clear that a similar observation would be made in a grazed chestnut orchard. Nutrient export (in livestock) and reduced soil fertility as a result of grazing animals could impact the yield of nut crop from the intercropping system, but this would need to be researched. Furthermore, given the apparent common practice of understory grazing in New Zealand, it might be more relevant to investigate if tree parameters or yields changed if stock were excluded. Grazing under chestnut trees is therefore a viable option, given appropriate management techniques are introduced. However, the impact of grazing under chestnuts will limit the extent of any net greenhouse gas (GHG) reduction compared to a system where stock are totally excluded.

Chestnuts in the Emissions Trading Scheme

As well as producing a nut crop, a chestnut orchard, like all forests will sequester carbon as they absorb carbon dioxide and store it in their above and below ground biomass. The current forest land defintion in the New Zealand Emissions Trading Scheme (ETS) specifically excludes chestnuts trees, along with other fruit and nut trees that are managed as food crops. The ETS has a specific definition for what a forest is, know as the 'forest land definition'. To be eligible, a "forest" must be 1 ha or more with an average minimum width of 30 metres, have a potential height of >5 metres and be capable of achieving 30% canopy cover (MPI, 2017).

Exclusion of chestnut trees from the ETS

Chestnuts, and other fruit and nut trees are classified as 'perennial cropland' with their primary growth being for a food crop. The inclusion of fruit and nut trees would alter New Zealand's carbon baseline and therefore GHG emissions reduction targets under the Kyoto Protocol accounting rules adopted by the nation (Lilley, 2021).

If a chestnut orchard was not managed as a food crop, it is possible that chestnuts could meet the forest definition and eligibility criteria required to be included in the ETS. Widely spaced exotic hardwoods, like chestnuts, oaks etc. are generally considered to be able to satisfy the 30% canopy cover requirement if planted at 16 m or less spacings (May, 2018). Planted with 12 m x 12 m spacings, a commercial chestnut orchard at 64 SPH is therefore expected to meet the functional definition of an ETS eligible forest.

On the basis that the amount of carbon sequestered in a chestnut forest is unlikely to be different from that sequestered in a chestnut orchard of the same size, as the NZ primary sector continues to move toward more carbon conscious food-production and the cost of greenhouse gas emissions increases, it may be valuable to understand the sequestration potential of the chestnut tree if this apparent anomaly was changed.

'Averaging' as a concept for accounting for carbon in post-1989 forest land became compulsory on 1 January 2023 for forests managed for production timber. The method enables ETS participants to receive carbon credits equivalent to the long-term average level of carbon storage in the forest across multiple rotations. On the basis that chestnut yield declines over time, it seems reasonable to assume that a permanent chestnut orchard will invariably remove and replace trees over time. As such, an averaging mechanism might be appropriate for accounting for the carbon sequestered in permanent tree nut crops, were they to be eligible for inclusion in the ETS. However, it has not been possible to ascertain what the average age of trees in a "permanent" chestnut orchard should be.

Carbon sequestration potential of chestnut trees

A 2014 American study sought insight on the potential effects of strategies for chestnut re-introduction and their carbon storage potential. The study found that chestnut planting can lead to a positive shift in the predicted biomass distribution of woody debris stocks, most likely due to the fact that chestnut wood decays at an unusually slow rate (De Bruijn, et al., 2014*a*). This suggests there is a real sequestration potential with the storage opportunity for the chestnut tree itself along with a slow decay rate (over 50 years).

There appears to be little literature on carbon sequestration by chestnut trees in New Zealand. International literature is sparse and difficult to compare due to different species and sequestration rates. An American study estimated that chestnuts sequester greater than 1.85 t C ha^{-1} over their first five years, scaling to more than 19.76 t C ha^{-1} by age of maturity of approximately 12 years (Davison et al., 2021). With these chestnuts yielding of approximately 2,000-3,000 pounds of chestnuts per acre (2.2 – 3.4 t ha^{-1}), we can assume this is a similar stocking density to the average chestnut orchard in New Zealand, given the broad similarity in yields. With 1 t C equivalent to 3.663 t of CO_2 based on atomic mass, the amount of CO_2 sequestered by a 64 SPH chestnut orchard is estimated to be 72.3 t CO_2 ha^{-1} at year 12.

Matheson and Muller (2020) analysed the carbon sequestration potential of space-planted poplars (a deciduous tree that grows in a similar temperate environment to that of a chestnut tree) in New Zealand based on a range of literature. A plantation of 25-year space-planted poplar planted at 156 SPH was estimated to sequester approximately 101.4 t C ha^{-1} or 371.4 t CO_2 ha^{-1}. Cannell (1999) reported that poplar trees planted at this density sequestered approximately 26 kg C per tree per annum (over a 25-year growing period). A chestnut orchard planted at 64 SPH is broadly equivalent to approximately 71% planting density of an 80 SPH space-planted poplar forest. Noting that as a tree ages, the likely carbon sequestration will increase by a certain degree we can assume that the carbon sequestered in a 25 year old forest should be greater than a 12 year old forest. On that basis, the estimated carbon sequestration of 72.3 t CO_2 ha^{-1} of Davison et al. (2021) at year 12 from a 64 SPH chestnut forest is in line with the 155 t CO_2/ha sequestration assessment for an ETS eligible 25-year-old poplar stand planted at 90 SPH of Matheson and Muller (2020).

Based on Cannell, the amount of CO_2 sequestered by a poplar stand at 156 SPH at 25 years is approximately 60% of that assumed by the New Zealand ETS look-up tables (Matheson and Muller, 2020), suggesting that the default assessments of lower density forests that still qualify for ETS inclusion overestimate carbon sequestration. Based on Davison et al. (2021), it would seem likely that a chestnut forest at 64 SPH would also, in actuality, sequester less CO_2 than the look-up tables assume. Based on the 1 t C equivalence to 3.663 t of CO_2, the amount of CO_2 sequestered by trees in the studies described is presented in Table 13 below. For the purpose of comparison, the maximum potential rate of carbon sequestration assumed is as per the Te Uru Rākau look-up tables for exotic hardwoods (MPI, 2017).

Table 13: Summary studies assessing the amount of carbon sequestration of space-planted poplars compared to the ETS look-up table for exotic hardwoods

Tree	Study	Density (SPH)	Age	Carbon (t ha^{-1})	Carbon (t CO2 e ha^{-1})*
Space-planted poplars	Cannell (1999)	156	25	101.4	371.43
	Matheson & Muller (2020)	90	25	42.32	155
Chestnut	Davison et al (2021)	64	12	19.76	72.38
ETS look-up table Exotic Hardwoods			10		251
			12		320
			25		618

The likely quantum of saleable carbon in a 12 year old chestnut orchard is approximately 72.3 t CO_2 ha^{-1}, similar to an indigenous forest of the same age (MPI, 2017). Assuming a new chestnut orchard was considered eligible for inclusion in the NZ ETS, the possible carbon income at different carbon prices and assessment mechanisms from a chestnut orchard after 12 years, assuming all the carbon was saleable, is presented in Table 14.

Table 14: Possible carbon income from a 3 ha chestnut orchard at different carbon prices with a planting density of 64 SPH

Carbon Price ($/NZU)[1]	Value in a 3 ha exotic hardwood forest (after 12 years)	Value in a 3 ha chestnut "forest" (after 12 years)
40	$38,400	$8,796
50	$48,000	$10,995
60	$57,600	$13,194
70	$67,200	$15,393
80	$76,800	$17,592

[1] January 2023 NZU price was approximately $75 per tonne carbon dioxide equivalent

A 3 ha chestnut "forest" able to enter the ETS would be expected to generate between $16,400 and $72,000 in carbon revenue per hectare over the first twelve years after establishment at a carbon price of $75/NZU, depending on whether sequestration was assessed using the current look-up tables for exotic hardwoods or an assessment expected to be closer to the actual (lesser) amount of CO_2 sequestered.

This variation between the exotic hardwood sequestration assumptions in the look-up tables (based off Eucalyptus data) and actual rates of sequestration from widely spaced hardwoods that still achieve "forest" parameters is now widely recognised and seems likely to be corrected in the future. On the basis this occurs, the amount of potential carbon revenue from chestnuts planted at 64 SPH is, in reality, likely to be significantly lower than that achievable under production radiata pine forest at the same age and chestnuts, either as forest or a theoretically eligible orchard, are unlikely to compete with *Pinus radiata* as a mechanism for carbon income. But even at the lower level of assessment presented in Table 14, the inclusion of carbon income would improve the investment returns from a chestnut orchard. In the four hectare orchard scenario explored above, when including potential carbon income the IRR of -10% improves to -9% based of the sequestration assessed using Davison et al. (2021) and a $75/NZU price. It improves further to -8% at an average carbon price of $150/NZU. These analyses are presented in Appendix 4: Discounted cash flow analysis for a 4 chestnut orchard with eligible carbon income ($75/NZU) and Appendix 5: Discounted cash flow analysis for a 4 ha chestnut orchard with eligible carbon income ($150/NZU). While this level of improved financial return is insufficient to provide for the individual ownership of post-harvest freeze drying plant, the additional $30,000 of additional revenue generated over a 15 year period at a $75/NZU carbon price might help with investment in collective processing.

3 Other considerations with changing land use to chestnuts

Land use driven by emissions pricing and environmental regulation

Under the Climate Change Response (Zero Carbon) Amendment Act 2019 there is a requirement for the agricultural industry to reduce gross methane emissions by 10% by 2030 and between 24-47% by 2050, and an independently set methane price will be a driver for this should methane targets not be met.

Under the NZ government's current farm level pricing proposal (Ministry for the Environment and Ministry for the Primary Industries, 2022), the effects of pricing methane and nitrous oxide emissions is expected to result in a reduction in production and revenue from the pastoral sector.

While emissions risk varies for each individual farm, the MfE and MPI analysis identified that compared with dairy, the sheep and beef sector emit more GHG's relative to the sector's overall net revenue. This results in the proposed emissions pricing expected to have a more severe impact on the sheep and beef sector (Ministry for the Environment and Ministry for the Primary Industries, 2022).

Chestnuts could be incorporated into sheep & beef farming systems through agroforestry and intercropping to help reduce gross methane emissions, reduce net long-lived gas emissions and provide a secondary income stream, the latter *potentially* being financially competitive with the underlying land uses. Providing multi-benefits such as shell to stock for feed, trees for timber, chestnut for human consumption and shade for grazing stock, there is opportunity for a so called circular production system from the chestnut, but this is more likely to occur on individual farm business, (i.e., Mangarara Station) than at industry scale.

In the absence of significant market opportunity, expansion in the areas of chestnuts planted seems unlikely to occur at a sufficient scale to be able to have a regionally significant impact on land use change and greenhouse gas emissions reduction, say in the way growth in the kiwifruit sector is reducing the scale of dairy farming in the Bay of Plenty. However, development of chestnut orchards targeting specialist markets could be significant for individual properties within a specifically located cluster.

Wider environmental impacts

Consideration will need to be given to the application of fertiliser to pasture if chestnuts are integrated into a farm system. One of the major advantages of the New Zealand chestnut industry is the organic status of chestnuts due to the lack of fertiliser or chemical application required for growth. If fertiliser is applied within proximity to chestnut trees, their organic status and therefore market access may be put at risk. One of the barriers that led to New Zealand ceasing access to the Australian chestnut market in 2007 was the methyl bromide fumigation requirement for fresh chestnuts. The requirement was introduced to remove the risk of unwanted pests, however the treatment removes the organic spray-free status of the chestnuts sold at a premium. This treatment has subsequently been discontinued in any case.

By-products

One of the potential challenges of the chestnut industry is the amount of shell waste produced due to product preferences, particularly if the industry expanded. For chestnut growers, using the by-product for an alternative use would be desirable.

With a high natural tannin and polyphenol content, chestnut shells could be a new stock feed option. The high-tannin product has not been explored on a large-scale commercial market yet. The properties offer improved animal health in a variety of species across the sheep, beef, dairy, and poultry sectors. A natural de-wormer, the potential stock feed product could offer growers an opportunity to eliminate the need for chemical intervention. Environmental benefits exist in the potential for reduced levels of nitrogen and phosphorus excretion and methane production (Klinac, 2016). High in carbohydrate and containing 5-7% protein as well as calcium and iron, understanding the competitiveness of the chestnut shell to other supplementary feeds in New Zealand would be useful.

New Zealand has an annual production of approximately 350 tonnes of chestnuts, of which approximately 35 tonnes is chestnut shell, on the assumption the shell makes up 10% of the chestnut. To put this production in context, if we assumed the shell was 80% dry matter, the annual production of chestnut shell would feed 400 cows eating approximately 2 kg DM/day for 35 days. With a similar, albeit not identical, supplementary value to Palm Kernel Extract (PKE), this makes 0.002% of the 1.9 million tonnes PKE that New Zealand import annually. If chestnut shell was sold at a value of $0.38/kg to be competitive with PKE (based on the current spot price of $384/t), the annual income would be in the vicinity of $13,300 for chestnut production nationwide – hardly significant in the context of the value of the industry or the stock food sector.

Despite the return being small in and of itself, the environmental benefits of the product could be used to market the product as a premium. There may be opportunity to explore collaboration with producers of organic total mixed ration feeds. A notable advantage of using the chestnut for animal consumption rather than human is the likely lower costs of compliance and ease of production for the grower.

However, unless operating at significant scale, chestnut shell for stock feed is far from able to satisfy the demand required. Olam Food Ingredients are conducting a trial of almond hulls (a by-product of almond processing) as a feed source for dairy cows in New Zealand (Te Waka Anga Whakamua Waikako, 2022). The trial is investigating packaging, transport and scale requirements to market almond hull on a commercial scale. Research findings from this trial may draw some applicable conclusions for the chestnut industry in New Zealand about the potential level of acceptability of this feed option

Research is currently underway looking at the potential for chestnut shell to be used as a potential renewable energy source as a typical agricultural waste is being explored (Shen et al., 2023). Chestnut timber from the exotic Castanea sativa is highly sought after due to its natural ground durability. These two product categories could be new product categories to explore with appropriate research and market testing.

Changes in labour requirements

Chestnut harvest occurs over a four-to-six-week period between mid-March to mid-April. Picking ranges between daily and weekly, however for best quality picking daily is ideal. Skills required for the low-intensity chestnut production system is minimal and labour skills from high-intensity operations such as sheep and beef or dairy are easily transferrable. The balancing of relationships with key industry partners will be crucial for the successful integration of chestnut into an existing sheep, beef or dairy farm system. If chestnuts were integrated into existing livestock farms in New Zealand, March to April tend to be low labour months, therefore the chestnut yield period would align well with a pastoral farming operations.

4 Conclusions

Scaling up the chestnut industry in New Zealand faces several significant challenges.

Despite chestnuts providing an alternative or integrated land use to pastoral farming, offering a lower methane and nitrous oxide footprint than that of dairy or sheep and beef and having inherent carbon sequestration potential, their economic potential appears significantly constrained.

With the nuts able to be grown almost anywhere in New Zealand and free of diseases prevalent in other countries, the chestnut industry has the potential to develop a supply chain to produce value-added chestnut products onshore before export to overseas markets. Markets with strong cultural preferences for chestnut products or the vegan and gluten free health market that attracts consumers to the potential "superfood" qualities of chestnuts could be explored.

However, the chestnut industry continues to face a series of challenges with reaching these markets and chestnut production being a viable land use in New Zealand.

While reported/projected status quo returns from chestnut production at $2,700/ha/year appear competitive with some other land uses, domestic demand for fresh chestnuts (on which these returns are based) seems unable to accommodate any significant increase in supply. Furthermore, the short two to three week shelf-life of the fresh chestnut prevents the export of the product in a fresh form to all but very close and very small Pacific Island markets. This makes the post-harvest processing of chestnuts all but a pre-requisite for any significant commercial expansion.

Unfortunately, the existing (but limited) processing infrastructure in New Zealand for peeling and processing is not well suited to the predominant varieties of chestnuts grown here, with their hard pellicle affecting the attributes of the processed chestnuts and limiting market demand. Growing a different breed of chestnuts, such as Asian, Japanese or European cultivars, would eliminate some of these quality issues but potential growers would need to have confidence in the suitability and growth success in the New Zealand climate of these new varieties, as well as ensuring such new types were free of the pathogens than limit yields in other countries.

The small seven to nine week window within which chestnuts must therefore be processed makes investment in processing equipment suitable for use by individual growers (behind the farm gate) almost impossible to justify. Larger scale, post-farm gate processing is certainly more capital efficient, but the amount of capital required to be invested in specialist machinery for such a short seasonal processing window erodes the available returns and ultimately requires a very high value product to justify. Development of a suitable co-operative with pooled capital or joint venture relationships could be a viable model for the industry to increase machinery utilisation and spread capital costs (and the low returns on this deployed capital). A co-operative might also help resolve the challenges of access to appropriate processing infrastructure and new market streams. However, the storage limitations of the fresh product and its lack of domestic demand, paired with the attribute limitations to supplying niche markets would remain significant challenges for the chestnut industry, even with a functioning co-operative.

In an environment where farmers and growers are shifting to lower emission land uses, chestnuts, as an alternative land use, offer multi-use, multi-benefits that may be attractive in the face of penalties or increased costs for high emission land uses. At commercial planting densities chestnuts could be incorporated into an existing livestock farm system without the complete loss of pasture from those areas while sequestering say 72.3 t CO_2 ha^{-1} over a 12 year period. If the eligibility of chestnut orchards for inclusion into the ETS was changed, then this carbon could have a cumulative value of between $5,400 and as much as $24,000 per hectare over their first 12 years of establishment (c. $700 -

$3,500/ha/year of additional revenue from years 5-12) at a $75/t NZU price, depending on how carbon volumes were assessed. While the likely true sequestration rates will generate less carbon income than from a radiata pine forest, these revenues would compare extremely favourably with the likely revenue from the sheep & beef farm system it might displace during that time period.

However, despite this, in the absence of significant market opportunity, expansion in the areas of chestnuts planted seems unlikely to occur at a sufficient scale to be able to have a regionally significant impact on land use change and greenhouse gas emissions reduction. Development of chestnut orchards targeting specialist markets could be significant for individual properties within a specifically located cluster, but once again seem likely to need sufficient scale to justify the required post-harvest processing and risks associated with a lag phase through to nut production.

To be sustain a viable export industry, it is concluded that the chestnut supply chain ideally needs:

- Improved scalable processing technology that aligns with New Zealand chestnut characteristics <u>or</u> to produce an alternative species of chestnut that is suited to both overseas consumer preferences and the existing processing technology. The development of innovative and low cost storage technology, that allows for extended processing or freight windows of the fresh nuts would be transformative.
- A market or, ideally, markets that are sufficiently stable and high value to justify the scale required and capital investment a chestnut farmer needs to make into the farm and equipment, either on farm or further along the supply chain, to support production.
- To explore production of high value-added chestnut products, particularly focusing on health products, which could provide better returns from the necessity of post-harvest processing and our distance to market.
- Recognition of the carbon sequestration potential of new chestnut orchards. While carbon revenue streams may not be reliable in the medium to longer term, they provide an opportunity to help with the transition to chestnuts as land use, either with on-farm investment, buffering uncertain chestnut revenue or helping fund the post-harvest processing that sector requires.

Potential production innovations that might accelerate early year yields or develop markets for by-products have potential value to the sector but will be irrelevant in the absence of a sustainable and profitable market for the chestnuts New Zealand currently produces, let alone additional production.

In summary, the observed supply chain challenges in the chestnut industry are not new and have plagued the scale-up of chestnuts in New Zealand for decades. The current environment for the industry is at a cross-roads. Stagnant and unchanging, left as is the industry will likely continue on its trajectory of decline with risk of fading out entirely. Sufficient investment and innovation would be required to shift the industry into the value-added product market for domestic and international production. Overcoming the current inability to reduce or eliminate the constrained processing window seems critical to future success, particularly with regards to improving capital efficiency and investment returns.

Ultimately identifying how the industry can ensure a reliable supply of chestnut products into the overseas market, considerate of export distance, seasonal supply and a perishable crop, will determine the fundamental future success, capacity for growth and ultimate longevity of the chestnut industry in New Zealand.

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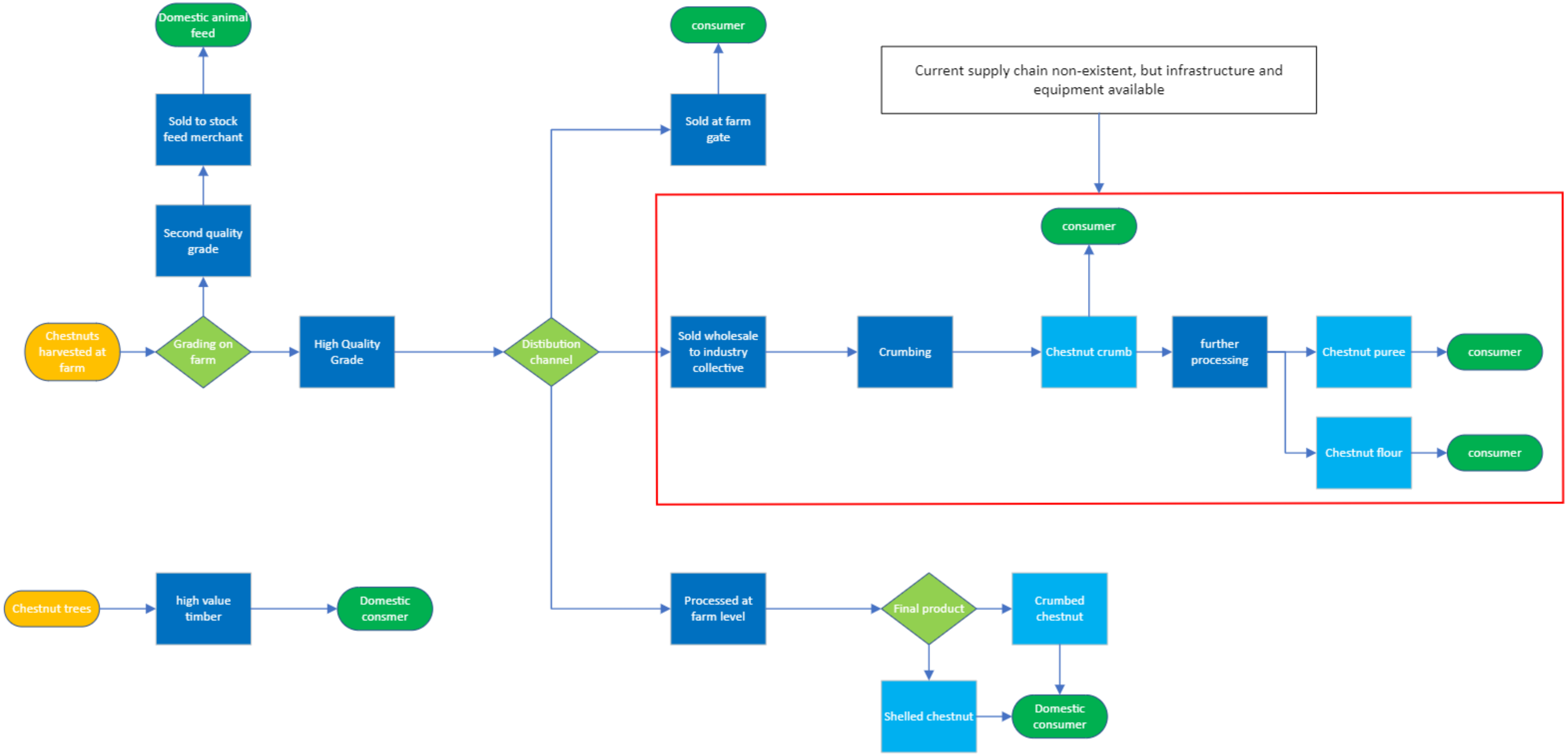
Appendix 1: Existing supply chain of chestnuts in New Zealand



Appendix 2: Discounted cash flow analysis for a 3 ha chestnut orchard

Fifteen-year discounted cashflow analysis for a 3 ha chestnut orchard investment with on-site freeze dried flour processing

Chestnut harvesting and processing infrastructure cashflow analysis: 100% grower investment

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total Revenue $																
Harvest income		$0	$0	$0	$0	$53,856	$53,856	$53,856	$53,856	$53,856	$53,856	$48,470	$43,623	$39,261	$35,335	$31,801
Total Revenue:	**0**	**$0**	**$0**	**$0**	**$0**	**$53,856**	**$53,856**	**$53,856**	**$53,856**	**$53,856**	**$53,856**	**$48,470**	**$43,623**	**$39,261**	**$35,335**	**$31,801**
Expenditure $																
Farm system expenses																
Capital: Trees	$13,440															
Capital: Tractor	$35,000															
Capital costs for processing																
Farm expenses	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500	$1,500
Capital: Vacuum harvestor					$30,000											-$6,484
Capital: Grading machine					$8,000											-$1,729
Capital: Shelling machines					$15,000											-$3,242
Capital: Freeze dryer					$950,000											-$205,322
Capital: Milling machine					$10,000											-$2,161
Capital: Vacuum packer					$2,000											-$432
Harvesting, processing and packing costs		$0	$0	$0	$0	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775	$29,775
Total Expenditure:	**$49,940**	**$1,500**	**$1,500**	**$1,500**	**$1,016,500**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**$31,275**	**-$188,095**
Annual Cashflow:	**-$49,940**	**-$1,500**	**-$1,500**	**-$1,500**	**-$1,016,500**	**$22,581**	**$22,581**	**$22,581**	**$22,581**	**$22,581**	**$22,581**	**$17,195**	**$12,348**	**$7,986**	**$4,060**	**$219,897**
Net present value (at 5% discount rate)	**-$667,019**															
Internal rate of return (IRR)	**-11%**															

Appendix 3: Discounted cash flow analysis for a 4 ha chestnut orchard

Fifteen-year discounted cashflow analysis for a 4 ha chestnut orchard investment with on-site freeze dried flour processing

Chestnut harvesting and processing infrastructure cashflow analysis: 100% grower investment

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total Revenue $																
Flour income		$0	$0	$0	$0	$71,808	$71,808	$71,808	$71,808	$71,808	$71,808	$64,627	$58,164	$52,348	$47,113	$42,402
Total Revenue:	**0**	**$0**	**$0**	**$0**	**$0**	**$71,808**	**$71,808**	**$71,808**	**$71,808**	**$71,808**	**$71,808**	**$64,627**	**$58,164**	**$52,348**	**$47,113**	**$42,402**
Expenditure $																
Farm system expenses																
Capital: Trees	$17,920															
Capital: Tractor	$35,000															
Capital costs for processing																
Farm expenses	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Capital: Vacuum harvestor					$30,000											-$6,484
Capital: Grading machine					$8,000											-$1,729
Capital: Shelling machines					$20,000											-$4,323
Capital: Freeze dryer					$950,000											-$205,322
Capital: Milling machine					$10,000											-$2,161
Capital: Vacuum packer					$2,000											-$432
Harvesting, processing and packing costs		$0	$0	$0	$0	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930
Total Expenditure:	**$54,920**	**$2,000**	**$2,000**	**$2,000**	**$1,022,000**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**-$179,521**
Annual Cashflow:	**-$54,920**	**-$2,000**	**-$2,000**	**-$2,000**	**-$1,022,000**	**$30,878**	**$30,878**	**$30,878**	**$30,878**	**$30,878**	**$30,878**	**$23,697**	**$17,234**	**$11,418**	**$6,183**	**$221,923**
Net present value (at 5% discount rate)	**-$632,850**															
Internal rate of return (IRR)	**-10%**															

Appendix 4: Discounted cash flow analysis for a 4 chestnut orchard with eligible carbon income ($75/NZU)

Fifteen-year discounted cashflow analysis for a 4 ha chestnut orchard investment with on-site freeze dried flour processing and eligible carbon income at $75/NZU

Chestnut harvesting and processing infrastructure cashflow analysis: 100% grower investment																
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Total Revenue $																
Flour income		$0	$0	$0	$0	$71,808	$71,808	$71,808	$71,808	$71,808	$71,808	$64,627	$58,164	$52,348	$47,113	$42,402
Carbon income						$2,033	$2,808	$2,808	$2,808	$2,808	$2,808	$2,808	$2,808	$2,808	$2,808	$2,808
Total Revenue:	**0**	**$0**	**$0**	**$0**	**$0**	**$73,841**	**$74,616**	**$74,616**	**$74,616**	**$74,616**	**$74,616**	**$67,436**	**$60,973**	**$55,156**	**$49,922**	**$45,210**
Expenditure $																
Farm system expenses																
Capital: Trees	$17,920															
Capital: Tractor	$35,000															
Capital costs for processing																
Farm expenses	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Capital: Vacuum harvestor					$30,000											-$6,484
Capital: Grading machine					$8,000											-$1,729
Capital: Shelling machines					$20,000											-$4,323
Capital: Freeze dryer					$950,000											-$205,322
Capital: Milling machine					$10,000											-$2,161
Capital: Vacuum packer					$2,000											-$432
Harvesting, processing and packing costs		$0	$0	$0	$0	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930
Total Expenditure:	**$54,920**	**$2,000**	**$2,000**	**$2,000**	**$1,022,000**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**-$179,521**
Annual Cashflow:	**-$54,920**	**-$2,000**	**-$2,000**	**-$2,000**	**-$1,022,000**	**$32,911**	**$33,686**	**$33,686**	**$33,686**	**$33,686**	**$33,686**	**$26,506**	**$20,043**	**$14,226**	**$8,992**	**$224,731**
Net present value (at 5% discount rate)	**-$614,265**															
Internal rate of return (IRR)	**-9%**															

Appendix 5: Discounted cash flow analysis for a 4 ha chestnut orchard with eligible carbon income ($150/NZU)

Fifteen-year discounted cashflow analysis for a 4 ha chestnut orchard investment with on-site freeze dried flour processing and eligible carbon income at $150/NZU

Chestnut harvesting and processing infrastructure cashflow analysis: 100% grower investment

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total Revenue $																
Flour income		$0	$0	$0	$0	$71,808	$71,808	$71,808	$71,808	$71,808	$71,808	$64,627	$58,164	$52,348	$47,113	$42,402
Carbon income						$4,066	$5,617	$5,617	$5,617	$5,617	$5,617	$5,617	$5,617	$5,617	$5,617	$5,617
Total Revenue:	**0**	**$0**	**$0**	**$0**	**$0**	**$75,874**	**$77,425**	**$77,425**	**$77,425**	**$77,425**	**$77,425**	**$70,244**	**$63,781**	**$57,965**	**$52,730**	**$48,019**
Expenditure $																
Farm system expenses																
Capital: Trees	$17,920															
Capital: Tractor	$35,000															
Capital costs for processing																
Farm expenses	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000	$2,000
Capital: Vacuum harvestor					$30,000											-$6,484
Capital: Grading machine					$8,000											-$1,729
Capital: Shelling machines					$20,000											-$4,323
Capital: Freeze dryer					$950,000											-$205,322
Capital: Milling machine					$10,000											-$2,161
Capital: Vacuum packer					$2,000											-$432
Harvesting, processing and packing costs		$0	$0	$0	$0	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930	$38,930
Total Expenditure:	**$54,920**	**$2,000**	**$2,000**	**$2,000**	**$1,022,000**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**$40,930**	**-$179,521**
Annual Cashflow:	**-$54,920**	**-$2,000**	**-$2,000**	**-$2,000**	**-$1,022,000**	**$34,944**	**$36,495**	**$36,495**	**$36,495**	**$36,495**	**$36,495**	**$29,314**	**$22,851**	**$17,035**	**$11,800**	**$227,540**
Net present value (at 5% discount rate)	**-$595,681**															
Internal rate of return (IRR)	**-8%**															