Scaling up to farm-sized production of papaya ground seeds (PGS) as a novel biofumigant for sustainable management of soil-borne plant pathogens – a white paper

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Introduction

Soil-borne diseases caused by fungi and nematodes bring about serious damage to many crops of agricultural importance. Conventional soil fumigation for controlling soil-borne plant diseases is most commonly based on synthetic chemicals many of which cause serious negative environmental impact and have been phased out. Biofumigation is an eco-friendly alternative for suppressing soil-borne pests and pathogens. Conventional biofumigation uses macerated green manures from glucosinolate-rich biofumigant plants, such as brown mustard, as soil amendments. This practice suffers from shortcomings that include costs and time associated with cultivating the biofumigant crop. Furthermore, cruciferous cover crops are often hosting common pests of leafy greens, and cover crop rotation is impractical for long-term orchard crops.

Recently, through the funding support of USDA Western SARE program, we developed a novel approach aimed at improving and simplifying the biofumigation practice, by using a new organic biofumigant that is based on papaya seed wastes to achieve instant and more precise biofumigation without the need for growing biofumigant cover crops. Papaya seeds contain a high level of benzyl glucosinolate that is enzymatically hydrolyzed via myrosinase to form benzyl isothiocyanate (BITC), which has potent pesticide activities against a range of soil-borne phytopathogenic nematodes, insect pests, and fungi.

Papaya is a major fruit commodity in Hawaii. In 2022, over 13 million lbs of papaya were produced (USDA/NASS 2022 State Agriculture Overview for Hawaii). A significant quantity of culled/unmarketable papaya fruits and papaya processing wastes are generated in Hawaii. In 2014, the cull rate was estimated at 35-50% of total production (USDA-NASS 2014; Heller et al., 2015), though this rate fluctuates over time, and in 2022, due in part to the COVID pandemics, the culled rate was reported to be about 16% (USDA-NASS 2022). About 15% of the fruit wet weight consists of seeds (Han et al., 2018), while the average seeds have about 8-12% moisture content. Based on these data, there are an estimated 281-878 thousand lbs of dry papaya seeds that may be produced from 2.1-6.5 million lbs of culled papaya fruits per year. This abundant seed waste represents a rich source of natural products that could be developed into potent soil biofumigants. By assuming 7 ft spacing between plants in rows 11 ft apart, and 1′×1′×0.5′ planting holes with 0.5% soil biofumigant amendment rate, about 115 lb of papaya ground seeds (PGS) derived from 848 lb of cull papaya is needed to treat one acre per PGS application, and hence the amount of seed waste is estimated to be sufficient for treating about 332-1,034 acres of crop fields. In 2022, the harvested acres of papaya fruits were estimated at 700 acres (USDA/NASS 2022 State Agriculture Overview for Hawaii). Therefore, with the quantity of PGS that can be produced on papaya farm from culls, PGS may be considered for treating papaya fields, especially since it is a more environmentally friendly alternative to the current chemical soil fumigation practice.

To help the papaya-seed biofumigant technology readily adoptable by the farmers, the goal of this white paper is to provide a technical guide for scaling up to farm-sized production of the papaya ground seeds (PGS) as a novel biofumigant for sustainable management of soil-borne plant pathogens.

PGS-based soil biofumigation offers an alternative way for effective management of certain soil-borne pests, such as *Fusarium* species, using a natural and renewable fumigant made from underutilized, locally sourced, agricultural waste, in a simple and environmentally friendly process. Development of papaya-seed biofumigants will reduce reliance on imported pesticides, while endorsing the concept of "reduce, reuse, and recycle" to promote sustainable agriculture and continuing growth of local farm community.

Technical guide for scaling up to farm-sized production of PGS as a novel biofumigant

Industrial process for papaya puree production is well established and unbroken seeds are generated as a waste byproduct from such manufacturing process. Therefore, production of papaya seeds from cull papaya fruits at an industrial scale is technically feasible. Alternatively, cull papaya fruits can be collected and processed into PGS on farm or at the packing houses for use as a value-added biofumigant product.

Here, we discuss methods and run-of-the-mill fruit processing machines that mimic the unit operations used in industrial puree production, for farm-scale papaya seed separation from cull fruits. Unlike operations in the commercial puree production plants, smaller and less costly processing equipment needs to be considered for processing cull fruits on farm or as an auxiliary operation in papaya packing houses, in order to justify the cost. In order to process a sufficient quantity of seeds, however, manual seed separation becomes impracticable. Thus, we describe the use of simple alternative off-the-shelf fruit processing equipment to achieve semi-mechanized separation of intact seeds from papaya pulp and peels.

With an estimate of about 100 papaya farms in the state of Hawaii, and the aforementioned fruit cull rate, on average 20,800 – 65,000 lb of culled papaya fruits are produced per farm per year. At this scale, one can use small, electric/motorized, apple/fruit crushers with a modest processing capacity (unit shown in Figure 1 can process about 3,307 lbs of papaya per hour, retailed at about $850), along with a fruit press and a sieving system to achieve semi-mechanized fractionation of whole papaya culls into juice pulp, peel, and undamaged seeds at a farm-size. The fruit crusher is traditionally used in wine/cider making. The process is depicted in Figure 2. We first chopped ripe papaya culls using a fruit crusher, followed by extracting (pressing out) the juice from the chopped ripe fruits using a hydraulic fruit press. The remaining seeds and peel pieces were then separated by sieving using a perforated plate

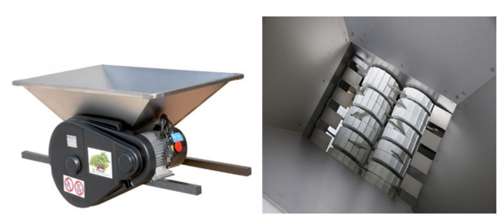

Figure 1. Electric fruit crusher (left); top view of the crusher revealing the roller with crushing blades (right). (image source)

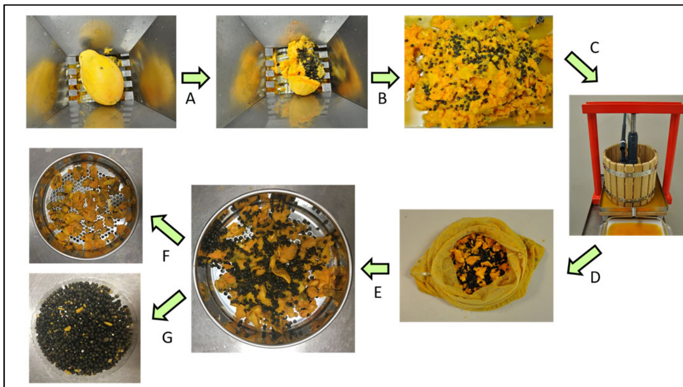

Figure 2. Fractionation of culled papaya fruit waste into puree, peel and unbroken seeds using only simple, low-cost and off-the-shelf craft cider-making equipment. (A,B) Crush culled papaya using a fruit crusher/grinder without damaging the seeds; (C,D) Press the crushed fruit to extract puree/juice using a fruit hydraulic press, and produce a seeds/peels mixture; (E) Fractionate the seed/peel mixture using a perforated plate sieve to generate fractions rich in peel (F) and seeds (G), respectively. The operation is particularly well suited for small producers or fruit packers typically do not own specialized puree processing equipment such as peeling machine and fruit pulper/finisher (Han et al., 2018).

sieve with an aperture size that allowed the seeds to pass through while retaining most of the peel pieces (e.g., Endecotts 200SCF16.0, Verder Scientific Inc., Newtown, PA). The sieving step can be facilitated by using a vibrating sieve shaker (Figure 3). Due to the large gaps between the crushing rollers in the fruit crusher (Figure 1), seeds are not damaged (and hence avoiding untimely release of the BITC biofumigant) while also allowing the whole fruit to be efficiently processed into chunky pulps as another value-added product for making single-cell proteins for animal or aquatic feeds. By eliminating the needs for peeling from initial processing, this simple fractionation method does not require costly and specialized fruit processing machines such as the energy-intensive rotating-drum peeling machine, pulper/finisher, roller mills, and scraping machines used in commercial papaya puree manufacturing (Chan, 1993; Harter & Villar, 1985). Instead, only very simple and low-cost machines are needed to recover undamaged seeds from papaya culls. Subsequent to seed separation from fruit pulps and peels, the seeds need to be dried and milled. The seeds can be dried at 45-50°C in an oven or solar dryer for 48 hours before being ground in an electric grain grinder mill into PGS. The PGS should be stored in a dry state in air-tight containers for long-term storage for over several months.

Figure 3. A vibrating sieve shaker (Image source).

Summary of processing equipment for farm-sized* PGS production

Equipment	Purpose	Example
Electric stainless-steel fruit crusher	To crush culled papaya fruits into pulps, peels, and seeds without damaging the seeds	https://www.juicegrape.com/Crusher-Electric-Stainless/
Fruit hydraulic press	To press out the juice	Amazon.com: Hydraulic Fruit Press GP-12 - Apple Press, Wine, Press, Cider Press, Grape Press : Home & Kitchen
Perforated plate sieve	To separate seeds from pulps and peels	Perforated plate sieves for reliable particle analysis - Endecotts
Vibrating sieve shaker	To facilitate sieving	https://www.amazon.com/Automatic-Machine-Vibrating-Stainless-Screens/dp/B0C61SFP3Y
Solar dryer	To dry the seeds	https://www.etsy.com/listing/1519620926/dry-for-free-mini-solar-dryer-solution?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=solar+dehydrator&ref=sr_gallery-1-1&frs=1&organic_search_click=1
Electric grain grinder	To grind the dried seeds into PGS	https://www.amazon.com/VEVOR-Electric-Commercial-Thickness-Adjustable/dp/B0CRVSC33L/ref=sr_1_5?crid=1IKK0DDSN6V78&keywords=electric+grain+grinder&qid=1708341094&s=home-garden&sprefix=electric+grain+grinder%2Cgarden%2C217&sr=1-5
* average production scale of PGS from about 65,000 lb of culled papaya fruits per farm per year		

Disclaimer

The mention of product and company names should not be construed as a preference for them over other suitable alternatives.

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