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Economic viability of indirect forced circulation solar dryer for roselle (*Hibiscus sabdariffa* L.) leaves processing in Gujarat's tribal regions

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***Abstract*—The study investigates the economic feasibility of an indirect forced circulation solar dryer for dehydrating roselle (*Hibiscus sabdariffa* L.) leaves, aiming to provide an affordable and efficient drying solution for rural tribal communities in Gujarat, India. Traditional drying methods such as hot air tray drying, microwave drying, freeze drying, and vacuum drying are cost-prohibitive for rural populations. The proposed solar dryer, with a total construction cost of ₹4,91,000, incorporates a 6 m² PV-thermal solar air heater, a 12 m² packed bed solar air heater, a 10 kg capacity insulated drying chamber with stainless steel trays, a 1 hp blower, and automated control systems. This technology targets small-scale cottage industries to enhance value addition and create employment opportunities, particularly for rural women. Economic viability was assessed using four indicators: net present worth, benefit-cost ratio, internal rate of return, and payback period. The study highlights the potential of roselle processing to boost local economies through export opportunities, addressing the lack of awareness and limited research on value addition in roselle farming. The findings suggest that the IFCS dryer could be a sustainable, cost-effective solution for rural communities, promoting commercialization and economic development in tribal areas.**

***Keywords:*Economic analysis, Net present worth, internal rate of return, benefit cost ratio, payback period, roselle leavesand indirect forced circulation solar dryer.**

1. NUTRITIONAL AND AGRICULTURAL SIGNIFICANCE OF ROSELLE LEAVES

Roselle (*Hibiscus sabdariffa* L.), a versatile shrub of the Malvaceae family, is extensively cultivated in tropical and subtropical regions, including India (notably Bihar, Assam, Tamil Nadu, and Andhra Pradesh), the Philippines, Malaysia, and the Caribbean [6,8]. As a home garden crop, roselle yields approximately 4 t/ha of fresh calyces, which are valued for their vibrant colour and nutritional properties. The plant is primarily grown for its stem-derived bast fibres', which are used in textile production, while the residual stalks serve as a sustainable fuel source. Roselle leaves (Fig.1), both fresh and dried, are integral to culinary traditions across various regions. In Gujarat and Maharashtra, they are processed into juices, drinks, and sweet-sour chutneys. In Andhra Pradesh and Telangana, roselle leaves are a staple in dishes, often combined with lentils, incorporated into dals, or used in salads, earning acclaim as a hallmark of regional cuisine. Post-monsoon, the leaves are dried, powdered, and stored for winter use in rice powder stews in parts of India [9]. The leaves, consumed raw or cooked with ingredients like onions and groundnuts, are prized for their spinach-like flavour with a spicy edge. The biochemical composition of roselle leaves underscores their nutritional value. Per 100 g, they contain 3.5 g of protein, 8.7 g of carbohydrates, and 0.3 g of fat, alongside essential vitamins such as thiamine (0.2 mg), riboflavin (0.4 mg), niacin (1.4 mg), and vitamin C (2.3 mg). They are also rich in minerals, including calcium (240 mg) and iron (5 mg) [9,27]. These attributes make roselle leaves a valuable dietary component, particularly in regions where nutrient-dense foods are essential for food security.

2. ROSELLE LEAVES PRESERVATION THROUGH SOLAR DRYING

Preservation of roselle leaves is critical to extending their shelf life and maintaining their nutritional and sensory qualities. Solar drying has emerged as a cost-effective and efficient preservation method for agricultural products, including roselle leaves. This technology leverages abundant, non-polluting solar energy, reducing reliance on grid power and enabling on-farm operations. Solar dryers are classified based on the mode of solar ray contact with the material and the type of media flow [23,10,16,18,5,24]. Among these, the indirect mode forced convection solar dryer (Fig.2) stands out for its superior drying speed and quality [4,7,17]. Unlike open sun drying, this method minimizes exposure to dust, insects, birds, and animals, preserving the colour, flavour, and nutrient content of the leaves. It also reduces drying time, labour costs, and the required drying area, while offering potential for automation and standalone operation. The advantages of indirect forced convection solar drying include its use of a non-conventional, cost-free energy source and its ability to produce high-quality dried products. These benefits are particularly relevant for roselle leaves, which are valued for both culinary and medicinal purposes. Given the cultural and nutritional significance of roselle, this study proposes to evaluate the efficacy and economic viability of an engineered indirect forced convection solar dryer for drying locally available roselle varieties. By optimizing drying conditions, this technology could enhance the quality and accessibility of dried roselle leaves, supporting sustainable agricultural practices and improving food preservation in tropical and subtropical regions.

Fig.1: Roselle leaves and its plants

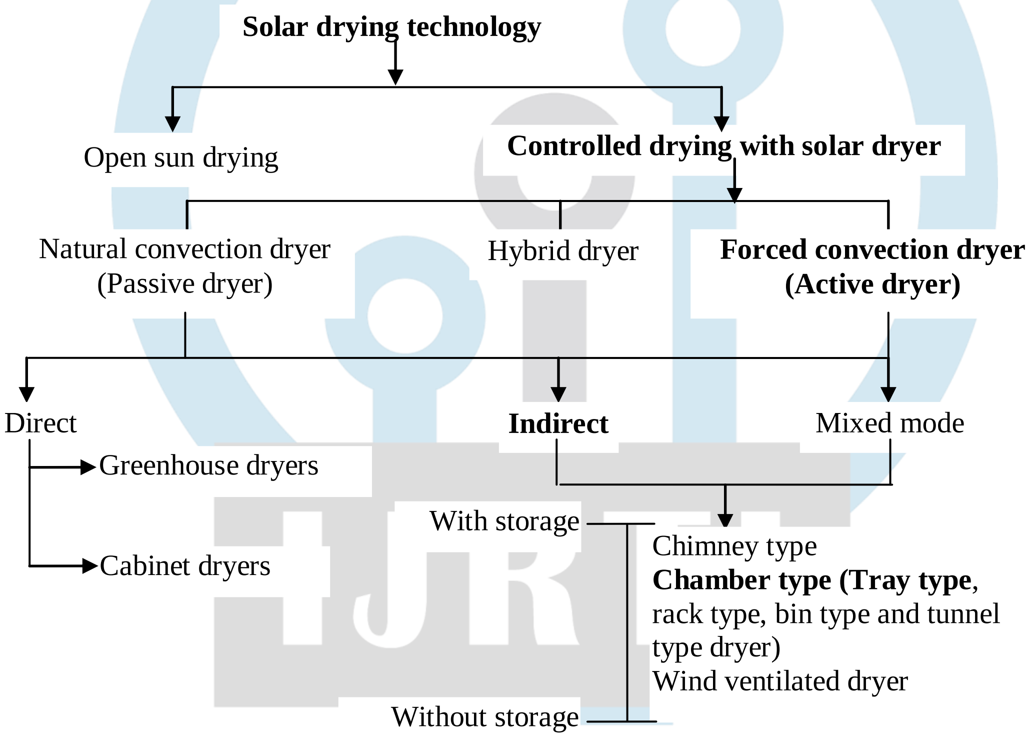

Fig. 2: Classification of solar drying technology

3. ECONOMIC EVALUATION OF RE GADGETS AND SOLAR DRYERS

Studies on renewable energy technologies, including solar dryers and biomass systems, have demonstrated their economic viability for agricultural applications. Greenhouse economics for rose and papaya nurseries using Net Present Worth (NPW), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PBP) was evaluated [19,20]. The commercial potential of briquetting technology using carbonized cashew nut shells was very much useful and confirmed to assess NPW, BCR, and PBP [22]. A PCM-integrated solar dryer, calculating a favourable PBP based on production scales and costs was also analyzed [2]. The economic feasibility of a hybrid solar dryer for spices, fruits, and vegetables, with a short PBP for ginger drying was established [3]. A PBP of less than one year for a greenhouse dryer, well below its four-year lifespan, highlighting the economic efficiency of the systems was evaluated [15].

4. TECHNICAL DESCRIPTION OF IFCS DRYER FOR ROSELLE LEAVES

Indirect forced circulation solar (IFCS) dryer consisted of PV-thermal as well as packed bed solar air heaters, drying chamber, ducting, SS trays, automation, safety and measuring sensors. IFCS dryer was installed in Energy Park of Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Dediapada, Dist. Narmada, Gujarat as shown in Fig.3 and Fig.4. Solar energy produced from the sun was used for air heating through PV-thermal and packed bed solar collector. This hot air was circulated through air blower which was placed between collector and drying chamber. Ambient air was circulated at constant flow rate of 4.1 to 4.4 m/s using air blower to absorb heat from the hot air flowing through absorber plate and to dissipate this absorbed heat inside drying chamber for drying of roselle leaves at constant temperature as well as variable temperature. The system was also provided with electrical heater to optimize in such a way that constant temperature was maintained throughout drying process. Technical specifications of the IFCS dryer are mentioned below in Table 1.

Fig.3: PV-thermal and packed bed collectorsFig.4: Ducting, drying chamber, control panel and blower

Table 1 Technical specification of IFCS dryer

Particulars	Details
PV-Thermal solar collector	Poly crystalline solar cells of 335W stitched on the inner side of the glazing ; Size = 2030 × 1035 × 90 mm; Air flow between solar cells and absorber sheet; Quantity: Three Nos.
Packed bed solar collector	Black painted Al spiral rings as packing material; Size = 2030 × 1035 × 90 mm; Air flow through packing material and over the absorber sheet; Quantity: Six Nos.
Collector stand	MS angle and MS base plate
Drying chamber	Type: Tray dryer; Loading capacity: 10 kg leaves of fresh roselle; Size = 950 × 800 × 950 mm; PUFF insulation; Air flow arrangement through the product
Perforated tray	Size = 630 × 730 × 25 mm; Quantity: 10 in a column
Air Blower	Centrifugal blower of 2000 m^3/h air flow rate; 1 HP AC power of 220V, 100 mm of water column
Ducting	26 SWG GI sheet with protective paint with 150 × 150 mm square having 25 mm PUFF insulation
Automation for weighing of material, flow arrangement, hot air recirculation, constant temperature drying	

5. MATERIALS AND METHODS

The economic analysis of the developed dryer was carried out to find out its economic viability. For the promotion and successful commercialization of any new technology, it is essential to known whether the technology is economically feasible or not. Therefore, an attempt was made to determine economics of the developed solar drying system for drying roselle leaves. Cost of solar dryer was made based on the loading capacity and drying duration per batch. In view of finding out economic viability and suitability of IFCS dryer, four different economic indicators namely Net Present Worth (NPW), Benefit Cost Ratio (B/C ratio), Internal Rate of Return (IRR), Payback Period (PBP) were determined for roselle leaves.

5.1 Payback Period

The payback period [21] is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.The payback period of the system indicates the time required to recover the invested amount.

$$P = \frac{I}{E} \dots \dots \dots [1]$$

Where, P is Payback period of the system, year; I istotal investment in the system, ₹ and E isannual net cash revenue or profit, ₹

Capital cost

The capital cost (C) was found out by determining the cost involved during the fabrication of the IFCS dryer which included the cost of solar air heaters, drying chamber with trays, automations and measuring instruments/devices & control panel.

Fixed cost

The fixed cost includes depreciation, interest, housing, insurance and taxes.

Depreciation (D): The annual depreciation is a measure of the amount by which the value of the machine decreases over a time [14].

$$D = \frac{C - J}{L} \dots \dots \dots [2]$$

Interest (I): The annual interest on the investment is calculated based on the average investment of the solar drying system, taking into account the system value of the first year and last year. [14]

$$I = \frac{i \times (C + J)}{2 \times 100} \dots \dots \dots [3]$$

Insurance and taxes (IT): Insurance and taxes charges were assumed @ 2 % per annum [14].

$$IT = \frac{2 \times C}{100} \ldots \ldots \ldots [4]$$

Total fixed cost

Total fixed cost, ₹/year = D + I + IT… … … [5]

Where, D = Depreciation, ₹/yr; C = Capital cost of solar drying system, ₹; J = Salvage value, 10 % of capital cost; L = Life of solar drying system in years; I = Interest per year; i = Rate of interest per year; IT = Insurance and taxes, ₹/yr

Operating cost

Operating cost includes cost of fresh roselle leaves and fruits, repair, maintenance, labour cost and other miscellaneous costs. The repair and maintenance cost are a product of system's capital cost [14].

RM = 4 % of annual purchase price or capital investment… … … [6]

Total cost of operation

It is a summation of total fixed cost and total operating cost.

Total cost of operation per year = Total fixed cost + Total operating cost… … … [7]

5.2 Net Present Worth (NPW)

The difference between present values of all future returns and the present money required to make an investment is the net present worth or net present principal for the investment. The present values of the future returns can be calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. The interest rate was assumed as the discount rate for discounting purpose. A project returns the same benefit in each of several years and need to know the present worth of that future income stream to know how much it is justified in investing today to receive that income stream.

The most straight forward discounted cash flow measure of project worth is the net present worth (NPW). The net present worth [21] may be computed by subtracting the total discounted present worth of the cost streams from that of the benefit stream. To obtain the incremental net benefit gross cost is subtracted from gross benefit or the investment cost from the net benefit.

$$\text{NPW} = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \ldots \ldots \ldots [8]$$

Where, C_t = Cost in each year; B_t= Benefit in each year; t=1, 2, 3................n; i=Discount rate, %; n =Project life, years

If NPW > 0 Investment is worthwhile; NPW < 0 Investment is not worthwhile and NPW = 0Neutral case

5.3 Benefit Cost Ratio (B/C Ratio)

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The formal selection criterion for the benefit cost ratio for measure of project worth is to accept projects for a benefit cost ratio of one or greater.

In practice, it is probably more common not to compute the benefit cost ratio using gross cost and gross benefit, but rather to compare the present worth of the net benefit with the present worth of the investment cost plus the operation and maintenance cost. The ratio is computed by taking the present worth of the gross benefit less associated cost and then comparing it with the present worth of the project cost. The associated cost is the value of the goods and service over and above those included in project costs needed to make the immediate products or services of the project available for use or sale. Project economic cost is the sum of installation costs, operation and maintenance and replacement costs. The mathematical benefit-cost ratio can be expressed as [21]:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \ldots \ldots \ldots [9]$$

If BC > 1 Investment is worthwhile; BC < 1 Investment is not worthwhile and BC = 1Neutral case

5.4 Internal Rate Of Return (IRR)

Another way of using the incremental net benefit stream or incremental cash flow for measuring the worth of a project is to find the discount rate that makes the net present worth of the incremental net benefit stream or incremental cash flow equal to zero. This discount rate is called the internal rate of return. It is the maximum interest that a project could pay for the resources used if the project is to recover its investment and operating costs and still break even. It is the rate of return on capital outstanding per period while it is invested in the project. The internal rate of return is a very useful measure of project worth.

The internal rate of return can be found out by systematic procedure of trial and error to find that discount rate which will make the net present worth of the incremental net benefit stream equal to zero. Internal rate of return is the discount rate i such that [21]:

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0 \quad \dots\dots\dots [10]$$

6. RESULTS AND DISCUSSIONS

The economic evaluation of the IFCS dryer for roselle leaves was accessed after analysing various economic parameters. The estimated cost break-up of the developed solar drying system are shown in Table 2. The calculation of payback period for developed solar drying system for drying of roselle leaves are shown in Table 3. Total cost of the developed system was ₹ 4,91,000/- including the 12 % GST and 15 % profit.

Table 2Cost break-up of the developed solar dryer

Sr. No.	Item	Cost (₹)
1.	PV-Thermal solar air heaters (3 nos.)	63090
2.	Packed bed solar air heaters (6 nos.)	68220
3.	Stand and locking arrangement (18 nos.) for solar air heaters	31500
3.	Insulated drying chamber with 10 Nos. of SS tray and online load cell and MS stand	110000
4.	Blower with motor (1 hp)	21000
5.	Ducting and insulation	20000
6.	Control panel with sensors automation and electric heater	51000
7.	Motorized damper with control limit switch (3 nos.)	12630
8.	Foundation for stand of solar air heaters, control panel, blower and drying chamber (48 nos.)	7200
	System cost	3,84,640
	Total cost including GST and Profit	4,88,493
	Electrical grinding machine	2,507
	Total system cost	**4,91,000**

Table 3 Assumptions for calculation of payback period

Initial cost of developed solar drying system	(C)	₹ 4,91,000/-	
Assumptions			**References**
Salvage value of developed solar drying system	(J)	10 % of capital cost	[1,25]
Useful life of developed solar drying system	(L)	10 years	[1,25]
Annual working hours	(H)	8 h/d × 300 d/year = 2400 h/year	[1,25]
Annual rate of interest	(I)	10 %	[1,25]
Annual rate of insurance and taxes	(IT)	2 % of initial cost	
Operating cost			
1. Cost of fresh roselle leaves	Rate of leaves = ₹ 25/kg	Mass flow rate = 3000 kg/year	₹75,000/year
2. Labour cost (1 labour)	Rate = ₹ 350/ labour/day	300 days in a year	₹ 1,05,000/year
3. Total energy cost 1 hp blower was operated with the help of DC power generated from the 1005 Wp PV-Thermal solar air heaters through inverter and battery bank.	Used energy = 109.2 kWh/year	Rate = ₹ 8/kWh	₹ 874/year
4. Maintenance cost	Repair and maintenance cost @ 4 per cent of capital cost per annum		₹ 19,640/year
		Total operating cost [A = 1 + 2 + 3 + 4]	**₹ 2,00,514/year** **₹ 66.84/kg**
Fixed cost			
6. Depreciation (D)			₹ 44,190/year
7. Interest on capital (I)			₹ 27,005/year
8. Insurance and taxes (IT)			₹ 09,820/year
		Total Fixed cost [B = 6 + 7 + 8]	**₹ 81,015/year** **₹ 23.15/kg**
		Total cost of operation [A + B]	**₹ 2,81,529/year** **₹ 90.00/kg**

Selling cost of dried product

The recovery (%) in terms of leaves fine powder after sieving was 19.8. The market rate of dried roselle leaves fine powder was ₹ 1200 per kg. The selling price of the dried products used for economic assessment of the developed system is always higher than the market rate of dried products. The selling rate of dried roselle leaves fine powder was ₹ 1200 per kg. Thus total cost of dried leaves (₹/year) is as follows:

$$\text{Market rate of dried roselle leaves fine powder} = Recovery(\%) \times Massflowrate\left(\frac{kg}{year}\right) \times SellingPrice\left(\frac{₹}{kg}\right)$$

Thus, total selling cost of dried leaves = ₹ 7,12,800/-

Table 4Estimated total cost of system dried roselle leaves

1	Weight of dried roselle leaves available from each batch of 10 kg fresh roselle leaves	2.10 kg (21.0 % of fresh roselle leaves)
2	Weight of good quality dried roselle leaves powder available from each batch of 10 kg fresh roselle leaves (fine powder after sieving)	1.98 kg (19.8 % of fresh roselle leaves)
3	Total weight of dried roselle leaves powder produced in a year (300 days drying for roselle leaves in a year)	594 kg/year
4	**Total price of system dried roselle leaves powder produced in a year (@ Rs.1200 per kg)**	**₹ 7,12,800/year**

6.1 Benefit

The benefit is a difference between total cost of dried product and total cost of operation, (₹/year)

Benefit (₹/year) = Total selling cost of dried product - Total cost of operation = 7,12,800 – 2,81,529 = **₹4,31,271 per year**

6.2 Net Present Worth (NPW)

The net present worth for the system is ₹ 21,58,974/-. The NPW is calculated for the next ten years and tabulated in Table 5.

6.3 Benefit Cost Ratio (B/C Ratio)

The present worth of the benefit stream after ten years was ₹.43,79,847/-, whereas the present worth of the cost stream after ten years was ₹.22,20,874/-. Both the value is calculated for the next ten years and tabulated in Table 5.

$$\frac{\text{Benefit (₹/10 years)}}{\text{Cost (₹/10 years)}} = \frac{4379847}{2220874} = 1.97$$

The benefit-cost ratio of the IFCS dryer is found to be 1.97

Table 5 Calculation of cost with cash outflow and cash inflow for IFCS dryer for roselle leaves

Year	Cash Outflow (₹)	PW of Cash Outflow (₹)	Cash Inflow(₹)	PW of Cash Inflow (₹)	NPW (₹)
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(5) – (3)**
0.0	491000	491000.0	0	0	-491000.0
1.0	491000	255935.5	712800	648000.0	392064.5
2.0	281529	232668.6	712800	589090.9	356422.3
3.0	281529	211516.9	712800	535537.2	324020.3
4.0	281529	192288.1	712800	486852.0	294563.9
5.0	281529	174807.4	712800	442592.7	267785.4
6.0	281529	158915.8	712800	402357.0	243441.2
7.0	281529	144468.9	712800	365779.1	221310.2
8.0	281529	131335.4	712800	332526.5	201191.1
9.0	281529	119395.8	712800	302296.8	182901.0
10.0	281529	108541.6	712800	274815.3	166273.6
Total		**2220873.8**		**4379847.4**	**2158973.6**
				NPW	**2158973.6**
				B/C Ratio	**1.97**

6.4 Internal Rate of Return (IRR)

The internal rate of return was found to be 87.98 % for ten years, which indicate that the developed solar drying system was cost efficient technology. The higher the percentage of internal rate of return indicated the good commercial return of the investment. The IRR of a solar dryer for drying 200 kg of roselle using hot air from roof integrated solar collectors was calculated and found to be 70.30 % [11].

6.5 Payback period

$$Payback period (years) = \frac{\text{Initial Investment (₹)}}{\text{Net Annual Cash Inflow (₹)}} = \frac{4,91,000}{4,32,771} = \mathbf{1.13 years or 13.56 months}$$

The IFCS dryer's payback period was estimated by adding the net cash flow to the project until the cumulative net cash flow was equal to the initial investment. It was clear from the above calculation that the IFCS dryer has a payback period of 13.56 months. It was reflected the value of a payback period of 2.14 years for forced convection multi-pass solar air heating collector system for drying of roselle [12]. The payback period of a solar heat pump fluid bed dryer integrated with a biomass furnace for rice drying was evaluated and estimated at 1.6 years [28]. The performance evaluation of solar collector unit with drying cabinet loaded with screw-pine and the economic analysis of the system was investigated and indicated with a payback period of 0.75 year [13]. The PBP of a solar dryer for drying 200 kg of roselle using hot air from roof integrated solar collectors was found to be 3.9 years [11].

The cost economics of developed indirect forced circulation solar dryer is shown in Table 6. The developed system with automation was found as a cost-efficient drying technology.

Table 6 Cost economics of IFCS dryer

Details	Value
Total system cost (₹)	**4,91,000**
Fixed cost (₹/year)	81,015
Variable cost (₹/year)	2,00,514
Total cost of operation (₹/year)	2,81,529
Selling cost of dried leaves (₹/year)	7,12,800
Benefit (₹/year)	4,31,271
Benefit cost ratio (B/C Ratio)	1.97
Payback period (Years)	1.13
Internal rate of return (IRR) (%)	87.98
Net Present Worth (NPW) for ten years	21,58,974

7. CONCLUSION

It was estimated that the total cost of IFCS dryer for roselle leaves drying was approximately ₹ 4,91,000/-. The fixed cost, operating cost, total cost of operation, selling cost of dried product and benefit of indirect forced circulation solar dryer were calculated and observed as 81,015/- (₹/yr), 2,00,514/- (₹/yr), 2,81,529/- (₹/yr), 7,12,800/- (₹/yr) and 4,31,271/- (₹/yr) respectively. The estimated benefit cost ratio, net present worth of investment made on dryer and internal rate of return for the indirect forced circulation solar dryer for roselle leaves drying were about 1.97, ₹ 21,58,974/- and 87.98 % respectively. The indirect forced circulation solar dryer is an effective solution to roselle grower who would be able to recover his investment on solar dryer within a period of 1.13 years by drying only roselle leaves. This type of processing gives more income with less effort. It means the indirect forced circulation solar dryer is very useful technology in tribal region of Gujarat for the economic development of farmers.

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