The potential for demucilagers to improve smallholder coffee quality and manage coffee berry borer in Papua New Guinea

Tobias Kumie[1] and Timothy Sharp[2]

ABSTRACT

The coffee industry in Papua New Guinea (PNG) today faces a range of challenges. Coffee production levels have stagnated since the 1990s and coffee quality has declined. One driver of this has been the declining returns to smallholder farmers. The challenges have been exacerbated by the arrival and subsequent spread of coffee berry borer (CBB). Increasing coffee production and improving coffee quality are central goals within the Coffee Industry Corporation's (CIC) *National Coffee Development Roadmap 2020-2030* and there is currently a strong focus on managing CBB. This paper examines the potential of small-scale demucilagers (mini-wet mills) managed by smallholder groups to improve coffee quality and to support smallholder management of CBB in PNG. Demucilagers are a machine used to process coffee cherry which produces clean washed parchment ready for sun drying without the need for fermentation. This paper reports the findings of a study which assessed whether coffee processed by demucilagers can achieve premium and specialty grade ratings, and therefore attract higher prices. Fermentation done well enhances the flavour profile of coffee, however, in the hands of smallholders it is frequently done poorly which adversely affects coffee quality. In this paper we show that demucilagers can achieve very good cupping results. Helping smallholders to achieve quality and consistency are critical to enabling them to access better markets and receive higher prices. Full and regular harvesting are critical to managing CBB. Demucilagers reduce the labour required for processing and improved quality can attain better prices for smallholders, and therefore encourage full and regular harvesting. We argue that this technology can help manage CBB and support the economic viability of coffee production in CBB-affected environments.

KEYWORDS: mini wet mills; demucilagers; coffee processing; smallholders

INTRODUCTION

The coffee industry in Papua New Guinea (PNG) today faces a range of challenges. Coffee production levels have stagnated since the 1990s and coffee quality has declined. One driver of this has been the declining returns to smallholder farmers. The challenges have been exacerbated by the arrival and subsequent spread of coffee berry borer (CBB) (*Hypothenemus hampei*). Increasing coffee production and improving coffee quality are central goals within the Coffee Industry Corporation's (CIC) *National Coffee Development Roadmap 2020-2030* and there is currently a strong focus on managing CBB.

[1] Coffee Industry Corporation, Aiyura, PNG. Email: tkumie@cic.org.pg
[2] Curtin University, Perth, Western Australia. Email: timothy.sharp@curtin.edu.au

This paper assesses the potential of demucilager technology for improving smallholder coffee parchment quality and productivity amongst coffee growers in the PNG highlands. Because of low parchment quality and inconsistent standards, smallholder coffee growers are paid relatively low prices for their parchment. The poor quality of smallholder parchment is an outcome of several factors, including poor processing, particularly poor fermentation. This has been a long-term concern for the industry, especially because the smallholder sector accounts for the great bulk of national production. If the processing of cherry to parchment is performed poorly, the payoffs from any investments in coffee husbandry will not be fully realised.

Demucilagers can assist smallholders to maintain the quality of their coffee because the process eliminates the fermentation stage. Fermentation is done to remove the mucilage on the coffee bean and if done well enhances the flavour profile of coffee, however, fermentation is the processing stage where smallholders have the most difficulty maintaining quality.

This research compared the cup quality of Arabica coffee using demucilager technology with the most common village method of processing cherry. Coffee was cup tested by internationally recognised 'cuppers'.

Helping smallholders to achieve quality and consistency assists them to access better markets and receive higher prices. Full and regular harvesting are critical to managing CBB. Because demucilager-processed coffee can command better prices through improved bean quality, and therefore encourage full and regular harvesting, we argue the technology can contribute to managing CBB and maintaining the economic viability of coffee in a CBB environment.

This paper first examines some of the challenges facing smallholder coffee farmers and the coffee industry in PNG. It then provides an overview of the demucilager technology and its introduction to PNG. The paper then reports on a CIC trial examining different coffee processing practices and their impact on cup quality. The paper lastly discusses the potential for demucilagers to support smallholder coffee production in the CBB environment.

Challenges facing smallholder coffee farmers in PNG

Smallholder growers produce around 85% of PNG's coffee (CIC 2020). Production levels, however, have stagnated, and perhaps even marginally declined, since the 1990s. The quality of coffee exported has also declined with premium grade coffee making up a smaller proportion of exports today than in the past (Sengere et al. 2019). The real income derived from coffee has also steadily declined since the drop in the value of the kina in the late 1990s, and due to low global coffee prices, though there have been recent periods of reasonable prices. At the same time, rural populations of the coffee growing areas have increased, meaning per capita returns on coffee are also lower. Smallholder farmers in PNG are highly responsive to price and returns to labour (Bourke 2022; Allen et al. 2009: 411-14). A range of other factors have impacted smallholder production such as poor market access, rundown infrastructure, low price incentives, and a decline in extension services. Declines in the quality of coffee, mean growers also get lower prices for their coffee, and the returns to labour are low. This in turn leads farmers to reduce their labour invested in coffee, leading to further declines in productivity and quality. Reduced investment of labour in coffee is particularly acute in accessible areas near town where smallholders have other income earning opportunities, notably the domestic fresh food trade, which competes for labour.

In recent years, the challenges facing smallholder farmers have been further exacerbated by the spread of a very serious coffee pest, coffee berry borer (CBB). CBB was first detected in PNG in 2017. Since then, it has spread widely, and now represents a major threat to the industry, particularly to smallholder production. Smallholders in PNG commonly invest little labour into coffee block management, with inadequate levels of pruning, weeding, shade management and pest and disease management (Aranka et al. 2021). Under such poorly managed conditions, CBB

infestation can build over time and up to 95% of cherries can be infested (Oliva et al. 2023; Newton et al. 2023). The pest then has the potential to significantly reduce production levels and to reduce quality. To manage CBB also requires increased labour and capital investment. When cocoa smallholders in PNG were faced with a similarly devastating pest outbreak, most farmers were unable or unwilling to shift to high input production practices (Curry et al. 2015). The need to increase labour to manage CBB will also further reduce the returns on labour to coffee. When global coffee prices are high, as they were from mid-2021 until mid-2023, the returns to labour were adequate to retain smallholder interest in coffee. However, if there are prolonged periods of low prices smallholder interest will likely decline further.

The key challenge for the coffee industry in PNG is to reverse the present trends of declining returns to labour, and to do so in a CBB environment. Two main ways to improve the returns to labour for smallholder farming families are to improve the prices they receive, and to reduce their labour input to produce and process a unit of coffee. While growers are not able to influence world coffee prices, they can improve the prices they receive by selling into premium and specialty markets. To do so, smallholders must improve the quality of the coffee they sell. Improved post-harvest processing has a greater impact on quality than any other strategy available to smallholders. And without improved processing, any other efforts to improve prices are likely to be fruitless. A beautiful red cherry plucked from the tree, with the potential to become a high value coffee, with poor post-harvest processing can within the space of a week become an ordinary low-value mass-commodity coffee. Establishing strong grower-exporter partnerships are also critical to securing improved prices.

A second means to improve the returns on labour is to improve labour efficiency and reduce the labour input per unit of coffee. The demucilager technology provides both a means to improve prices as well as to reduce labour input per unit of coffee. This paper is primarily focussed on the role of demucilagers in improving coffee quality and price. The influence of demucilagers on labour savings and market performance was explored under the ACIAR-funded project ASEM/2016/100 *Improving livelihoods of smallholder coffee communities in Papua New Guinea*[3], and the findings from this research will be reported in a future paper. Lastly, by improving the returns to labour, demucilagers have the potential to stimulate greater labour investment in coffee in ways that assist the management of CBB, notably through increased harvesting rates which are critical to breaking the pest's lifecycle and reducing infestation rates.

The demucilager technology

Demucilagers, also referred to as 'mini wet mills' and 'ecopulpers', are machines used for coffee cherry processing (Plate 1). These machines pulp the cherry and remove foreign elements, however unlike a standard pulper the machine also removes the mucilage. The mucilage is the slippery pectin-rich layer (the grease) that remains around the bean following pulping. In PNG, the mucilage is conventionally removed through fermentation. In plantations with centralised processing this occurs in large water-filled tanks, whereas in the smallholder setting pulped parchment is fermented inside bags (either hessian or woven plastic). The fermented beans are then thoroughly washed to stop fermentation and then dried. In contrast, demucilagers remove the mucilage mechanically[4], and therefore eliminate the fermentation step. This is significant as the fermentation and subsequent washing are often performed poorly under smallholder conditions, having an adverse impact on cup quality and therefore price.

[3] The project explored how to increase returns to labour, particularly for women, through the adoption of new technologies and farming practices that improve coffee quality and total production while being compliant with the environmental criteria of the main certification organisations.

[4] The mucilage is stripped off the beans through the friction of beans rubbing against one another as they are forced upwards within a perforated cylinder.

There are various demucilagers on the market. This study used a Penagos UCBE-500 demucilager with integrated pulper which processes up to 500 kg of cherry per hour. The demucilaging component has rotary arms attached to a vertical shaft which removes mucilage through a rotational motion. Wet parchment with mucilage enters vertically and discharges without mucilage at the top chute. The clean wet parchment is then ready to be moved to drying beds.

Plate 1: Demucilager (Penagos Hermanos UCBE-500)

There are other advantages to the technology: 1) Water consumption is low (0.2 litres/Kg of cherry) compared to typical wet processing, and labour is reduced as less water needs to be carried to the processing site; 2) Waste discharge is minimal, and this reduces contamination of waterways; 3) There is minimal bean damage or loss; 4) The machine is reasonably portable; 5) Drying time is reduced by almost half compared to conventional wet-mill processing[5], which can increase throughput, and reduce labour; 6) Establishment costs are low compared to the conventional wet-mill facilities; and 7) Running costs are low relative to the premium received.[6]

Demucilagers in PNG

Demucilagers are used reasonably widely in other coffee producing countries, however, to date, there has been limited adoption in PNG. Demucilagers were initially trialled in PNG under ACIAR-funded project ASEM/2004/017, which finished in 2010, to help control coffee quality and reduce water consumption and waste production (Driscoll et al. 2010), however, there were problems with initial uptake, and little subsequent adoption of the technology. In recent years, a small number of demucilagers, and associated infrastructure, have been established with coffee groups in PNG. Four demucilagers were established with funding from Fairtrade ANZ in 2015, including with the Komkul group near Banz (Jiwaka), the Untpina Group in Nebilyer (Western Highlands); the Neknasi Group in Erap LLG (Morobe), and with the Unen Choit Group in Siassi LLG (Morobe). A fifth demucilager was established at the CIC Coffee Research Institute Research Station at Aiyura. Demucilagers have also been set up at Yonki (EHP) and Tolu near Banz (Jiwaka) in 2017 and, under the ACIAR-funded project ASEM/2016/100, in Bena (EHP) in 2019.

[5] Trials by Kumie at Aiyura found that the drying time for a fermented washed coffee to reach 11% moisture was 11 days, whereas the demucilager coffee reached the same moisture level within 7 days. The demucilager also reduced processing time by removal of the 1-2 days fermentation stage.

[6] Trials by Kumie calculated the running costs for a UCBE-500 to be K27 per tonne of cherry.

Impact of demucilagers on cup quality

The main objective for trialling the demucilager technology was to address the inconsistency in coffee quality produced by the smallholder growers to attain a product of uniform quality that is consistent over time. As part of assessing the viability of demucilager technology in PNG, Kumie with CIC colleagues undertook a research trial to evaluate the impact of different wet processing methods, including the demucilager technology, on the organoleptic attributes of Arabica coffee (those affecting smell and taste). In total, the trial assessed 12 treatment methods, including methods using enzymes, however this paper only reports the findings of 2 treatments that are considered most relevant to the PNG smallholder context. The overall trial undertook the treatments at five trial sites and included three replications over the harvest season, however, budget constraints and NAQIA export volume restrictions meant that only treatments of a single replication and from three trial sites were sent overseas for cupping.

Smallholders in PNG for a range of reasons, including labour availability, do not fully follow the recommended 'traditional' wet processing method (Treatment A in this trial). Smallholder processed coffee is often over fermented or unevenly fermented and inadequately washed (Curry et al. 2017), so more complex processing methods are unlikely to be successfully adopted.

METHODS

Treatments and processing to green bean

Two primary processing treatments were considered most relevant to the PNG smallholder context and were carried out using 10 kg of ripe red cherry of Typica variety. The treatments came from three trial sites – Unen Choit and Neknasi (Morobe), and Aiyura (EHP). The two treatments were:

A	Hand Pulper → Fermentation → Washing → Sun Dry
F	Demucilager →Sun Dry

Treatment A: Hand Pulper → Fermentation (36 hrs) → Washing → Sun Dry

This treatment is the most conventional method of coffee processing by smallholder farmers in PNG and for this study was closely controlled. It involved using a hand pulper to pulp the cherry using 0.4-0.6 L of water per kg. The pulped beans of known weight were stored in white plastic polybags and fermented raised off the ground for 36 hours. The fermented beans were then washed with water of the same quality as that for pulping and then dispatched to a raised bed for sun drying. Using a bag ferment, rather than tank ferment, more closely approximates smallholder processing.

Treatment F: Demucilager → Sun Dry

In this treatment, the cherry was processed in a demucilager with an integrated vertical pulper (Plate 2), using 0.2 L of water per kg. The wet parchment containing no mucilage were exited through the demucilager outlet and then dispatched straight to the raised bed for sun drying (Plate 3). The running time for the operation was recorded as well as the labour requirements, fuel and water consumption and the efficiency of pulping.

Plate 2: Farm trial using a demucilager

Plate 3: Sun drying of demucilager coffee

Following the application of the treatments by Kumie and smallholder farmers on site, all treatments were sun dried until the parchment reached a moisture content of 11%. This took a minimum of 7 days for the demucilager coffee and 11 days for the fermented beans. The dried parchment was hulled and polished, and the polished green beans were then graded using hand sieves and a physical assessment. The physical assessment involved the observation (colour, shape and size) of 2 kg of green bean from each treatment. Defect counts were made by inspecting nipped, under-washed, cracked, over-fermented, and foreign elements.

Cupping methods

Green bean samples from the different treatments were sent for independent testing. The cup quality assessment was carried out by a panel of Q-Graders at Bolhaven farms of Hong Kong.[7] Liquoring and scoring followed the Specialty Coffee Association of America (SCAA) format. The following describes the application of the SCAA cupping format by CIC Q-Graders (Figure 1).

Within the cupping room, the beans were roasted according to their grades to achieve uniform medium roast (7 minutes on average) using a roasting machine (Probat BRZ6, Germany) with a cylinder heat of 150-200°C. After cooling for about ten minutes, the samples were blown to remove the loose silver skins. The roasted beans were ground to medium, and 8 g was placed in each cup, each 180 ml and consistent in shape. Cups of the different coffees to be graded were arranged randomly. Boiled water was poured into each cup to half volume, and thereafter the volatile aromatic quality and intensity parameters were recorded by sniffing. Then, the cups were filled with boiled water to the brim and left to cool for 3 minutes to around 60°C (palatable temperature). The foam from each cup was then skimmed off with a spoon and discarded. The testers then tasted the coffees and noted the sensorial quality attributes. Aroma (aromatic quality and intensity), flavour, acidity, aftertaste, body, balance, uniformity, clean cup, and sweetness were scored from 0 to 10. There was also an overall standard for liquor quality that ranged from 0 to 10.

The quality assessment was made using the globally accepted cupping template from the SCAA. Under the SCAA format, to be considered a Q Certified Coffee, the coffee must meet certain minimum requirements (Table 1). Two Q Grade classifications are recognised: *specialty* and *premium*.

[7] Samples of some treatments were also sent for testing to Coffee Plant of South Korea. CIC also did an internal cupping assessment of the treatment. These results are not presented here.

Table 1: Q Grade cupping score and defect specifications

	Q GRADE/SPECIALTY	Q GRADE/PREMIUM	BELOW Q GRADE
CUP	85+	80 - 84.99	< 80
GREEN	0 Primary defects and ≤ 5 secondary defects	≤ 8 defects, inc. primary and secondary defects	> 8 defects, inc. primary and secondary defects
ROASTED	0 Quakers*	≤ 3 Quakers	> 3 Quakers

Source: Specialty Coffee Association of America

*A quaker is an undeveloped or immature bean that remains pale or light-coloured even after roasting

Physical assessment and defects count

Roasting of samples

Weighing roasted samples before grinding

Weighing water before mixing with ground coffee

Internal quality cupping by CIC coffee tasters

Figure 1: CIC Q-Graders applying SCAA cupping format.

CUPPING RESULTS AND DISCUSSION

The below cupping results were provided by the panel of Q-Graders from Bolhaven farms. Table 2 shows the average total scores for each of the graders for each treatment for the three sites. It also reports the combined average for each treatment.

Table 2: Mean cupping scores for Treatments A and F by Q-Graders at Bolhaven Farms

		Cupper 1	Cupper 2	Cupper 3	Average	Combined treatment average
Treatment A (fermentation)	Neknasi	81.3	81.5		81.4	81.6
	Unen choit	82.5	82.5		82.5	
	Aiyura	80	82	80.3	80.8	
Treatment F (demucilager)	Neknasi	80.8	82.3	81.8	81.6	82.0
	Unen choit	82.5	82.3		82.4	
	Aiyura	80.8	81.8	83	81.9	

Both the conventional fermentation treatment and the demucilager treatment received similar and high cupping scores, and both attained the Q Grade premium standard.[8] This demonstrates that demucilagers can produce very good coffees, coffees on par with conventional washed coffees which have had fermentation and washing closely controlled. This shows that demucilagers do not have a negative effect on the organoleptic attributes of coffee, a finding consistent with those from a previous ACIAR funded project (Driscoll et al. 2010:21).

Fermentation contributes to the flavour profile of coffee, so there was concern the elimination of the fermentation step may reduce cup quality. This may be true of plantation coffee where fermentation best-practice can be strictly adhered to, but for smallholders, we found that fermentation is more likely to be done poorly and therefore adversely affect cup quality.

There is potential for higher scores to be achieved if all the processing stages are strictly scrutinised, especially the method of drying and bean conditioning to achieve uniformity in moisture content prior to hulling and polishing, however, these are not realistically achievable for most smallholders. Slightly higher scores were achieved by two treatments using enzymes. These treatments were more complex and are not considered suitable for smallholders.

Higher quality coffee produced using more complex processing techniques may attain a higher price, however it is important that any introduced practices also improve the returns to labour for smallholder growers. Smallholder farmers in PNG are sensitive to returns to labour (Allen et al. 2009:5.20; Curry et al. 2015; Overfield 1998), so if new practices require substantial labour inputs which are not sufficiently compensated for by higher prices, then it is unlikely that PNG smallholders will adopt the practice. PNG smallholders, in coffee and other cash crops, commonly adopt a low input farming approach (see Curry et al. 2015; Curry et al. 2017), so technologies that are compatible with a low input system are most likely to be adopted.

The potential for demucilagers to support smallholder coffee production in a CBB environment

There is potential for demucilagers to play an important role in the future of the PNG coffee industry, particularly if they provide a solution to how to live with CBB. As noted earlier, smallholders in PNG are highly sensitive to returns to labour and readily shift their attention between different activities based on their assessment of the relative returns (Curry et al. 2021). In the rural highlands close to urban centres, many households have shifted their focus from

[8] All but one of the other ten treatments sent for analysis also attained the Q Grade Premium standard, and this reflects the close supervision of the different treatments.

coffee to the domestic fresh food market which has expanded considerably since the early 2000s (Sharp et al. 2022). Through the same period, for more remote coffee farmers, low coffee prices and increasing transport costs have undermined the viability of coffee. Smallholders also highly value the social and cultural activities within their lives, and these are generally prioritised over cash-earning activities, particularly when returns are low (Koczberski et al. 2021). Improving the returns to labour for smallholder farmers is essential to addressing the stagnation of coffee production in the country. One way for coffee farmers to improve the returns to labour is through entering the speciality coffee market. This can be hard for smallholder farmers due to the difficulty in controlling the fermentation process. Demucilagers, by eliminating the fermentation stage and by reducing drying time, make it easier for smallholders to control the quality of their coffee. Demucilagers, by centralising processing, can also assist to standardise quality. PNG's exporters want to partner with groups that can produce consistently high-quality coffee, and such partnerships provide the basis for entering the specialty market and to securing price premiums for smallholders. This study has demonstrated that coffee processed using demucilager technology can achieve premium scores by Q-Graders. The role of demucilagers in reducing the work involved in coffee production, further improving returns to labour, was studied under ASEM/2016/100 (Curry et al. 2021). Improving the returns to labour can also assist to tackle another major challenge facing the coffee industry: coffee berry borer.

CBB represents a serious threat to the PNG coffee industry. Coffee smallholders in PNG frequently adopt a 'foraging' approach to their coffee (see Curry et al. 2015 in relation to cocoa farmers), an approach that frequently leads to under-harvesting. Under-harvesting is particularly problematic in a CBB environment because unharvested cherry harbour CBB which then reinfest the coffee garden. Full and regular harvesting is critical to CBB management because it can break the CBB lifecycle and reduce reinfestation rates (Newton et al. 2023). Demucilagers have the potential to improve harvesting rates by providing a strong price incentive to farmers. Harvesting rates may also increase due to reduced labour time in processing. Findings of ASEM/2016/100 indicate that demucilagers can substantially reduce labour time associated with pulping, fermentation, washing and drying. Labour availability is a key constraint upon coffee farmers during the coffee season (Curry et al. 2017), and so by freeing up labour time, demucilagers may enable farmers to increase their harvesting effort. Cultural management of CBB also works best when it is adopted as an area wide approach, otherwise unmanaged coffee gardens can lead to reinfestation of neighbouring managed gardens. Because demucilagers are likely to be run by groups due to the establishment costs being beyond the capacity of most smallholders, demucilagers can assist to establish area wide management. These groups may also serve as effective channels for agricultural extension officers to deliver pest management training—specifically for CBB. This includes promoting end-of-season strip harvesting alongside the already emphasised practices of consistent harvesting and coordinated area-wide management (Newton et al. 2023)

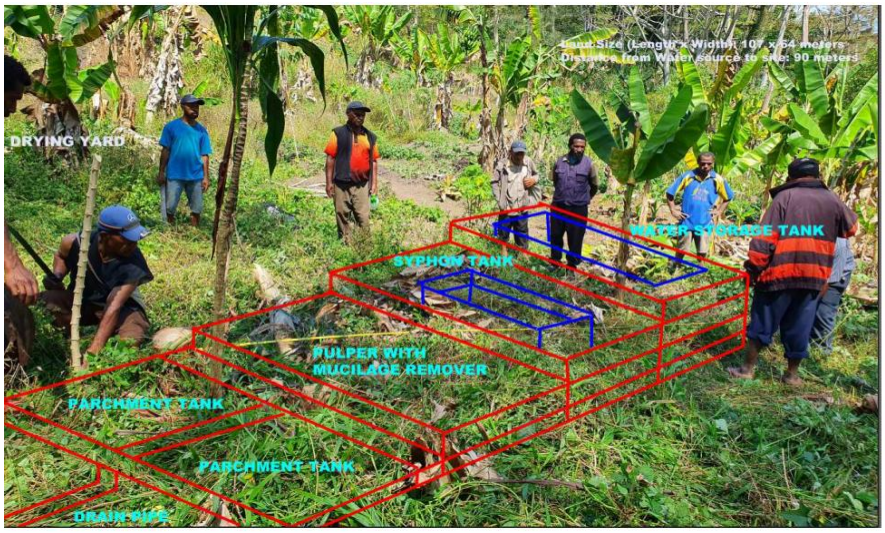

Plate 4: Site sketch for the establishment of a demucilager in a CBB environment.

Centralised processing (Plate 4) also provides an opportunity to incorporate quality control measures that assist farmers to remove poor quality and some CBB infested beans prior to demucilager processing. Floating of cherry in water, and the removal of any floating cherries prior to the cherry being fed into the demucilager, provides a first stage of quality control. The demucilager (and combined pulper) itself also removes CBB-infested cherry. A second float of the mucilage free parchment can also assist to remove any remaining CBB damaged beans. CBB also frequently affects only one of the two beans in each cherry (Aristizábal et al. 2016). One CBB infested bean may cause the cherry to float in the first float, resulting in the other good bean being discarded. If the floating cherries from the first float are processed through the demucilager as a separate batch, good beans remaining within the floaters can be recovered, and recombined with the other quality parchment (Figure 2).

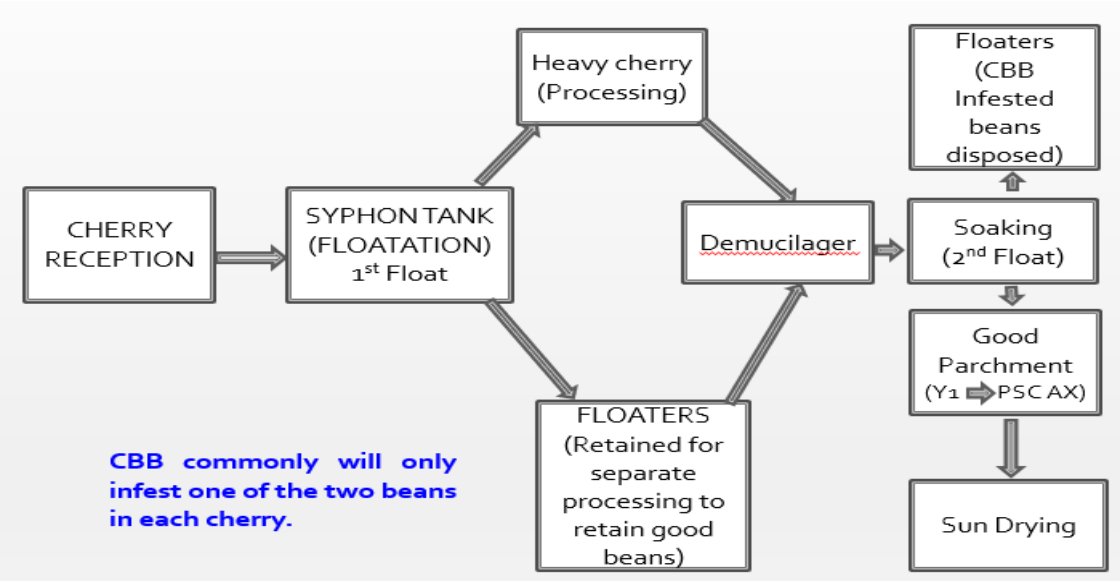

Figure 2: Model for quality management of CBB-infested cherry through a demucilager.

CONCLUSION

PNG's coffee industry faces a range of challenges. One key challenge is how to improve the returns to labour for smallholder coffee farmers, and to do so in the context of increasing impacts from CBB. This paper has highlighted the potential for demucilager coffee processing technology

to help address this challenge. The paper has shown that demucilagers do not adversely affect the organoleptic attributes of coffee and are capable of producing coffees with cup quality in the premium grade. These coffees have the potential to attain price premiums over a traditionally fermented smallholder coffee. Under smallholder conditions, fermentation is often performed poorly leading to poor and inconsistent coffee quality. By removing the fermentation stage, demucilagers provide a means for smallholders to achieve quality and consistency. Demucilagers also have the potential to assist CBB management. The best approach to managing CBB in the smallholder context is to harvest fully, to harvest regularly, to strip pick at the end of season to break the insect's life cycle and for this management to be carried out across an area (area wide management). The promise of demucilagers is to assist to provide the incentives and means to achieve these management practices.

Demucilagers have some other advantages in the PNG context. Demucilagers are relatively affordable for group enterprises, with a full demucilager setup costing less than a vehicle – the most common investment for group enterprises in PNG. Although demucilagers cannot really be considered portable, they are small enough that they can be moved if they need to be relocated for operating purposes or in response to inter-group conflict.

While demucilagers have potential, there are numerous challenges that need to be overcome. The expense of demucilagers makes them suited to groups, and this means that demucilagers come with all the familiar challenges of group organisation and governance in PNG. That said, demucilagers are not so expensive that the group size needs to be large, and the machines come in a range of scales to suit group size. There is also an inherent risk to adopting a more technological approach. Although the technology is not overly complex, because the technology is relatively new to PNG, finding experienced mechanics and sourcing parts in the event of breakdown is likely to prove a challenge in the early adoption period.

REFERENCES

Allen, M., Bourke, R.M. and McGregor, A. (2009). Cash income from agriculture. In Bourke, R.M. and Harwood, T. (eds.), Food and agriculture in Papua New Guinea (pp. 283–424). Canberra: ANU Press.

Aranka, J., Apis, B., Asiota, B., Bafeo, M., Bekio, J., Curry, G.N., Hamago, M., Inu, S.M., Kiup, E., Koczberski, G., Togonave, P. and Webb, M. (2021). Smallholder farmers' knowledge of coffee pests and diseases in Eastern Highlands Province, Papua New Guinea. PNG Coffee Journal 15(1): 23–29.

Aristizábal, L.F., Bustillo, A.E. and Arthurs, S.P. (2016). Integrated pest management of coffee berry borer: Strategies from Latin America that could be useful for coffee farmers in Hawaii. Insects, 7(1): 6.

Bourke, R.M. (2022). Returns on labour inputs to smallholder cash crops in Papua New Guinea. Development Policy Centre Policy Brief No. 23. Development Policy Centre, Canberra.

Coffee Industry Corporation (2020). National coffee development roadmap. Goroka: Coffee Industry Corporation.

Curry, G.N., Koczberski, G., Inu, S.M., Hamago, M., Kiup, E., Aranka, J., Bekio, J., Apis, B. and Togonave, P. (2021). Socio-economic constraints on smallholder coffee production in the Papua New Guinea highlands: The case of labour. PNG Coffee Journal, 15(1): 14–22.

Curry, G.N., Webb, M., Koczberski, G., Pakatul, J., Inu, S.M., Kiup, E., Hamago, M., Aroga, L., Kenny, M., Kukhang, T., Tilden, G. and Ryan, S. (2017). Improving livelihoods of smallholder families through increased productivity of coffee-based farming systems in

the Highlands of PNG. Project Final Report. Canberra: ACIAR. Available at: https://www.aciar.gov.au/sites/default/files/project-page-docs/final_report_asem.2008.036_a.pdf

Curry, G.N., Koczberski, G., Lummani, J., Nailina, R., Peter, E., McNally, G. and Kuaimba, O. (2015). A bridge too far? Socio-cultural constraints on the adaptation responses of smallholders to a devastating pest outbreak in cocoa. Global Environmental Change, 35: 1–11.

Driscoll, R., Srzednicki, G., Shaw, W. and Maika, N. (2010). Assessment and improvement of quality management during postharvest processing and storage of coffee in Papua New Guinea. Project Final Report ASEM/2004/017. Canberra: ACIAR.

Koczberski, G., Inu, S.M., Curry, G.N., Bekio, J. and Hamago, H. (2021). Coffee smallholder households and livelihood diversity. PNG Coffee Journal, 15(1): 3–13.

Newton, I., Chambers, D., Aranka, J., Tilden, G., Curry, G. and Hughes, M. (2023). Unit 2 Module 6: Coffee berry borer management. In Curry, G., Tilden, G. and Aroga, L. (eds.), Smallholder coffee production in Papua New Guinea: A training package for extension officers and farmers. ACIAR Monograph No. 220. Canberra: Australian Centre for International Agricultural Research.

Oliva, M., Rubio, K.B., Chinguel, D., Carranza, J., Bobadilla, L.G. and Leiva, S. (2023). Coffee berry borer infestation and population per fruit relationship with coffee variety, shade level, and altitude on specialty coffee farms in Peru. International Journal of Agronomy, 2023: 6782173.

Overfield, D. (1998). An investigation of the household economy: Coffee production and gender relations in Papua New Guinea. Journal of Development Studies, 34(5): 52–70.

Sengere, R.W., Curry, G.N. and Koczberski, G. (2019). Forging alliances: Coffee grower and chain leader partnerships to improve productivity and coffee quality. Asia Pacific Viewpoint. https://doi.org/10.1111/apv.12222

Sharp, T.L.M., Busse, M. and Bourke, R.M. (2022). Market update: Sixty years of change in Papua New Guinea's fresh food marketplaces. Asia & the Pacific Policy Studies, 9(3): 483–515.