

Techno-Economic Analysis of a Refractance Window Dryer Prototype Developed by Kenya Industrial Research and Development Institute

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Authors' contributions

This work was carried out in collaboration among all authors. Authors WAN and GWW designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JK and SW managed the analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The Refractance window dryer (RWD) is a fourth generation dehydration technology. RWD is used to dry heat-sensitive materials because it retains high nutrient content, colour, flavour, aroma and bioactive compounds. The dehydrated products have a high sensory quality. There were no RWD in East Africa despite their excellent performance hence need for local fabrication of RWD Prototypes that can meet the technical, economical and socio-economical requirements. This paper describes the performance evaluation and economic analysis of the RWD prototype developed at the Kenya Industrial and Development Institute (KIRDI), Kenya. Indicators such as drying rate and drying time were used to assess its technical performance. The economic performance of the dryer was appraised using Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PBP). Mango pulp and African leafy vegetables were dried using the RWD

prototype at KIRDI between May-July, 2021. During drying process, moisture content of mango pulp was reduced from 88% to 15% in one hour while African leafy vegetable from 88% to 5% in 40 minutes. The economic evaluation of the dryer revealed an IRR of 31%, NPV of 808223.515 @ 24% and PBP of 3.6 years. KIRDI RWD prototype is a versatile technology that can be deployed in remote settings resulting to reduction of post-harvest losses as well as carbon emission. Currently, sun drying, solar drying, cabinet drying, spray drying, drum drying, fluidized bed drying and freeze drying are available in Kenya. They possess various advantages and equally significant drawbacks. Therefore the adoption of KIRDI's Refractance window dryer would be beneficial to Micro Small and Medium enterprises in providing timely drying services and improve their socio-economic status.

Keywords: KIRDI Refractance Window dryer; economic analysis; technical performance.

1. INTRODUCTION

Mitigation of postharvest losses (PHL) is recognized as the most urgent development priority and a key pathway to food and nutrition security in sub-Saharan Africa [1-5]. According to the National Bureau of statistics, Kenya loses about a third of its agricultural produce to post-harvest losses annually. For example, in 2017, smallholder farmers cumulatively lost 1.9 million tons of food worth over KSH 150 billion, It is estimated that adoption of appropriate post-harvest technologies such as dehydration could save approximately 68% of these losses [6]. There is evidence that application of postharvest handling, storage and processing technologies results in significant reduction of postharvest losses of agricultural produce [7-10] even in humid climates [11].

Drying is one of the indispensable techniques for large-scale food preservation, but is one of the most energy-intensive operations [12]. Dried foods offer numerous benefits including storage stability, lowering packaging requirement, and reducing the bulk for transportation [13]. An ideal drying technology can confer many advantages such as a safer operation, higher capacities, and better product quality, less environmental impact, higher energy efficiency and at a lower cost [14].

The global demand for dehydrated foods has been increasing rapidly due to consumer demand for healthy and convenient products with a higher shelf-life [15]. Key market players dominating international trade in dehydrated products leverage on advanced dehydration technologies which produce products of superior quality as demanded by the elite consumers. Currently, dried natural products have gained importance as ingredients in different food products. Although drying of food products is widely applied in various industries globally, it

has been a challenge for the Micro Small and Medium enterprises in Kenya, who still uses of rudimentary drying technologies producing inferior products which are unable to compete with imported variants [16]. Upgrading drying technologies in Kenya's food industry is therefore a matter of great national interest. The Refractance window dryer (RWD) is a fourth generation dehydration technology that is gentle, simple, and a relatively low-cost drying system [17]. It is used to dry heat-sensitive fresh produce that preserves the nutrient, colour, flavour, aroma and bioactive compounds as well as the sensory quality [18]. RWD is versatile technology that can be deployed to remote settings even at farm level. The larger capacity if the RWD is a continuous belt system based for industrial use although the mechanisms of operations remain the same.

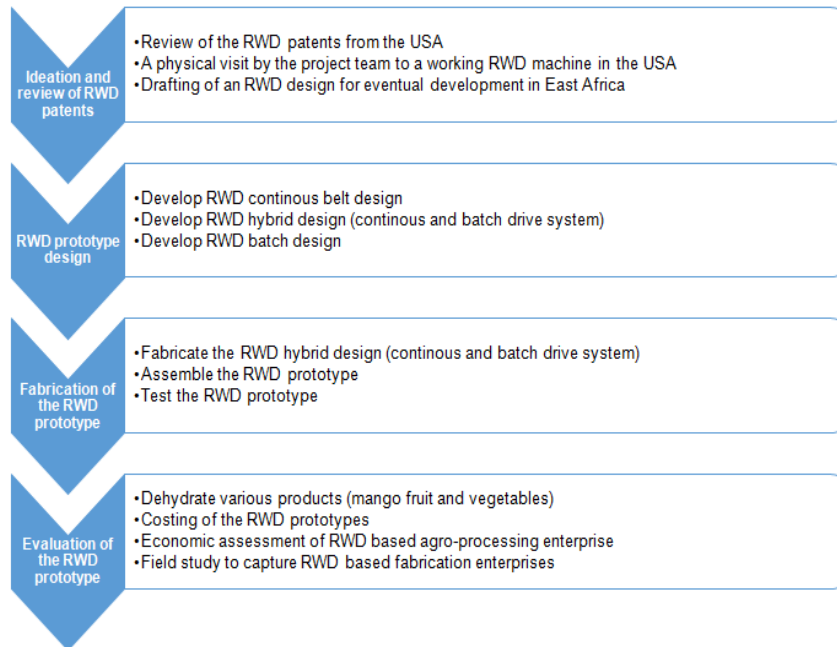
Studies conducted on the RWD technology show that the system demonstrates high retention of product quality (colour, vitamins, and antioxidants) when compared with other conventional drying methods [19]. The quality of the dried products is comparable to those obtained by freeze drying, yet the cost of the equipment is several times lower. RWD achieves substantial reductions for total aerobic counts, coliforms and E. coli. A number of foods that are difficult to spray dry without the addition of non-sugar carriers have also been handled successfully in the RW dryer. These attributes of RW drying make it suitable for processing of high-value foods, nutraceuticals and food supplements where high standards of quality and safety are required.

The economic and technical appraisal of drying technologies is vital for their adoption by Micro, Small and Medium enterprises. Successful assessment of these low-cost technologies drives their scale-up from research laboratories to commercialization and adoption. This study

sought to assess the economic and technical performance of Refractance window dryer prototype developed by Kenya Industrial and Development Institute.

2. MATERIALS AND METHODS

2.1 Research Methodology

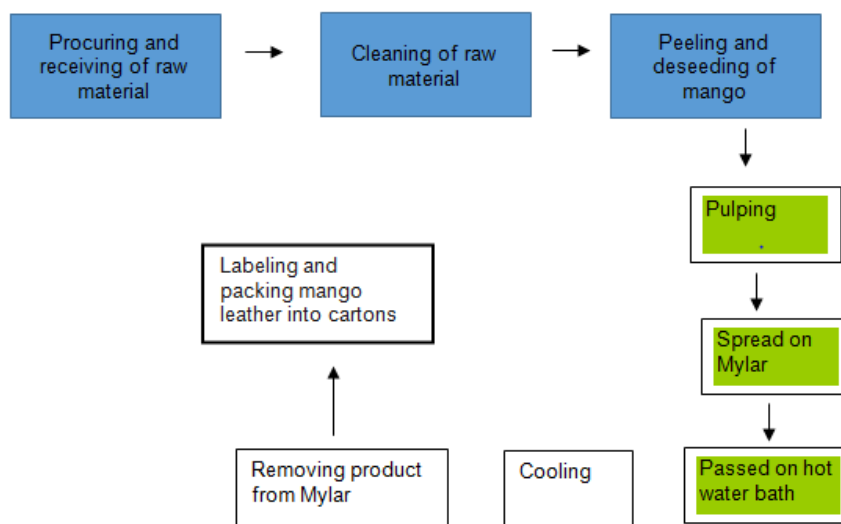


2.2 Technical Performance Study

2.2.1 Study site

The drying experiment was conducted at the Engineering Development Service Centre of Kenya Industrial Research and Development Institute (KIRDI) in Nairobi South C of Kenya.

2.2.2 Process flow



2.2.3 Dehydration procedure

The RWD prototype was used to dehydrate *Mangifera indica* (mango) pulp/puree and African leafy vegetables; *Solanum nigrum* L. (black night shade) and *Cleome gynandries* (spider plant, cat whiskers). The fruit and vegetables were bought from a popular supermarket chain, in Nairobi.

The raw materials were thoroughly cleaned and prepared; the mangoes were peeled, deseeded, and the flesh pulped using a commercial blender and spread thinly over Mylar, the vegetables were destalked, blanched using a boiling water bath for 2 minutes, cooled and spread over the Mylar. The materials were constantly being monitored until they reached the recommended moisture content of below 20% for mango leather and below 5% for the vegetables. The dried materials were moved to the cold water section for cooling and then scrapped off the Mylar

2.2.4 Dryer description

The newly developed prototype of Refractance Window Dryer unit (RWD), shown schematically in drawing (Fig.1), was fabricated at department of Engineering and Development Services in KIRDI. The KIRDI version of RWD and consists of three major parts, namely; the drying chamber/mylar paper, the water system and the frame assembly. The parts are all fabricated and assembled together as a single unit. The system

can be motorized to remote destinations and therefore provide drying services to the SMEs. The prototype design allows for continuous and batch systems with an approximate loading of 20 kg of fruit pulp per batch. The drying chamber has an overall dimension of 110*150 cm.

2.3 Dryer Performance Indices

Dryer performance indices such as drying rate was considered for the performance assessment of the KIRDI prototype RWD Equations (i) show the expressions that was used to determine the performance indices.

Determination of Drying Rate, DR

$$DR = \frac{M_i - M_d}{t} \quad (i)$$

Where M_i and M_d represented initial moisture content (% w.b.) and final moisture content (% w.b.) after drying respectively, and t = drying time.

2.4 Economic Performance Study

The economic assessment on the Refractance window drying system was appraised from the perspective of a Micro, Small and Medium enterprises using the discounted method where the time value of money was considered

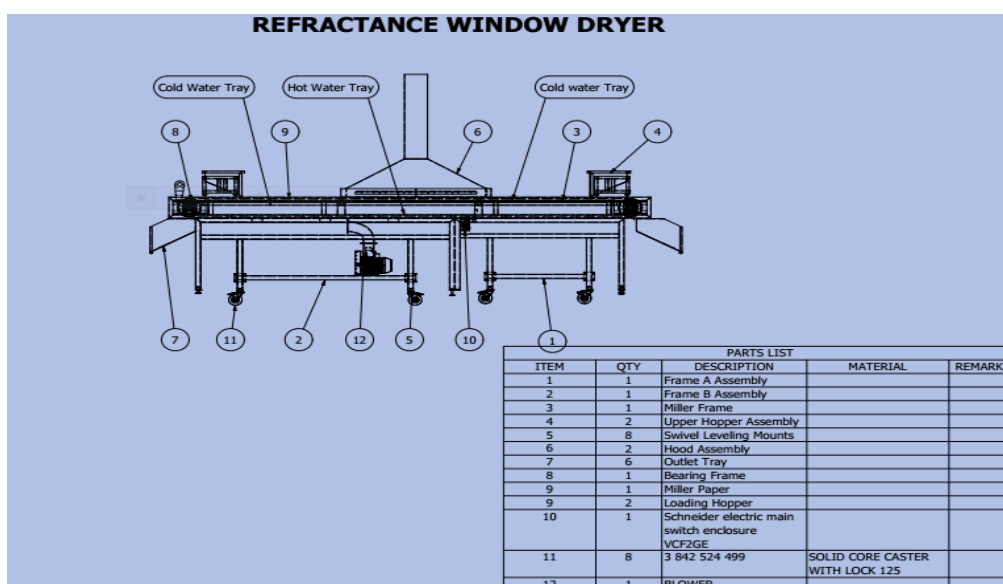


Fig. 1. Schematic illustration of the KIRDI RWD Prototype

2.4.1 Case study scenario

The following assumptions were made for the scenario considered for the study:

- a) An SME owns the refractance window dryer.
- b) The SME buys the raw material in this case mango and African leafy vegetable.
- c) The SME sells the dehydrated products.

2.4.2 Estimation of cost and revenue

The cost component was made up of the investment cost and cost of operation and maintenance. The investment cost consisted of all the expenses required to set up the complete drying system. The cost of acquiring raw material for drying plus any auxiliary raw material was considered, electricity for operating the drying system during operation and a flat rate of 2% of equipment and machinery cost was assumed to be operation and maintenance costs, respectively. The revenue generation stream was sourced from the price charged for sale of dried products. The prices and quantity of dried product were presented in the economic model to determine the annual total revenue generated

2.4.3 Economic appraisal

Discounting methods for investment analysis, including net present value (NPV) and internal rate of return (IRR) were used to analyze the financial viability of the RWD when drying mango pulp. However, the undiscounted method (payback period) was also used to determine how quickly the installed dryer generates enough funds to cover initial capital investments. Economic analysis was also performed to additionally highlight the potential for job creation for the youth in the study area from the scale-up of the KIRDI RWD. The number of SME-beneficiaries and potential economic loss of fruits/horticultural crops due to post-harvest loss prevented by using the dryer as against other common methods was also estimated. The economic output indicators were determined using Microsoft Excel analytical tool.

Net Present Value (NPV): NPV as a discounting method for evaluating the economic viability of investments that refers to the present worth of the net cash flow of a firm. NPV is the difference between the present value of an investment cash inflows (benefits) and the present value of

the investment cash outflows (costs) at a given discount rate [20]. Positive NPV indicates an economically feasible investment or project while a negative value shows that it is not economically feasible to carry out such an investment or project. Mathematically, NPV is expressed as indicated in Equation (ii).

$$NPV = \sum_{n=1}^N P_n (1+i)^n - FC \quad (ii)$$

Where: Where, P_n is the discounted present value to be invested in the n years in the future; the net cash flow at a specific time; (n) the number of years (10 years); (i) is the financial discount factor; (FC) total investment outlay

Internal rate of return (IRR): The IRR refers to the average annual percentage return expected from a project, where the sum of the discounted cash inflows over its life is equal to the sum of the discounted cash outflows. It therefore represents the discount rate that results in a zero NPV of cash flows [21]. Generally, the higher the IRR compared to NPV the more desirable it is to undertake the project [22].

Payback Period (PBP): The payback period estimates the number of years it takes to recover an investment's initial capital. It provides a simple way to assess the economic merit of investments. Cash inflows for the PBP are undiscounted hence do not consider the time value of money. The payback period was mathematically expressed using Equation (iii)

$$PBP = \frac{C_i}{S} \quad (iii)$$

Where: C_i is the initial investment cost; S is the net cash flow

Financial Assumptions: The following financial assumptions were made during the assessment:

- a) Cash flows were discounted over a ten-year period based on the expected useable lifetime of the RWD
- b) An operation period of three hundred days per year is considered
- c) The dryer is anticipated to dry 30 tons of mango pulp per year.
- d) The dryer will be operated by two employees
- e) Assumed price increment of 10% after five years

- f) A discount rate of 24%, which is Kenya’s discount rate of August 2021, was used for the analysis.
- g) A percentage of 2% of the investment cost was assumed to be maintenance cost in the financial analysis.

essential consideration for adopting fruit pulp dryers. The prototype capacity matches most of the Micro, Small and Medium enterprises production rate, making the KIRDI RWD dryer suitable for most enterprises in food drying.

3. RESULTS AND DISCUSSION

3.1 Technical Performance Evaluation

3.1.1 Dryer performance specification

The Table 1 show results of KIRDI’s RWD technical performance, the result satisfied the drying needs of small and medium enterprises. The average temperature distribution of 88.5 ± 2.8 °C in the drying chamber was not too much of a drying temperature that can result in the loss of nutrients in a fruit paste viability. This is an

3.1.2 Drying of various food materials using KIRDI RWD prototype

Indigenous vegetables (African night shade and cat whiskers) and the ripe mango fruit were prepared and dried as mentioned previously. The materials dried sufficiently to below the required moisture content in a short time. The drying time was 40 minutes and 1 hour respectively for vegetable and mango pulp. This was a major reduction when compared with the hot air electric cabinet driers that take 8 hours and 16 hours to dry similar materials respectively.

Table 1. RWD prototype technical performance

Parameter	Value
Dryer mode	Batch
Initial mass of fresh material	20 kg
Initial moisture content –mango fruit pulp	86%
Final moisture content- mango fruit leather	15%
Initial moisture content -African leafy vegetable	88%
Final moisture content -African leafy vegetable	5%
Average drying time (fruits)	1hr
Average drying time for vegetables	40 minutes
Drying rate	71/1 hour
Specific energy consumption	1kw per run
Average hot water temperature	92°C



Fig. 2. Pictorial presentation of vegetables preparation, spreading of the fresh materials on mylar sheet, dried vegetables and mango leather

3.1.3 Drying Rate, DR of mango pulp using KIRDI version of RWD

$$DR = \frac{M_i - M_d}{t} \quad (iv)$$

Where M_i and M_d represented initial moisture content (% w.b.) and final moisture content (% w.b.) after drying respectively, and t = drying time

$$\frac{86\% - 15\%}{1hr} = 71/hr.$$

The result achieved the recommended moisture content of 18%-33% (db) for intermediate moisture food like mango leather, even though the drying time was still high of 1 hr and did not conform to experiment conducted by Kaur, G et al who achieved similar result but within 12 minutes using RW dryer with Mylar sheet [23].

3.2 Economic Performance Evaluation

3.2.1 Technical and financial analysis of the drying system

The design capacity of the KIRDI RWD is 20 kg of mango pulp per batch and assumed to operate at five batches per day. Given that the dryer will operate 300 days/year, it's anticipated that the dryer would be used to dry thirty tones (30,000kg) of mango/fruit pulp/year. To match the rise in the operating and maintenance cost due to inflation, the revenue items is projected to increase at 10% after every five years of operation.

3.2.2 Cost of building KIRDI RWD

KIRDI RWD was estimated to cost Kenya shillings 1,571,500 to build/develop (Table 3), this is basically the material cost. The cost for RWD drying system presented in Table 3. The main cost component was the water tray assembly, estimated to be 34.4% of the total investment cost for the dryer.

3.2.3 Estimated cost of manufacturing KIRDI RWD by a fabricator

The estimated material cost of KIRDI RWD is Kenya shillings 1,571,500 (table 3), this cost would shoot up after adoption of the technology by the fabricators. In this study we anticipate an estimated retail price of about Ksh 2,500,000

(table 4) for the dryer this inclusive all the relevant taxes plus direct cost and little profit margin' comparing the price with hot-air driers it would be affordable to most entrepreneurs.

3.2.4 Operational cost of KIRDI RWD

The costs associated with the operation and maintenance of the dryer is presented in Table 4. An amount of Ksh 50,000 representing 2% of the dryer acquisition cost was allocated for maintenance and overhead expenses. A total power of 1050 kWh required in the beginning year of operation but it will increase to 1500 kWh at the third year in which the dryer shall have achieved full scale operation, an amount of Ksh 42,000 was estimated as the cost of electricity for the operation of the drying system in the first year. The cost of electricity was estimated at Ksh 40 per kWh in Kenya. Labour cost was estimated at Ksh 800 per day and will require two people to operate the dryer, hence for 300 days in which dryer will be operation results to Ksh 480,000 as cost of labour for one year. The dryer will require water for its operation, and the project assumed water bill of Ksh 30,000 per annum.

3.2.5 Economic analysis - net present value

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project. From the financial result NPV was found to be positive and high at Ksh. 808,223.515 using discounted rate of 24%.

3.2.6 Payback period

The payback period was estimated by deducting cash flows to recover the initial capital invested. It provides a simple way to assess the economic merit of investments. Table 6 presented the estimated years it took to recover the initial investment.

The table indicates that the real payback period is located somewhere between Year 3 and Year 4. There is Ksh 734,700 of investment yet to be paid back at the end of Year 3, and there is Ksh. 1,190,100.00 of cash flow projected for Year 4. We assume the same monthly amount of cash flow in Year 4 which means that we can estimate final payback as being just short of 3.6 years.

Table 2. Financial and technical parameters

Parameter	Value
Capacity of dryer (kg)*	20 kg of Mango pulp
Number of batches	5 per day
Number of hours required per batch of drying	1 hr for mango pulp and 45 minutes for vegetables
Number of operational days per year	300
Number of operational hours per day	8
Number of operational months per year	11
Quantity of mango pulp processed per year	30,000 kg
Number of direct employments generated (persons)	2
Lifespan of the dryer (yr.)	10
Cost of purchasing mango pulp per kg (Ksh)	90
Selling price of dried mango leather per kg(Ksh)	1200

Table 3. Capital cost of RWD system

Assembly Description	QTY	Unit COST (KSH)	Total Cost
Air systems (Blower and Hood Assembly)	1	147,500.00	147,500.00
Water Assembly	3	180,000.00	540,000.00
Drive (Assembly, Rollers, Motor, Sprocket, Mylar and Adjusters)	1	409,000.00	409,000.00
Tray and Hopper (feeding and product removal)	1	130,000.00	130,000.00
Frame Sub-Assembly	2	90,000.00	180,000.00
Fixtures (Switches, Cabling, Temp Controller and Fasteners)	1	130,000.00	130,000.00
Finishing (Polishing and Painting)	1	35,000.00	35,000.00
Total			1,571,500.00

Table 4. Cost of KIRDI RWD

Details	Amount (Ksh)
Material cost	1,571,500.00
Overheads	598,660.00
Taxes and levies	339,840.00
Total	2,500,000.00

Table 5. Cost of operating RWD

Operations	Cost (Ksh)/Operation
Salary for 2 persons	480,000
Maintenance cost	50,000
Water bill	30,000
Cost of Electricity	42,000
Total	602,000

3.2.7 Summary of the financial analysis

The financial analysis indicates that the project is viable. This is indicated by the positive and high Net Present Value (NPV) of 808223.515 at 24% as well as the high Internal Rate of Return (IRR) of 31% as indicated in appendix II. The IRR of 31 per cent compared to 24 per cent discount rate or cost of capital is quite high and would

favour the project even when compared to other investments. The plant will recover initial investment within a period of 3 years and 7 months after which it will start earning for the owners. In the case of unforeseen constraints, this could shift to the next year in which case the investment would be covered within 5 years.

Table 6. Net Present value for food dehydration business using KIRDI RWD Dryer

Year	Equipment cost (Ksh)	Net cash flows	Interest(i)	Present value Factor	Discounted Net cash flows
0	2,500,000	-2500000	24%	1	-2500000
1		131,700	24%	0.8065	106216.05
2		484,500	24%	0.6504	315118.8
3		1,148,100	24%	0.5245	602178.45
4		1,190,100	24%	0.423	503412.3
5		1,232,100	24%	0.3411	420269.31
6		1,438,810	24%	0.2751	395816.631
7		1,449,310	24%	0.2218	321456.958
8		1,449,310	24%	0.1789	259281.559
9		1,491,310	24%	0.1443	215196.033
10		15,33,310	24%	0.1104	169277.424
Total					808223.515

Table 7. Payback period for entrepreneur investing in KIRDI-RWD

Year	Cash Flow (Ksh)	Net Invested Cash (Ksh)
0		-2,500,000
1	+131,700	-2,368,300
2	+484,500	-1,882,800
3	+1,148,100	-734,700
4	+1,190,100	0

Table 8. Internal Rate of return/NPV

Item/Year	0	1	2	3	4	5	6	7	8	9	10
Total revenue		381,700	734,500	1,398,100	1,440,100	1,482,100	1,688,810	1,699,310	1,699,310	1,741,310	1,783,310
Total cost incurred	2,500,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000	250,000
Net cash flows	-2500000	131700	484500	1148100	1190100	1232100	1438810	1449310	1449310	1491310	1533310
Discounted factor	1	0.8065	0.6504	0.5245	0.423	0.3411	0.2751	0.2218	0.1789	0.1443	0.1104
Discounted net cash flows	-2500000	106216.1	315118.8	602178.5	503412.3	420269.3	395816.6	321456.9	259281.5	215196.0	169277.4

*Net present value @ 24% is 808223.5
Internal rate of return: 31%
Payback Period: 3.6 years*

In the case of unforeseen constraints, this could shift to the next year in which case the investment would be covered within 5 years. The economic indicators' values prove the viability of the case scenario where an SME can invest in owning and running RWD dryer as a business in the study area. The study results agree with studies by Adams, who worked on

the financial feasibility of a mango-chip processing and small-scale meat production, respectively, in Ghana [20]. In their studies, the authors reported the economic viability of their case studies in Ghana, where there were similar trends in NPV and IRR for the operational period of the individual start-ups.

4. CONCLUSION AND RECOMMENDATION

The techno-economic performance of a 20kg capacity RWD prototype was successfully assessed. Mango at 86% was dried to a final moisture content of 15% within a period of one hour. The average drying rate recorded during the study was 71%/h. The economic feasibility of the drying unit was assessed to be viable for an MSME or an investor, however, the applicability of the economic analysis in its present form is restricted to the assumptions made. The economic analysis over a 10-year lifespan operation of the dryer resulted to a positive Net Present Value (NPV) as well as the high Internal Rate of Return (IRR), it is worth mentioning that economic analysis depended upon the parameters used in the calculations. Finally, the positive performance indicators provide confidence for scale-up and adoption of the KIRDI RWD prototype by micro, small and medium enterprises in Kenya. It is recommended that the entrepreneurs who will adopt this technology should target high-end market since the products produced by the unit were of high quality. In order to facilitate this adoption, awareness creation to the micro small and medium enterprises in the dehydration industry particularly those dealing with fruits and vegetable should be undertaken, and the knowledge of the technical and economic performance of KIRDI version for the RWD system explained.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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