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Techno-economics study of scheffler solar concentrator based cooking system for elephant foot yam (*Amorphophallus* spp.)

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Abstract
In present scenario solar energy had wide scope in solar thermal sector, as prices of conventional fuels are increasing day by day. Hence, in present experiment steam generation system based on scheffler solar concentrator for cooking of Elephant Foot Yam was design and developed. similarly, over solar cooking traditional cooking test was carried out for Elephant Foot Yam using (*Acacia wood*) and kerosene as fuel source. The specific fuel consumption of Elephant Foot Yam was 0.17 kg/kg when (*Acacia wood*) was used and 0.0675kg/kg when kerosene was used. Similarly, time spent to cook per kg of Elephant Foot Yam was 40.34min/kg for biomass (*Acacia wood*) fuel and 30.36 min/kg for kerosene fuel. Results showed that over conventional cooking, presently developed solar concentrator-based steam generation system could saves fuel and time for cooking of yam. During techno economics study, results revealed that the net present value of developed solar based steam generation system for Elephant Foot Yam was Rs. 269541.5. Benefit-Cost ratio of steam generation unit for Elephant Foot Yam was 1.33. The payback period of solar steam generation unit for Elephant Foot Yam processing was found to be 1 year 5 months.

Keywords: Elephant foot yam, kerosene, scheffler solar concentrator, steam, drying

Introduction
India is located in the equatorial sun belt of the earth, there by receiving maximum radiant energy from the sun. In most parts of India, clear sunny weather is experienced 250 to 300 days a year. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year. (Ummadisingu and Soni, 2010). Solar energy can be used for different purposes and especially in agriculture for cooking, drying, dehydration, water heating, steam generation, distillation, electricity generation, etc.
The konkon region receives average solar intensity about 450 – 600 W/m^2 for 7 to 8 hours in a day and 250 days in a year. But solar energy is mostly underutilised in Konkan region for domestic, industrial and agricultural sector. The energy scenario in India shows that cooking consumes a major portion of the total energy. The household sector alone consumes about 11 per cent of the total energy consumption; out of which cooking energy demands a major share. The solar cookers can offer a partial solution to the poor and warmer sunnier developing region of the world. Solar cooking is an alternative to deforestation with all its ecological implications or to the burning of manure, which otherwise could have been used as fertilizer or simply it is needed because it would reduce the number of hours spent in search for firewood in many villages around the world. Kumar and Chandrashekara (2015) [4] presented four cases where Scheffler reflectors were installed among community kitchen, laundry, electricity plant and bakeries.
The solar energy can be utilized for agroindustry and processing of agricultural produce. Elephant Foot Yam *(Amorphophallus paeoniifolius.)* is an important tuber crop belongs to family Aracea, which grows in the high rainfall Konkan region of Maharashtra during kharif Season. The tubers of Elephant Foot Yam are commonly used as a vegetable after cooking and in preparation of indigenous ayurvedic medicines (Mishra and Swamy 2002) +. Root and tubers are the second most staple food crops after cereals which are grown in tropical regions of the world. (Chandrasekhar and Kumar, 2016). The production potential of this crop is 50-80 t/ha and net economic return is over 1 lakh rupees per ha (Ravi *et al* 2009) [8].

Material and Methods

The Konkan region of Maharashtra is long narrow strip between 15° 37' and 20° 20' N latitude and 72° 7' E and 74°30' E longitude. The present investigation "Design, development of steam generation system compatible to scheffler solar concentrator for Elephant Foot Yam" was carried out at the Department of Electrical and Other Energy Sources, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, During study system component such as receiver, header tank, and steaming vessel were fabricated and installed at the experimental site. For the tracking purpose solar photovoltaic based tracking mechanism was provided which needed one time manual adjustment at morning throughout the day. To overcome the problems faced in traditional cooking, efforts are made to design and developed solar steam generation unit for steaming of Elephant Foot Yam slices. The schematic diagram of solar steam generation system are drawn in Fig.1 as below.

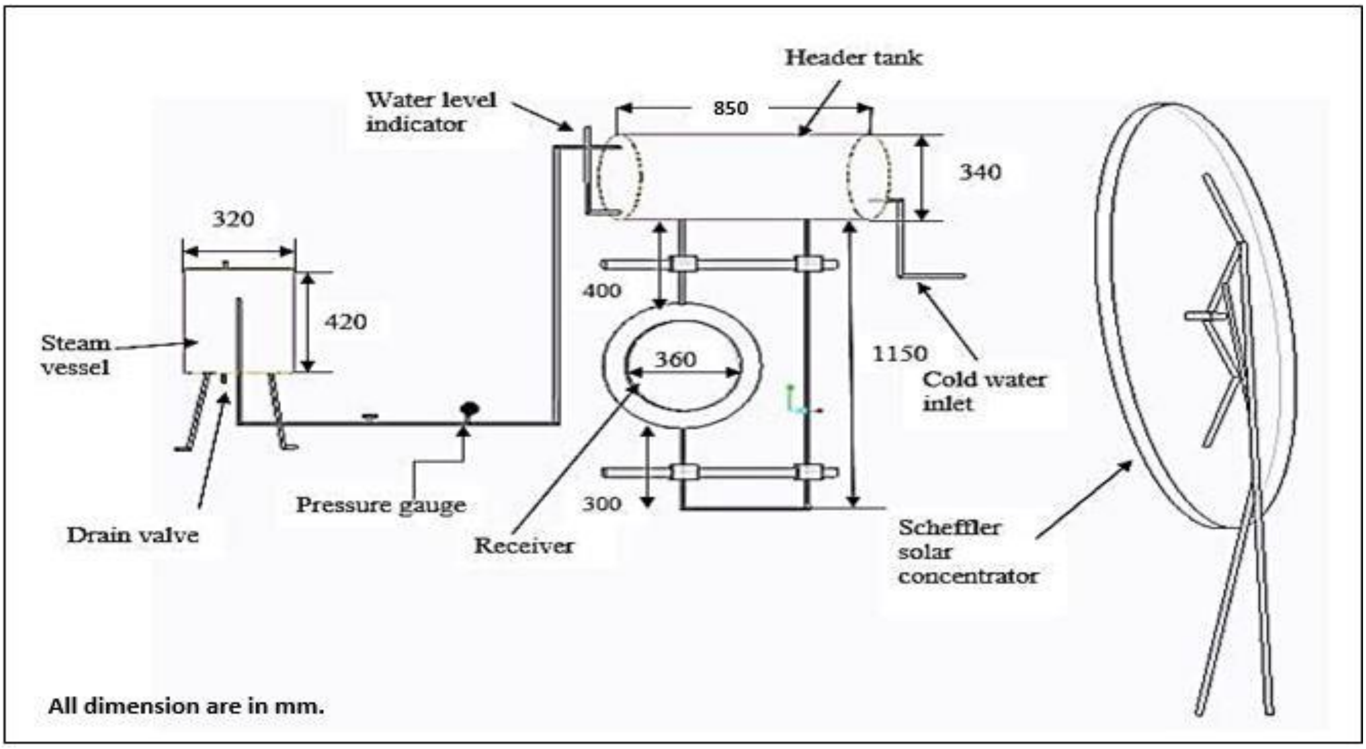

Fig 1: Schematic view of solar based steam generation system for Elephant Foot Yam

The Fresh and healthy corms of Elephant-Foot Yam (*Amorphophallus paeoniifolius.*) (Variety Gajendra) were procured from the Central Research Station Wakawali, Dist: ratnagiri under Balasaheb Sawant Krishi Vidyapeeth Dapoli, Maharashtra, India. The procured corms were washed and sliced into a rectangular shape of size 3 × 2 × 1 cm. The cooking process for Elephant Foot Yam samples were performed on developed stem generation unit at energy park CAET, Dapoli.

Production of Elephant Foot Yam flour

Processing layout of Elephant Foot Yam flour production were explained in following flow chart (Fig.1). The aim of the present experiment is to make proper utilization of solar thermal energy for production of Elephant Foot Yam flour. The Elephant Foot Yam is lost after 5-6 months of storage after harvesting, so after cooking and drying of Elephant Foot Yam slices or milling into Elephant Foot Yam flour to make the availability of Elephant Foot Yam in various forms to the consumers, which may be used in food processing industry as thickening agent, Elephant Foot Yam flour is more effective medicine for piles and diabetic patients.

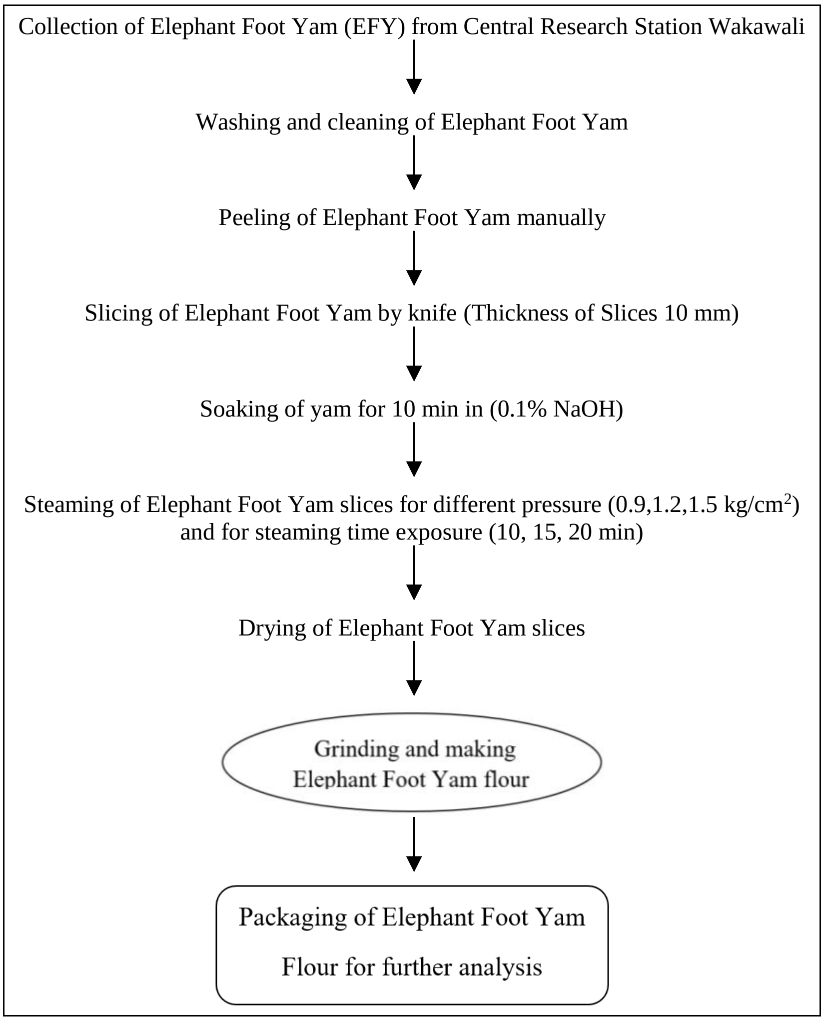

Fig 2: Process flow chart for preparation of Elephant Foot Yam flour

Elephant Foot Yam slices were dried until constant weight was obtained. The dried Elephant Foot Yam slices were ground and made powder by using laboratory grinder and sieved by using 60 mesh screens to obtain Elephant Foot Yam flour. The flour Samples were then stored in air tight plastic containers for analysis.
According to Danshehu *et al.* (1992) [1], the SFC and the time requirement (T) for cooking per kg of food material were computed from the data as follows.

$$\text{Specific fuel consumption} = \frac{\text{Mass of consumed fuel}}{\text{Total mass of cooked food}}$$

$$\text{Specific Fuel Consumption} = \frac{(m_{\text{fo}} - m_{\text{f1}})(1 - x) - 1.5\text{m}_c}{(m_{\text{pc}} - m_p)}$$

$$\text{Time required for cooking} = \frac{\text{Total Time Spent in Cooking}}{\text{Total mass of cooked Food}}$$

$$\text{Cooking Time (T)} = \frac{T_0 - T_1}{(m_{pc} - m_p)}$$

T = Cooking time for 1kg of foodstuff, (min/kg);
T_0 = Initial time before cooking (min);
T_1 = final time after cooking (min);
m_{pc}= mass of pot with cooked food (kg);
m_p = mass of empty pot (kg);
x = moisture content value of fuel assumed to be zero, i.e., 100% dryness;
m_c = mass of charcoal left (kg);
m_{fo} = Initial mass of fuel before combustion (kg);
m_{f1} = final mass of fuel after combustion (kg).

Techno-economic feasibility of developed scheffler solar concentrator based steam generation system

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or not. Therefore, an attempt was made to determine economic of the developed solar based cooking system under climatic condition of konkan region for cooking of Elephant Foot Yam.

Net present worth (NPW)

The difference between the present value of all returns and the present money require making an investment is the net present worth. The present value of the future returns was calculated through the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. (Pawane *et al*, 2018) [7]

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = discount rate

Benefit cost ratio

This is the ratio obtained when the present worth of the benefit stream was divided by the present worth of the cost stream. The mathematical benefit-cost ratio can be expressed as:

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

Where,
C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n (year)
i = discount rate

Payback period

The payback period 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. The payback period of the project was estimated by using the straight forward formula:

$$P = \frac{I}{E}$$

Where,
P= Payback period of the project in years,
I = Investment of the project in rupees and
E = Annual net cash revenue in Rs.

Result and Discussion

During study the economics feasibility of solar based steam generation system for Elephant Foot Yam processing were discussed in this section. The economic indicators such as cost benefit ratio (B.C), NPV (Net present worth) and payback period of solar based steam generation system for Elephant Foot Yam was calculated by considering the initial investment of steam generation unit, initial investment on the system components, average repair and maintenance cost, cost of raw material and selling price of the material after drying Based on the study, average parameters were calculated for economics analysis depicted in Table.1

Table 1: Cost analysis of developed solar based steam generation system for Elephant Foot Yam processing.

Sr. No	Description	Particulars
1	Initial investment (Rs)	85,000
2	Annual use no. of batches	150
3	Cost of raw Elephant Foot Yam (Rs yr-1)	90,000
4	Cost of labour (Rs yr-1)	(150*180) 27000
5	Repair & maintenance cost (10% for every5 year)	1,700
6	Total dried product (kg)	1,260
7	Total cost of finished product, @140Rs/kg	1,76,400
	Economic indicator	
a	Net Present Worth (Rs.)	2,69,541.5
b	B:C ratio	1.33
c	Payback period	1.47 yrs. 1 year, 5 month

Comparative study of solar cooking verses conventional cooking

The Comparative fuel requirement over solar cooking, performance of locally biomass material (Acacia wood) and kerosene fuel were used for domestic cooking of Elephant Foot Yam. Cooking test was carried out for Elephant Foot Yam using biomass *Acacia auriculiformis* (Subabul) wood and kerosene. During experiment specific fuel consumption (SFC) value of Elephant Foot Yam was 0.17 kg/kg, when *Acacia auriculiformis* (Subabul) was used and 0.0675kg/kg when kerosene was used. On the other hand, time spent to cook per kg of Elephant Foot Yam was 40.34min/kg for *Acacia auriculiformis* (Subabul) fuel and 30.36min/kg for kerosene fuel. The Variability observed in cooking time due variability in calorific value of fuel utilized in experiment. The calorific value of the subabul wood was found to be 16.8-17.2 MJ/kg as against that of kerosene which is around 43.1MJ/kg (Karen 2004). Utilization of solar energy in cooking sector, we could saved the long term negative environment impact from conventional fuel sources such as biomass woody material and kerosene.

Net present worth (NPW)

The net present worth for solar based processing of Elephant Foot Yam was found Rs. 269541.5.based on the NPV it could be concluded that developed solar based steam generation system for Elephant Foot Yam was economical and substantial increase the income by processing of Elephant Foot Yam.

Benefit cost ratio

The BC ratio of the present system was calculated by dividing the present worth of the benefit stream and the present worth of the cost stream. Table.1 revealed that benefit cost ratio of steam generation unit for Elephant Foot Yam found 1.33 thus it concluded that investment for Scheffler coupled steam generation system for production of Elephant Foot Yam flour is justified and economically viable.

Payback period

The payback period of solar steam generation unit for Elephant Foot Yam processing was found to be 1 year 5 months for recovery of the initial investment of solar steam generation system. Thus, it could be concluded that the present developed solar steam generation system seems to be economical for steaming of Elephant Foot Yam.

Conclusions

Scheffler solar concentrator based developed solar steam generation system for Elephant Foot Yam was found to be economical and substantial increase the income by processing of Elephant Foot Yam. The drying process has a positive influence on marketing storability and help to increase the demand of the Elephant Foot Yam flour. Thus economic status of the Elephant Foot Yam growing farmers may be improved by the value addition and generate scope for product development. Solar energy could be efficiently utilized for agroindustry and processing of agricultural produce to save commercial fuels such as LPG, natural gas and kerosene.

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