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Chapter 8

A PV-BATTERY-POWERED 12V GAS MEMBRANE WITH WOOD DESICCANTS FOR POSTHARVEST HERMETIC GRAIN STORAGE

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ABSTRACT

Around half of agricultural production in sub-Saharan Africa is ‘lost’ or ‘wasted’ due to lack of an available market, poor handling at postharvest (methods and technology), and through poor road access. Effective postharvest processing is critical to ensure small producers best access local markets and in nearby villages. This chapter explores small portable (renewable energy-powered, oil-less) compressors and high-pressure gas membrane technology as technical zero-emission alternatives to selectively purge seed and grain storage systems. The gas membrane uses inert and non-toxic gasses (including nitrogen) which are effective in preventing production loss to pests (fungus, insects, and others) by use of physical and environmental barriers only (i.e., no chemical fumigants) to reduce conducive conditions (especially moisture). Furthermore, the use of simple dry wood desiccants may be also a cost-effective solution for moisture management in sealed seed and grain storage. This chapter demonstrates that while proprietary gas membrane technology is expensive for sub-Saharan African smallholders, commercial arrangements (including generic drug provision at cost) can create a viable tool and foster food security by improved storage for various production conditions under variable climate.

Keywords: Photovoltaic, desiccant, gas membrane, hermetic, grain, sub-Saharan Africa.

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INTRODUCTION:THE NEED FOR POSTHARVEST STORAGE

The 2007-2008 global food price 'spikes' refocused governments' aid support to Africa towards addressing issues of fundamental importance to ensure food security and to improve current agricultural productivity, including the provision of agricultural extension services, transport infrastructure, diversification of crops, conventional improved varieties, develop strategic and efficient markets, and postharvest storage technology (Lynd and Woods, 2011; Ellis, 2012). Postharvest methods and technologies (including transportation options) are fundamental to reduce agricultural production loss and meeting safety standards (Opara, 2011). Reducing postharvest losses and waste represents a major opportunity to invest in modern technology (de Janvry et al., 2000; de Janvry and Sadoulet, 2002; Godfray et al., 2010). As more than half of sub-Saharan Africans live in rural areas and rely on subsistence agriculture (Barrett, 2008; Rosegrant et al., 2009), by incorporating suitable postharvest technologies rural people are given the opportunity to produce a marketable surplus (Opara, 2006; Barrett, 2008). The majority of the sub-Saharan population store their seasonal production until planting in the beginning of the next crop season. As such, postharvest technological innovations can be instrumental in the development of interventions fundamental to reducing poverty by directly benefitting subsistence farmers by reduced loss in production and storage, and indirectly through technology transfer (de Janvry and Sadoulet, 2002; Barrett, 2008). At present it is common for the poorest farmers to either consume or sell all of their grain during periods of acute food shortage or when a crop fails, and also when market prices happen to be high (David and Sperling, 1999; Barrett, 2008). This can jeopardize their own needs for food security at the (family) farm level. Therefore, there is an urgent need for the implementation of effective postharvest technology, which in this context can maximize social benefits, with particular importance to regions with extensive poverty, weak local markets, little institutional support, public goods provision (de Janvry and Sadoulet, 2002; Barrett, 2008), and by implication have a greater exposure to climatic change and little adaptive capacity.

CONTROLLED LOW OXYGEN HERMETIC POSTHARVEST STORAGE

Crop postharvest storage and processing technology can be expected to improve food security through increased produce availability, nutrient density, safety, market value, climate resilience and overall decreased loss of primary harvests (de Janvry et al., 2000; Wenhold et al., 2007). Controlled internal atmosphere storage technology aims to extend the life of products at a higher quality (Yahia et al., 1983). For example, poor drying techniques and or poor storage conditions can lead to increased exposure of products to high relative humidity and temperature, which are conducive to mould establishment, faster respiration of grains, and associated decline in seed/grain quality (decay), and major losses to insects, rodents, and birds (Rickman and Aquino, 2004). Controlled climate postharvest storage technology includes the use of chemical fumigants, yet their practical application is complicated with the growing safety concerns of how they may be appied, and also the very high costs associated with testing new fumigants to meet registration requirements (Savarie et al., 1980). In recent decades the expansion of cheaper chemical fumigants is raising concern for public health and the ecological risks from their continued use (Moreno-Martinez et al., 2000). In comparison to toxic chemical fumigants, storage using toxic gas purging (such as carbon monixode, CO) in a controlled atmosphere has a number of useful advantages (Yahia et al., 1983), yet will remain controversial for the high likelihood of accidental death associated with its use. Therefore, in order to maximize benefits and minimize risks, this chapter explores the use of small-scale gas membranes that produces a nitrogen gas (N_2) steam to displace residual O_2 for small-scale sealed grain to improve energy and food security, and climate resilience.

Various technologies can be safely used to control internal atmospheric conditions for grain storage and may include more traditional storage options and/or more modern moisture control, such as air-conditioning and cold storage options, aluminium sacks, and hermetic (impervious to gas transfer) containers (Rickman and Aquino, 2004). Hermetic storage can prevent moisture uptake from the atmosphere, reduce live insect infestations, prolong seed viability, and maintain high quality grain when compared to traditional and air-conditioned storage; in addition to being an option that is both safe to users and to the environment (Navarro et al., 1994; Rickman and Aquino, 2004). Agriculture in tropical countries is particularly susceptible for product storage issues due to consistenly warmer temperatures and high humidilty conditions commonly conducive to rapid decay; and are in need of cost-effective options for hermetic grain storage (Navarro et al., 1994; Moreno-Martinez et al., 2000). Such storage options have the additional ability to protect the agricultural production chain from adverse climate change impacts and extremes.

Controlling the equilibrium moisture content of grain below 10-12% during storage is importatnt in tropical countries, and to accomplish this grains must often be dried more than once (Navarro et al., 1994; Moreno-Martinez et al., 2000; Rickman and Aquino, 2004). Research from the Philippines shows seed germination capacity was unaffected (i.e., at 82% germination) after 12 months in a hermetic storage (in air-conditioned at with moisture content between 12-13 %); with the germination controls comparing favourably against the traditional system (bag) (26%), demonstrating comparable results from Bangladesh, Cambodia, and Vietnam (Rickman and Aquino, 2004). Generally, hermetically stored grain exhibits lower germination rates if grains are not properly dryed (Moreno-Martinez et al., 2000; Rickman and Aquino, 2004). For instance, maize with moisture content above 15% will not germinate well after hermetic storage, which can be at best used for a short-term storage option (Moreno-Martinez et al., 2000). However, hermetic storage impact, associated costs, and subsequent adoption is heavily dependent on the technology chosen, storage capacity, and the traditional storage already established (Rickman and Aquino, 2004). For example, in the Philippines Rickman and Aquino (2004) published research at the International Rice Research Institute (IRRI) for developing a 50 kg hermetically sealed bag that fits into traditional storage bags, and also explored a range of smaller bags from 3-30 kg. Following from Rickman and Aquino (2004), this chapter explores the economics and technical potential of grain storage using PVC bag liners inside traditional grain bags.

LOW OXYGEN AND DESICCANT PEST AND MOISTURE CONTROL

Hermetic storage is effective by the interference of a pests respiratory metabolism (Emekci et al., 2001). Grain, fungus, and insect respiration in sealed storage containers decrease internal atmospheric O_2 levels to below 10% in a relatively short time (Moreno-Martinez et al., 2000; Rickman and Aquino, 2004). Insects and fungus respiration consumes O_2 in the storage container in addition to the grain respiration (Moreno-Martinez et al., 2000). When the container is unsealed, O_2 re-entry occurs after an initial depression (Rickman and Aquino, 2004). Ensuring low O_2 concentrations is known to be an effective postharvest measure for pest mitigation (Navarro et al., 1994), including insects and/or rodents (Rickman and Aquino, 2004). However, in practice hermetic storage technology will most likely not be able to completely eliminate all gas and moisture transfer. For hermetic storage systems to be practically sound, O_2 levels must be mantained between 1% and 5% (Emekci et al., 2001), with an additional daily ingress of 0.05% O_2 into the hermetically stored grain sufficient to arrest insect infestations (Navarro et al., 1994). In hermetically stored conditions, pest respiration rates can be expected to sharply decrease at the oxygen concentration levels up to 3% (Emekci et al., 2001; Emekci et al., 2004). For hermetic grain storage, fungal growth and spore production can be expected to cease at 1% O_2, yet fungal spores can endure inactivity for prolonged periods until environmental conditions are favourable (Moreno-Martinez et al., 2000). Generally speaking, an O_2 concentration level between 3-5% will stress adult insect metabolic activity, and at 2% O_2 concentrations will exterminate all insects (Moreno-Martinez et al., 2000; Emekci et al., 2004). With effective hermetic storage, 100% of insects and fungus die within a few days, and the very low percentage of insect eggs that do hatch also die in a few days (Moreno-Martinez et al., 2000).

In uncontrolled grain storage conditions, after drying the hygroscopic nature of grain will cause the grain to reabsorb moisture from the surrounding environment; while in a sealed storage system the grain moisture will remain relatively consistent to the initial moisture content of the grain (Rickman and Aquino, 2004). Post-grain drying, desiccants can be used to reduce moisture and hermetically sealed bags ensure lower moisture levels are maintained. While the process of chemical adsorption is stronger than physical adsorption, the process of physical sorption is completely reversible (Time, 1998), and the use of non-chemical wood desiccants with physical adsorption capacity is an attractive technology. For a cheap diseccant, virtually any wood material can be heated, used, and reused many times to be eventually replaced and disposed as fuel to heat the wood replacing it. Wood chip desiccants can simply be produced in a kitchen oven (or similar), where the moisture in wood biomass can be reduced to close to zero in a few minutes, and by inserting dry wood chips into bags or containers of grains that can be hermetic sealed. In order to restore a balance in wood humidity with the immediate surroundings, the humidity released from grains within the hermetically sealed container will be transferred to the wood. Wood (like grains) is a hygroscopic material and will slightly shrink during drying, and regain some humidity from the immediate environment to reach new internal equilibrium, which constitutes a important characteristic making wood an appealing active and passive desiccant material.

A live tree standing before harvest (green) has around 50% moisture content, and after harvest it tends to achieve a balance with the environment in which its stored. Harvested wood adsorption and desorption characteristics may also differ due to wood physical properties (before and after drying), as well as due to the presence of liquids such as exudates and volatiles present in the wood before and after drying (with different behaviours to water). These characteristics will vary between species, tree growth conditions, harvesting, processing, storage and drying conditions (Friend et al., 1991; Fisher and Binkley, 1999; Forest Products Laboratory, 1999; Watson et al., 2000). According to the same authors, ‘dry’ biomass is obtained by placing the wood parts at high temperatures (~103^{o}C) until a constant weight is achieved, at which point it has reached the Fiber Saturation Point (FSP)., i.e., whereas the wood retains about 30% humidity and all ‘free water’ has evaporated compared to the water (and wood exudates) that are strongly held in the cell walls. The greatest possible drying of wood surpassing the FSP is desirable for use as a diseccant. As below the FSP point the force of attraction of the wood for water is so great that it appreciably increases the amount of heat required to cause evaporation, and reduces the relative humidity of the sorrounding air. Because cell walls are saturated and the cell cavities are free from water at the FSP, the wood shrinks, and in general it can be assumed that the volumetric shrinkage of a wood block as a wole is equal to the volume of the water removed below the FSP (i.e., that the cell cativities do not change in size, or that is an homogenic material in permeability, when in fact these are in variable sizes of pores or cativities). This research assumes that a hermetic storage technology with a small ingress can maintain low grain moistures by using dry wood as a natural desiccant.

METHOD

Daily and monthly mean data were derived from a selected meteorological ground-station located at Quelimane, Mozambique; Lat.(N): -17.9, Long.(E): 36.9, 16 m above sea level. Quelimaine is the administrative capital of Zambezia Province, the most populous province of the country. Major local agricultural production includes rice, maize, cassava, sugar, and tea. The transformed meteorological data were sourced from RETScreen's (version 4) climate database. The 15-minute interval technical simulations of the photovoltaic (PV)-battery-compressor-membrane system were performed using HOMER version 2.68 beta. Monthly average meteorological data were used to simulate the technical performance of a polycrystalline PV module array to supply a commercially available suitable 12V 100 Ah lead-acid battery for a portable 12V oil-less air compressor. The simulations used technical data from a commercially available 400 W (max) 12 V and 30 A (max) 150 psig (max) or 10.34 barg, where 1 barg is equal to 100 kPa above atmospheric pressure, 72 L/min air compressor coupled to a small, generic nitrogen gas (N_2) producing high-pressure membrane. As Quelimane is located on the sea, no adjustment for atmospheric pressure was undertaken for this analysis. The membrane unit was used to fill a theoretical 25 kg hermetic grain/seed bag. A simple stand-alone economic model was developed in a spreadsheet to include production, costs, rates, assumptions (etc.) which could be easily changed and modified for both assumptions and formulae flexibility. The model incorporated the HOMER simulation output data, and estimated market prices projected over a 10-year project lifetime. The model included a 9% real discount rate after inflation (5%) (calculated annually), used to calculate a Net Present Value (NPV) over the 10 years, under the guidance of research by Irvine-Halliday et al. (2008).

The porosity of grain used to refine the technical simulations was defined as the volume fraction of air void space and is presented as a ratio of air void to the total volume, and is dependent on a number of variables, including of the moisture content of the grain (Chung and Lee, 1985). Research by Chung and Lee (1985) on the physical properties include the bulk density and porosity of grain and seed were used to derive generic figures for volumes of air required to be purged from filled grain/seed bags with N_2. Using arbitrarily selected data from Table 1 and Table 2, the 'Long' paddy rice with a moisture content of 12-18%, the bulk density of 585.6-615.1 kg/m^3, and a porosity of 56.9-59.6% indicate an approximate volume of air to be purged from a 25 kg bag. In a theoretical 25 kg bag of 'Long' rice the 12% moisture content rice would roughly exhibit a paddy bag volume of 42.7 L, with a void space of 25.4 L, reflecting the values from Chung and Lee (1985). For the 18% moisture content 'Long' rice, the same calculation would yield a paddy rice bag of 40.6 L, with a void space of 23.1 L. Therefore, the total minimum volume of N_2 to displace the air void in both bags individually would be 26 L. Similarly, using the 'Yellow dent' maize, the identical calculations suggest that the low and high moisture content void volume in a 25 kg bag would be 15.0 L and 11.8 L, respectively. These void volumes can be used to indicate volumes of N_2 purging gas, and a minimum value to be exceeded by users of the N_2 membrane for hermetically storing grain. The N_2 flow rates for purging the 25 kg grain bags would be relatively slow yet induce sufficient turbulence to displace the air originally in the filled bag. As the compressor increases the air temperature to around 50 ^{o}C, the N_2 should ideally be directed through the top of the unsealed bag towards the bottom of the bag via a tube and effectively 'push' the cooler air above the end of the tube out the top seal as it rises. The oil-less compressor was simulated as producing 6.9 barg (~100 psig) producing a 98% N_2 concentration, with a flow rate of 7 L per minute (Figure 1).

Table 1. Comparisons of approximate moisture contents (wet basis), and porosity of various selected rice and maize samples. Source of data collation: (Chung and Lee, 1985).

	Variety	**Moisture content (%)**	**Porosity (%)**
De-husked rice	Honduras	11.9	50.4
	Wateribune	12.4	46.5
Paddy rice	Durar	11.4	51.0
	Short	14-22	46.4-47.6
	Medium	12-18	58.5-53.1
	Long	12-18	56.9-59.6
	Unspecified	12-16	48
Maize	No. 1	9.0	40.0
	Shelled Yellow Dent	15	40
	Yellow	9-14	38.5-47.6
	Yellow Dent	12-23.4	37-42
	Unspecified	12-16	40

Table 2. Comparisons of approximate moisture contents (wet basis), and bulk density of various selected rice and maize samples. Source of data collation: (Chung and Lee, 1985). (Numbers in parentheses indicate standard deviations).

	Variety	**Moisture content (%)**	**Bulk density (kg/m^3)**
De-husked rice	Caloro	8.6	571.1 (1.7)
	Calrose	9.2	570.7 (6.2)
	Hy Mix Early	8.8	591.2 (9.3)
Paddy rice	Short Caloro	11.24-20.95	632-664
	Medium, Saturn	12-18	598.3-648.3
	Long	12-18	585.6-615.1
	Unspecified	12-16	590.0
Maize	Pfister 347	6.7	744.5
	Shelled Yellow Dent	16.3	752.7
	Seed	16-44	710.3-734.1
	Yellow Dent	12-23	698.4-784.3
	Stauffer	12-18.2	731-826

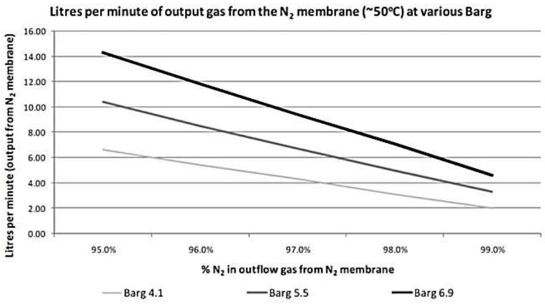

Figure 1. Generic performance curves of a N_2 membrane at various gauge pressures.

The simulation conservatively assumes the N_2 bag purging requires a volume of N_2 twice the void volume of a 25 kg bag of the particularly low bulk density ‘Long’ paddy rice. Therefore, the membrane will require around 7.5 minutes per bag to produce of 52 L of N_2, and is able to complete 8 bags (or 200 kg of paddy rice per hour). Note the ‘Yellow dent’ maize would require only 15 L of void per bag, and 30 L of N_2 from the membrane could be produced at the above pressures. The associated filling time would be around 4.5 minutes, or 14 bags (350 kg) per hour. Based on these assumptions, the PV-battery-compressor-membrane system would operate around 4 hours per day per tonne for the paddy rice, and 3 for a tonne of maize. The simulations use a value of 2 hours of system operation, sufficient for half a tonne of paddy rice daily.

In terms of the amount of wood used as a desiccant, the theoretical 25 kg bag of ‘Long’ rice with average initial moisture of 10% is assumed to be sealed in perfect hermetic conditions. Therefore, there is 2,500 mL of water in the bag that is contained in the rice grains, ignoring the small amount of moisture in the minimum of 26 L of N_2 that has been used to purge the air from bag. With a total sample of 1 kg of ‘oven dry’ (0% moisture) wood inside the bag displacing 1 kg of grain, the total volume remains the same (ignoring the difference in bulk density of the grain versus the wood). However, in theory the total moisture in the bag at equilibrium is 9.6%, a direct reduction due to the adsorption of moisture by the dry wood - a theoretical 400 mL of water vapour. Figure 2 shows the simple relationship between the ratios of dry wood to grain at a theoretical 10% moisture content in storage of a fixed volume. However, this theory also applies to larger silos where retrofitting of temporarily dry hygroscopic organic material-containing vessels is possible. This research assumes that a total 1 kg of dry wood can be placed within a 25 kg purged and hermetically sealed grain bag without displacing any grain.

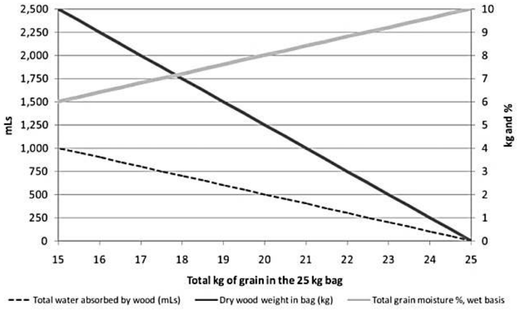

Figure 2. Relative total theoretical decrease in % moisture content of grain when it is displaced by dry wood in a 25 kg hermetic system. (Note: This assumes a linear and perfect isotherm.)

RESULTS AND DISCUSSION

The Quelimane site's annual average clearness index was 0.543, the annual average horizontal plane solar irradiance was 5.23 kWh m^{-2} day^{-1}, and the annual average temperature was 23.0 degrees Celsius. HOMER compared the theoretical electricity demand of the compressor-membane components, and performed energy balance calculations of the individual flows to and from each component of the designed system incorporating Quelimane climatic variables. A stand-alone PV-battery system was simulated to supply the portable compressor- membrane system. The simulated PV system was a 0.3 kW_p polycrystalline PV array and a 12V 100 Ah lead-acid battery supplying an electric load (0.8 kWh average daily load, 0.537 kW_p) in parallel through a small standard maximum power point tracking control unit, all off-grid to the electricity network. The battery bank nominal capacity was 1.2 kWh, 0.72 kWh of useable nominal capacity on a 12V DC bus, which is roughly similar to a standard 4WD vehicle battery rating. The simulation random variability of 'day-to-day' and 'time-step-to-time-step' were allocated 10% and 3%, respectively to reflect the consistent demand profile, which would vary little depending on the number of bags to fill each day. The total annual average output of the small PV array was 450 kWh. The excess electricity generated that was 'dumped' by the system over the year was 122 kWh due to 100% battery state of charge and zero load requirements. Therefore, the useful electricity provided by the PV system to the battery was 219 kWh. The difference between the annual throughput of the battery (196 kWh) and the useful electricity provided to the battery (175 kWh) of 43 kWh was attributable to the simulated battery technology cycle efficiency of 80% (The total does not sum due to rounding). The battery capacity and lifetime curve data was derived from available commercial battery specifications of similar types. The battery bank remains at a very high state of charge (>90%) for around 60% of the simulated year if operating to manufacturer specifications. The 'hour of day' data shows the PV system matched the battery and load demand well on average for all months, while some days with simulated lower solar irradiance and associated PV output meant the system was unable to operate at the scheduled times for the entire duration. This was a minor occurrence, and further system optimisation is possible, yet with the simplicity of the system and the minimising of excess wasted electricity production, this system will be able to supply the compressor with sufficient electricity for around 98% of the year. The average level of autonomy of 7.53 hours achieved with the battery, and the minimum state of change of 40% was used to protect the battery ensuring a medium 'expected life' of 4.67 years, consistent with known battery operation under such conditions (McHenry, 2009).

The simulation of the hermetic storage of the PV-battery-compressor-membrane system was modelled against non-hermetic storage of paddy rice. The analysis used the value of the difference between a theoretically assumed 100% of the value of the produced paddy rice could be retained by effective hermetic storage with N_2 purging, while 25% of the paddy rice value in traditional storage was valueless (due to an assumed average postharvest loss over time). The price of paddy rice for the model was based on the FAO 2009 Mozambique 'producer price' LCU (local currency unit) national average at the 'farm gate' (of all grades, varieties, and prices) of US$322.30 per metric tonne. (The producer price is the net return to the producer after all relevant taxes, and excludes any grain freight or transport costs) (Food and Agriculture Organization of the United Nations, 2012). As paddy rice loses weight when de-husked, the quality of the milling equipment will determine the final processed weight (and also the price per unit of weight). This research uses a generic conversion of 1:0.75 to convert the paddy rice weight/value to de-husked rice weight/value, and the a market price of the de-husked rice of US$429.70 per tonne. (Note this assumes a zero processing cost, of which would likely reduce the value to less than US$400 t^{-1}). In the year 2011/12, Mozambique exhibited an average processed rice yield per ha of 0.69 t ha^{-1}, from an approximate total rice planted area of 182,000 ha, with an average per capita consumption of 23 kg (Wailes and Chavez, 2012). The authors note the colonial legacy in Africa has resulted in severe land inequalities between smallholders (defined in this work as <10 ha), with around 25% of families in Southern and Eastern Africa approaching landlessness (<0.11 ha per person) (Jayne et al., 2010). Therefore, one tonne of processed rice is roughly an average total yield for a producer in Mozambique, on average produced on a land area of 1.5 ha. (Note that the price of rice is projected to increase in Mozambique from around US$ 410 t^{-1} in the year 2011/12 to US$574 t^{-1} in the year 2021/22, a real increase of around 3% per annum (Wailes and Chavez, 2012). The simple modelling assumes a 10-year constant real value.

The simplified model further assumes the PV-battery-compressor-membrane system is only in use for 2 months of the year as a grain production input. The modelling presented specifically looks at paddy rice-only purging, and assumes no other uses of economic value (Note this is a very conservative assumption, as it is highly likely that at least some of the system components would be put to further productive uses during the year). Therefore, using previous assumptions of 200 kg of paddy rice per hour purged and hermetically sealed, with an average use of two hours per day over a 60 day period, the system has the ability to supply N_2 to 24 t of rice paddy. (Note this is approximately equal to a de-husked rice weight of 18 t, produced from an average area of 26 ha). The model assumes US$322.30 t^{-1} for the rice paddy value totals US$7,735.20 for all 24 t purged and hermetically sealed in 25 kg bags. The model also assumes that 25% of this value is lost in traditional storage systems resulting in a value of US$5,801.40 for the 18 t of theoretically remaining paddy rice. The model assumes one hermetic bag costs US$1 and is only used once, and that the cost of oven dry wood is US$0.1 kg^{-1}. All unsubsidised capital costs and values for all components including PV module, battery, and balance of system prices were based on the actual system costs in 2012 to the producer. Zero storage technology costs (both operating and capital) were assumed in the traditional storage model only. The NPV calculations included a 9% real discount rate after inflation (5%) calculated on an annual basis over the ten year interval. The analysis assumed no borrowings and thus no interest rates were included. No system replacements were assumed for the PV-battery-compressor-membrane system, except for one battery replacement in year 6, and minor maintenance in each year. The remaining value of the PV-battery-compressor-membrane system is incorporated in the final year into the NPV. The authors have also modelled a scenario with a zero capital cost of the N_2 membrane component, and a zero value for the associated ‘remaining value’. This was to illuminate the difference between a very low cost N_2 membrane technology (as most gas membranes are expensive), and the membrane unit cost of US$2,000 used in this model. This one component represents more than two-thirds of the capital cost of the PV-battery-compressor-membrane system. Figure 3 graphically shows the capital costs and operating costs for the two alternative postharvest storage technologies in Mozambique, and the additional ‘no membrane’ cost scenario.

The results show that in practice there is little difference to the producer in terms of value over time between each technology based on the economic model assumptions. Whilst the full-cost purged hermetic technology option generates around 8.5% more value than the traditional storage technology option, this is a very small difference over a 10 year interval, and well within the uncertainty of the model. The ‘no membrane’ modelled cost scenario achieved an additional discounted value over the interval relative to the traditional option of 13%, reflecting primarily the membrane cost savings. These simple models indicate why the numerous number of modern storage technologies are not in use in developing countries. More effective storage technology is often more expensive and the net value to the producer tends to be roughly equal at sale. This suggests that exploring extremely low cost, yet effective hermetic systems for grains will be of most value to the producer. The use of the additional N_2 purging in terms of its separate value would require further analysis, in additional to any alternative to decreasing O_2 concentrations in hermetic storage. The wood desiccant in theory is an effective and cheap option, particularly when small amounts of internal moisture exist, and when hermetically sealed grain space is not a premium. Note the modelled analysis does not take into account the total factor productivity cashflow associated with reduced postharvest storage grain loss from the saving of inputs such as land, fertiliser, fuel, labour, and the percentage of postharvest yield gains would roughly reduce input costs by an approximately equivalent percentage. However, within the known limitations, this research suggests that at the smallholder level, Mozambique producers, and sub-Saharan Africa in general will likely not have sufficient incentive to adopt N_2 purged hermetic storage technology. The small premium margin that a smallholder may attract requires much greater production volumes to justify the investment. Larger seed suppliers and processors will likely have a greater capacity to invest in capital-intensive technology and make the most of the margins available. Bridging the gap may require subcontracting for economies of scale to bring benefits to smallholders (Start, 2001).

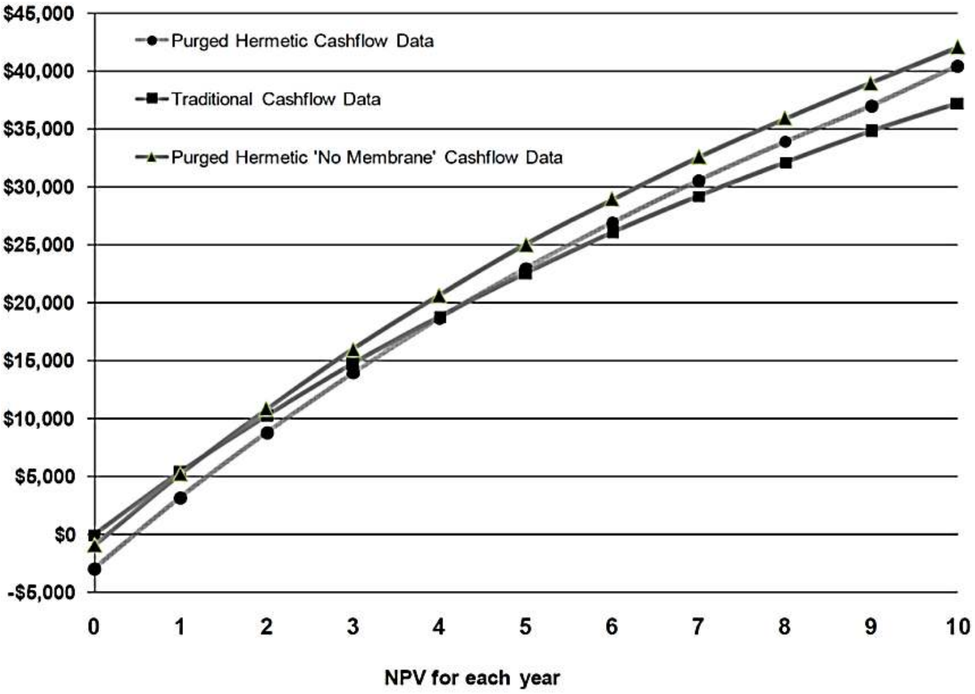

Figure 3. Discounted NPV calculations for each technology option over a ten-year interval.

CONCLUSIONS

The primary objective of this research was to assess technical approaches that improve energy security, food security, and climate resilence as a consequence of new technology adoption. The simulations demonstrated the attractive technical potential for small-scale renewable energy-powered N_2 gas purging of hermetically sealable technology. Further work is required to develop technically appropriate hermetic storage options and assess their effect on seed and grain quality. Oven-dry wood desiccants seem an accessible desiccant technology for use in hermetic storage, and further analysis of suitable wood species and volumes are necessary within sealed systems. However, the simple economic model suggests that there is little benefit in terms of market value in the adoption of new, more effective postharvest storage technology unless the new technology is comparable to existing costs of traditional storage technology. The authors suggest that collaborative commercial opportunities for several small-scale postharvest technologies can reduce costs of new systems. Such collaboration is not uncommon, i.e. generic drugs at cost for less-developed countries.

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