Small Scale Batch Dryers for Developing and Underdeveloped Countries

A write-up on compilation of small-scale batch dryers

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Introduction

Post-harvest losses significantly reduce the volume of agricultural commodities available for consumers around the world. The problem of postharvest loss is especially prevalent in less developed countries, where postharvest management is challenged by changing climate, poor physical infrastructure and weak market institutions. Agricultural commodities have to undergo a series of operations like harvesting, threshing, winnowing, drying, bagging, transportation, storage, processing and exchange before they reach the end consumer [1]. Drying is a critically important step in the postharvest systems because inadequate drying can lead to quality and quantity losses during later stages including storage and milling. The critical role of drying is often reflected in significant discounts on grain prices based on moisture content [8].

High moisture content coupled with warm temperatures increases the potential for pests, insects, mold and fungi to infest grain, reducing its quality and market value. High moisture content causes grain to respire faster, which leads to its faster deterioration during storage. Indeed, there is a strong association between moisture content and mold and other sources of loss during storage. High moisture content also lowers the germination rate of the grain intended for seeds. Drying the grain before storage allows more time for postharvest field activities. It also allows for safe transport over longer distances without suffering spoilage and can be a necessary condition for efficient milling. Hence, improved drying technology is often identified as a key step to addressing postharvest losses.

Small scale drying refers to drying of grains on an individual or a co-operative level by farmers who do not have large volumes of production, usually less than five tons. Such farmer must either own their own drying equipment, haul grain to a centralized dryer, receive services from a mobile service provider, or suffer from either high storage losses or low sales prices as a result of failure to dry grain appropriately. The practicality of a drying process is defined by its appropriateness for smallholder producers who may lack easy access to centralized services. In the most basic process, drying can be carried out on open, unassisted air on a drying floor or in the field. Drying can also be be mechanized through use of forced convection of dry air. Small-scale forced air drying methods include batch drying in either flatbed dryers or circular bin dryers.

Sun Drying

1. Open Sun Drying

Open sun drying consists of spreading grain on the ground in a yard or leaving cut grain in the field. In some cases, grain is spread on a tarp or mat which can reduce losses. Open sun drying is the least resource-and-cost-intensive method of drying and is suitable for small batches. However, the effectiveness of open sun drying depends on weather and is subject to exposure from insects, birds and farm animals as well as soil and rain. In may regions climate change and shifting crop calendars are increasing the negative impacts of exposure to weather on open sun drying. This method is also time-consuming and requires substantial labor for either mixing or guarding grains. As a result, it becomes increasingly problematic as rural wages rise or labor scarcity intensifies. Finally, unassisted drying can only decrease the moisture content up to a certain level reflecting relative humidity and temperature, after which mechanical

Sun drying in yard

intervention becomes necessary. Accordingly, it may be beneficial to consider mechanized drying alternatives to add value to the farming business. A survey of 200 smallholder rice growers in Bangladesh, for example, found sun drying to require three to five days in the field or two to three days in a yard and suffer losses of about 5% in field at 3% in yards. Despite the time losses, 99% of farmers used direct sun drying either in field on in yards with no mat or paving. (Saha 2018)

2. Solar Bubble Dryer

The Solar Bubble Dryer uses solar energy for heating and electric energy for forcing air through the grains. It is a tunnel-type dryer, designed as an alternative to open field drying. The bubble-like drying tunnel made of low-density polyethylene (LDPE) plastic acts as a solar energy collector, which heats the air trapped in the tunnel. Grain is placed in the bubble and a fan circulates the warm, dry air throughout the tunnel to dry the grain. When coupled with photovoltaic solar panels to generate electricity, the solar bubble dryer can be used completely off the grid with no requirement of fuel for heating or convection. Even drying may require mixing the grain, which can be accomplished either by opening the bubble and raking the grain or by dragging a small roller underneath the dryer throughout its length.

Fig. 1: GrainPro's Solar Bubble Dryer. [2]

Characteristics:

Capacity: The Solar Bubble Dryer is manufactured by GrainPro Corporation and comes in two variants based on capacity: SBD25 and SBD50 with 500 kg and 1000 kg capacity respectively per batch. SBD25 has a drying area of 269 ft^2 whereas SBD50 has an area of 538 ft^2.

Drying performance: The manufacturer claims that the Solar Bubble Dryer can reduce the moisture content by one percentage point every two hours for rice and corn given good weather conditions. Accordingly, during sunny days, a batch of rice can be brought from 22% to 14% moisture content in one day. The drying rate in sunny weather is comparable to that of direct sun drying. During cloudy weather or rains, drying may take up to two days in the Solar Bubble Dryer. Direct sun drying is such conditions can lead to grain quality losses that are avoided with the Solar Bubble Dryer. The Solar Bubble Dryer can be only operated in nighttime if the relative humidity of the surrounding is lower than the equilibrium relative humidity of the grain.

Costs of Owning and Operating.

The purchase price for a Solar Bubble Dryer depends on the size of the device and the power source, as indicated in table XX.

Table XX: Solar Bubble Dryer Estimated Price as of October, 2018.

Power type	Capacity (kg)	Price (USD)
Electricity	500	1,350
	1000	2,050
Solar	500	1,925
	1000	3,125

Source [2]

Setting aside labor, the operating cost for the Solar Bubble Dryer with a solar powered fan is zero. The electric solar bubble dryer comes with a 500 W transformer and the cost of operation will depend on the costs of operating a generator or purchasing electricity from a grid. The manufacturer has published no information about its operating costs. A cost-benefit analysis reported by the International Rice Research Institute finds that in Southeast Asian countries a breakeven point can be reached if the dryer is used by individual farmers with two hectares of rice fields and two crops per year as long as they receive a price premium for better quality paddy. Such premiums may not exist in many local rice markets. The report does not indicate whether a farmer with less than two hectares could recover the investment cost in the Solar Bubble Dryer at current prices.

General comments:

- Compared to open sun drying, the Solar Bubble Dryer provides protection from environmental elements like insects and vermin and also keeps the grain from contact with soil and rain.
- The dryer can be disassembled and rolled up to be carried in a bag.

Advantages:

- Can be used in areas with no electricity, when equipped with solar powered fan.
- Highly portable and easy to assemble and disassemble.

Disadvantages:

- Less effective during the night and in cloudy conditions.
- Relatively high capital costs.
- Requires large space per batch and has low bed height.
- LDPE material is susceptible to damage by rodents.
- Raking grain may be labor intensive and failure to rake may lead to uneven drying.

For further information see:
http://www.knowledgebank.irri.org/images/docs/fs-solar-bubble-dryer-2016.pdf?pdf=Solar-Bubble-Dryer-fact-sheet
http://www.knowledgebank.irri.org/step-by-step-production/postharvest/drying/mechanical-drying-systems/the-solar-bubble-dryer

For purchasing see: https://grainpro.com/grainpro-bubble-dryer/

B. Circular Bin Dryers

Circular bin dryers hold grain in some type of bin and ventilate the grain radially outwards to dry it. They are compact and can dry grain in a faster and more controlled manner than open air systems or sola and save floor area. However, drying is relatively uneven as compared to other flat surface drying techniques.

1. STR dryer

Fig. 2: Photographic view of an STR dryer. [3]

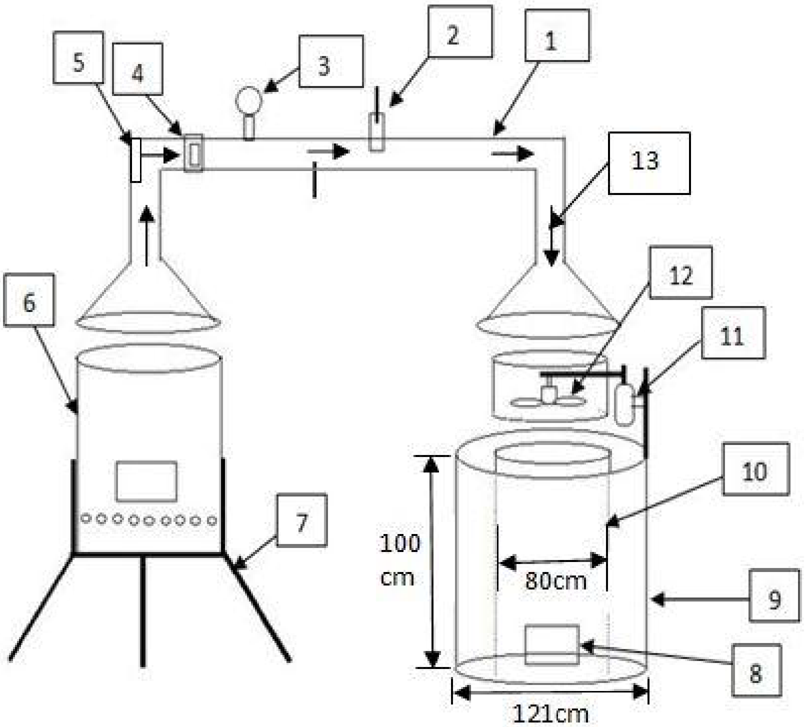


Fig. 3: Schematic view of an STR dryer. [3]

(1) Hollow pipe; (2) Digital temperature sensor; (3) Pressure gauge; (4) Digital anemometer; (5) Gate valve; (6) Stove; (7) Tripod stand; (8) Discharge gate; (9) Outer cylindrical bin; (10) Perforated inner cylindrical bin; (11) Motor (12) Fan and (13) Hot air

The STR dryer represents a bin dryer for use on farm by smallholder farmers. It uses a small stove to heat air, which is drawn through a pipe by a fan and into an inner bin made of perforated material. The inner bin rests inside an outer mesh bin (Figures 2 and 3). Grain that has been loaded into the outer bin, leaving the inner bin empty, is dried by warm air moving into the inner bin and through the grain. A one-horse power motor is required to run the fan, and a valve can be added to the pipe to introduce ambient air for temperature control. The bottom of the bin may be set at a 15° slope for easy discharge of dried grains, but the bin bottom can also be laid flat on the ground. As adapted by the Bangladesh Agricultural University, the BAU-STR dryer uses an adjustable wire outer bin to hold between 0.4 and 0.5 tons of rice paddy (Fig. 2 and 3) and includes a cover over the bins to improve convection. Bins may be made of steel mesh, bamboo or other material. In Bangladesh, locally available rice husk briquettes are used as fuel, but other fuel sources can also be used. The BAU-STR dryer is designed for easy disassembly, which makes the dryer portable in a small pickup truck or trailer [3].

Characteristics:

Capacity: With the dimensions shown in figure 3, the dryer can hold 500 kg of grain per batch. In this design the layer of grain being tried is roughly 30 centimeters (12 inches) thick. This relatively thin layer allows for even drying with little moisture variation given the air flows from the fan. If the bin were enlarged, the drying time would increase per batch, the fan motor would need to be be larger and stirring the grain might be needed to achieve even drying.

Drying performance: Using a 390 mm diameter axial blower powered by a 1 hp motor to produce 1.5 m/s air velocity for the given dimensions of the STR dryer, 500 kg of paddy was dried from 24.75% to 8.5% moisture content in 7.5 hours with 43°C temperature of drying air. This corresponds to an average moisture reduction of 2.17% per hour. With the same set up but increased temperature of about 57°C and with 3.0 m/s air velocity, the drying time can be reduced to as low as 3.5 hours. However, operating at these conditions may lead to over-drying and loss of germination capacity in the grains [3].

Economic feasibility:

Components required for fabrication: Stainless steel mesh for creating inner and outer bin (variants using bamboo instead of steel have also been made), axial blower, hot air conveyor pipe, biomass stove, bricks, stone or soil clod, polythene sheet for covering the top of bin, bamboo and rope. The fan can be powered by either electricity from the grid or by using a diesel generator.

Capital cost: User of the STR dryer in Bangladesh and India report fabrication costs of around USD $500. This excludes the cost of a diesel generator which may be required to operate the fan. If a generator is required the costs approach USD $700. The economic service life of the dryer is estimated to be 10 years. [7]

Operating cost: Engineers at the Bangladesh Agricultural University calculated the operating cost of the STR dryer to be USD 6.80 per batch of 500 kg grains. This includes the rice briquette consumption and the 0.6 liter diesel required to run the diesel generator for powering the blower per batch. The operating cost could be reduced marginally if the power to run the blower can be obtained from the national grid instead of the generator. [7]

Economic analysis: Based on calculations from engineers at the Bangladesh Agricultural University working with rice and studies from the Rajendra Prasad Central Agricultural University (Bihar State, India) the payback period for the dryer is estimates to be one to two years, depending on the capacity utilization. The economic gains are higher when there are multiple crop harvests and when sun drying is costly or difficult due to weather. [7]

General comments:

Advantages:

- The dryer can be fabricated by local artisans in developing countries.
- It can be disassembled and made portable.
- It is compact in size.
- It offers low capital and operating cost.
- It allows efficient drying regardless of weather conditions.
- It is suitable for small volumes of grain, commensurate with needs of smallholder farmers.

Disadvantages:

- The dryer has no heat exchanger which means that ash can come into direct contact with the grain.
- Heating and drying can be uneven unless airflow and temperature are managed with some care.
- The STR dryer cannot be scaled up easily. Drying more than one ton per day would require additional dryers which could be challenging to simultaneously monitor and manage.
- The dryer is inappropriate where fuel is unavailable or costly.

For more information or for blueprints of fabrication, contact Dr. C. K. Saha at +88 091 674016 or email at cksaha@bau.edu.bd or Ashok Kumar at +91 641 2452609 or email at dabausabour@gmail.com.

Reference:

- Alam, M.A., Saha, C.K., Alam, M.M. et al. “Neural network modeling of drying of rice in BAU-STR dryer” Heat Mass Transfer (2018) 54: 3297. https://doi.org/10.1007/s00231-018-2368-5

- Ashok Kumar, Satish Kumar and Sanoj Kumar, “Performance Evaluation of Modified STR Dryer for Drying of Paddy in Process of Reducing Post-Harvest Losses” International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706 Special Issue-7 pp. 2959-2968

2. Solar Assisted Grain Dryer

Like the STR dryer, a Solar Assisted Grain Dryer is a circular bin batch dryer. The innovation in the of this solar assisted dryer is to increase the temperature of the ambient air by passing air through a solar heat collector to absorb the solar energy and then using this heated air to remove the moisture from the moist grains. It is similar to the STR dryer, but replaces the stove with a solar collector to heat and dehumidify the air flowing into the drying chamber. As shown in Figure 4, a blower or fan is required to move the air and the bin drying chamber is closed, rather than perforated.

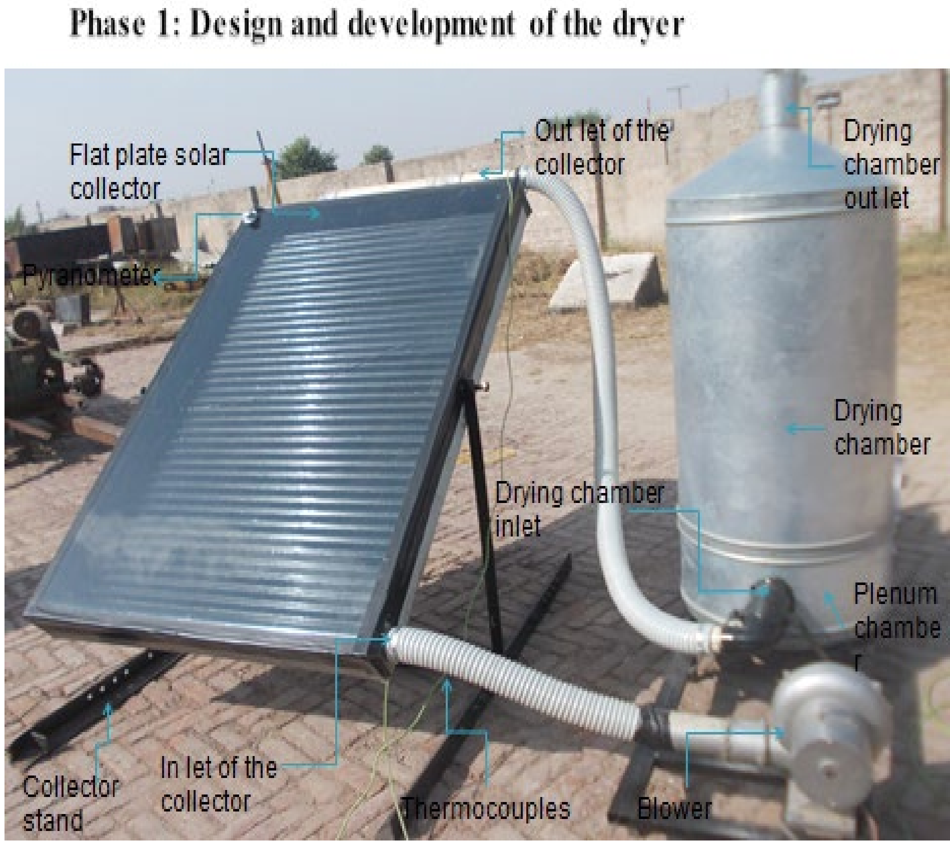


Fig. 4: Photographic view of solar assisted paddy dryer. [4]

Characteristics:

The commercial availability of either the blueprints of this dryer or the entire dryer could not be determined at the time of this writing. Accordingly, all information about the characteristics is based on a research article published by its developers [4].

Capacity: The developers of the solar assisted dryer pictured in figure 4 ran a volume of 100 kg paddy. As the solar collector offers very limited capacity for heating circulated air, it would be difficult to dry larger volumes in this design.

Drying performance: Using a 0.5 hp blower, 100 kg of paddy was dried from an initial moisture content of 24% to 14% moisture content in 7 sunshine hours with drying air temperature of 43°C. The incident solar radiation was 850 W/m^2 with collector efficiency of 30 - 50%. This corresponds to an average moisture reduction of 1.43% per hour.

Economic feasibility:

Components required for fabrication: flat plate collector made from wood with U-corrugated absorbed plat with triangular fins, glass wool for insulation, colorless glass sheet as cover for collector, food grade stainless steel for the inner and outer bins of the drying chamber, blower and SS duct pipes.

Capital cost: The developers estimated the purchase price of this dryer to be about USD 700. This price included the labor. The useful life was assumed to be 10 years.Use of galvanized metal rather than food grade steel in the outer bin could reduce cost.

Operating cost: The inventors estimated the operating cost to be USD 1.67 per batch of 100 kg paddy (converted from INR to USD). The estimate included the fixed cost of the dryer, energy cost for running the fan, repairs for the dryer and the labor cost for loading and unloading the grains.

General comments:

Advantages:

- No ash comes in contact with the grains.
- This dryer can serve as a cleaner (less polluting) version of the STR dryer.
- Uniform drying.
- Convenience of loading and unloading with a screw conveyor on the side of the drying chamber.

Disadvantages:

- Cannot be used during the night, cloudy weather or rainy season.
- No / limited control on drying air temperature as compared to the STR dryer.
- Low volumes
- Capital cost and operating cost of the dryer is high considering the capacity. The payback time can be expected to be five times longer than that of the STR dryer as the drying volume is 20% of that of the STR dryer, at best.
- Efficiency of the dryer is subject to the weather.
- Dryer is not commercially available.

For more information, email the author of this article Sidrah Ashfaq at sidrah708@uaf.edu.pk

3.0 Other Bin Dryers

C. Flat Bed drying:

In the flatbed dryers, grain is laid out on a perforated screen, and dried by forcing heated air from below. A fan that provides the drying air is usually a simple axial flow fan. A furnace provides drying heat. The height of the grain layer is usually 25 - 40 cm. An air temperature of 40 - 45 ºC is normally used with a heater capable of raising the air temperature 10 - 15 ºC above ambient. Loading onto the bed is done manually. Unloading may be manual there could be unloading ports build into the walls of the bed through which dried grains can be channeled out. Multiple versions of the flat bed dryer have been developed for use by smallholders.

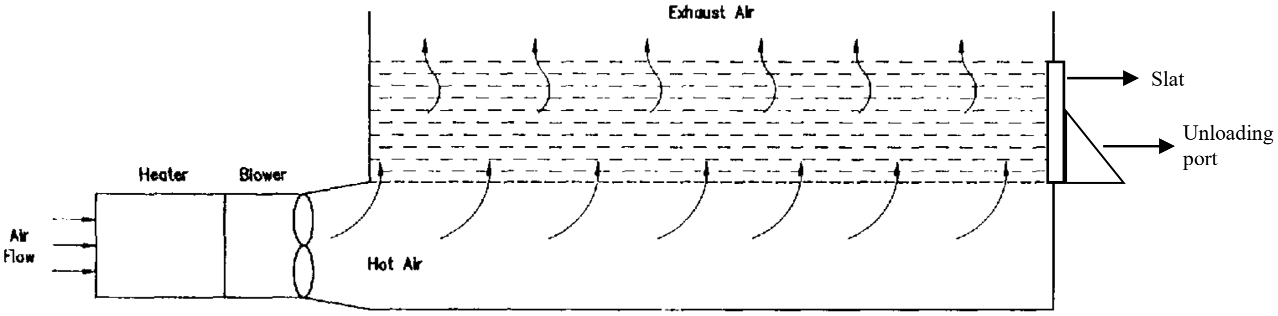


Fig 1. Conventional flatbed dryer with unloading port. Adapted from [8].

1. IRRI Flatbed dryer

This flatbed dryer, developed by International Rice Research Institute (IRRI), Philippines, is the classic example of a simple flatbed dryer. It is a shallow layer dryer, with the grain supported on a mesh tray.

Fia.2 A PhilRice flatbed drver [6]

Characteristics:

Capacity: The developers indicate that the minimum economically viable bed size accommodates 3 tons of wet grain per batch. Further, the area of the bed can be increased to hold as much as 10 tons, as long as the grain depth is not more than 25 cm. Given this depth, the bed size should be approximately seven square meters m^2 per ton of grain. As a rule of thumb, the length of the bed should be twice the breadth. If a flatbed dryer is working properly, there will be a steady flow of air through the grain on the bed. To test for threshold air flow, letter-sized sheet of paper may be placed on top of the grain at various locations. If the paper floats freely above the bed, the air flow is sufficient.

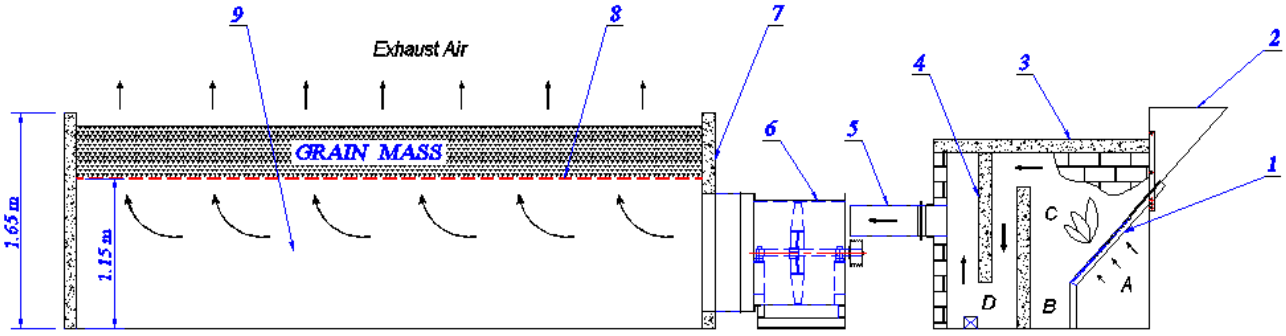


Fig.3 Schematic diagram of a flatbed dryer [6].
(1) Inclined-step grate, (2) Feeding hopper, (3) Top cover, (4) Baffle, (5) Furnace outlet, (6) Dryer fan, (7) Drying bin, (8) Perforated floor, (9) Air plenum chamber
A - Primary air; B - Ash pit; C - Combustion chamber; D - Ash trapping chamber

Drying performance: Using a 750 mm diameter axial flow fan with an air flow of 4 m^3/s, a 4 ton batch of paddy can be dried from 25% to 15% moisture content in 9 - 11 hours, assuming the drying air temperature is ~ 42 °C. This gives an average moisture reduction rate of 1% per hour. The same result can be obtained for an 8 ton batch, with the only change being that, to maintain sufficient airflow, two fans will be required [5], [7].

Table 3. Source [3]

	Grain				
	Paddy Rice	Maize	Maize-on-cob	Peanut	Coffee (pulped)
Quantity (ton)	4	5	15	4	4
Drying time (h)	10	10	48	12	14
Moisture content Initial and final (%)	25 – 15	30 - 15	30 – 20	25 - 10	45 - 15

The model shown in Figure XX uses a rice husk furnace. However, any biomass source can be used to generate heat and dehumidify air, but operators need to minimize generation of smoke to avoid damage to the crops and health risk for operators. To reduce the inconsistency in drying / over or under-drying, the grains should be mixed periodically. The drying air temperature should not exceed 43°C for most crops, since temperatures higher than that negatively affect the germination capacity of the grain. Increasing the temperature will reduce drying time; however, will lead to uneven drying unless airflow is appropriate. Increasing the airflow may reduce the drying time and/or may help in decreasing moisture content; however, it will increase the energy cost. When drying for milling, maintain the moisture content at 14% so that the grain weight and milling yield will not decrease.

Economic feasibility:

Components required for fabrication: Bricks with concrete or metal sheets to create the furnace, housing for the blower and the bin, an axial flow blower (can be either made or bought from the market), fine wire mesh or perforated metal to place over the plenum, a diesel generator (or connection to the electrical grid) to power the blower and a shed (optional, however, recommended for rainfall-prone regions)

Capital cost: For a 6 ton conventional flatbed dryer with concrete bin, a blower, rice husk-fed furnace, a diesel engine and a steel-type and open-type shed, the initial investment was ~ USD 10,570 (including labor, taxes and insurance) [8]. The cost estimates are based on data from The Philippines and can vary across countries and regions.

Operating cost:

Table 1. Operating costs calculated from a 6 ton batch of newly harvested long grain paddy in Philippines, 2011 [4]

Rice husk consumption rate (kg/h)	33
Rice husk cost (USD/kg)	0.017
Diesel fuel consumption rate (L/h)	1.1
Diesel fuel rate USD/L	0.65
Labor cost for operator USD/h	0.72
Labor cost for loading and unloading (USD/ton)	3.82

Values converted from PHP to USD. USD 1 = PHP 53

Economic analysis:

Table 2. Source [4]

Drying cost (USD/ton)	13.00
Payback period (years)	1.7
Internal rate of return (%)	54.4
Breakeven point, (batches/year)	42.5
Annual net income at 120 batches per year (USD)	5,555.87

Values converted from PHP to USD. USD 1 = PHP 53

These rates are based upon assumptions in [8].

General comments:

Advantages

- This dryer can be used in any weather, so long as it is covered during operation. This can be done by either covering just the bin with a tarpaulin or making a shed over the entire dryer.
- The dryer can be used as an integrated storage vessel as well, as long as care is taken to prevent damage due to insects and vermin.
- With occasional repair and maintenance, this dryer will work for at least 5 years.
- Incorporation of an ash trap into the furnace to reduce exposure of sooty gas to grains due to combustion of biomass.

- Doesn't depend on weather. Can be used in humid regions just as easily as in dry regions.
- Offers storage and drying ability.
- Doesn't require skilled labor or operators.

Disadvantages:

- Size can become unmanageable at high scales
- Minimum scale may be too large for smallholder to independently operate
- Not portable
- Requires frequent attention during drying.
- Deep grain beds may result in inconsistent drying.
- Doesn't incorporate a heat exchanger in the furnace, thereby allowing ash to come in contact with the grains.

Troubleshooting:

For troubleshooting, the IRRI link provides solutions to all the problems which one may face during the use of these dryers. Click here: http://www.knowledgebank.irri.org/training/fact-sheets/postharvest-management/drying-fact-sheet-category/item/troubleshooting-a-flat-bed-dryer-fact-sheet

For information regarding fabrication or in general, email postharvest@irri.org or call +63 2 580 5600.

2. Reversible Air Flatbed Dryer (SRA Dryer)

Reversible air dryers, such as the Vietnamese SRA Dryer, improve on the conventional unidirectional flow flatbed dryer by introducing the principle of airflow-reversal drying. The reversible air dryer adds a cover to a standard flatbed dryer and an air channel to allow the operator to force air from the top down or from the bottom up. By reversing the airflow, these dryers reduce the moisture differential between the topmost and bottommost layers of grain, thereby increasing the consistency in drying.

Characteristics:

Capacity: The SRA dryer is akin to many reversible air dryers. This dryer can be modified to have capacities ranging from 500 kg all the way to 12 tons per batch. The bed height can be as high as 60 cm. However, to keep the airflow even, the length of the bed should be two to three times the breadth. The deeper bed implies that for the same area as a conventional flatbed dryer, the reversible air dryer can have almost two times the capacity. Unlike the case for the standard flatbed dryer, one may not need to test the threshold air flow in an SRA dryer by the paper floating method, since the air flow will be reversed in the second drying period.

Drying performance: Using a 900 mm diameter two stage axial flow fan with an air flow of 8 m^3/s, an 8 ton batch of paddy can be dried from 24% to 12.5% moisture content in 9 - 11 hours, assuming the drying air temperature is ~ 42 °C. After roughly 5 hours of drying in upward flow, the

Fig 4 SRA dryer [9]

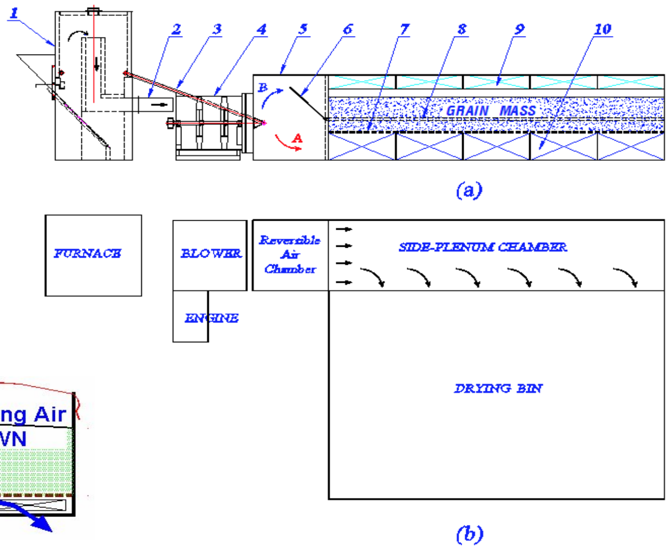
plate must be adjusted to reverse the air to downward flow (Figure 5). This gives an average moisture reduction rate of 1.15% per hour. In order to make the dryer of different capacities, it may be necessary to experiment with different airflow rates in order to optimize the heating time without compromising dried grain quality.

A mobile variant may be constructed for a reversible dryer. The developers of the SRA dryer have experimented with a mobile dryer of 3 ton/batch capacity (Figure 6).

Economic feasibility:

Components required for fabrication: Bricks with concrete or metal sheets to create the furnace, housing for the blower, plenum chamber and the bin, an axial flow blower (can be either made or bought from the market), fine wire mesh or perforated metal to place over the plenum, tarpaulin cover attached to the bin with a zip or fastened to the bed through ropes, a diesel generator (or connection to the electrical grid) to power the blower and a shed (optional, however, recommended for rainfall-prone regions)

Capital cost: For an 8 ton SRA - 8 dryer with concrete bin, a blower, rice husk-fed furnace,



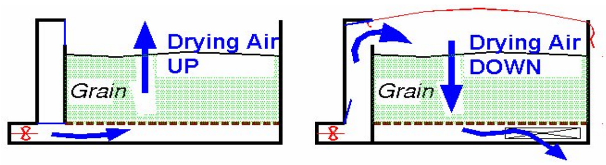


Fig.5: Schematic diagrams of an SRA dryer. [9] a) Front view, b) Layout plan. (1) Furnace (2) Furnace outlet (3) Secondary air pipes (4) Blower (5) Reversible air chamber (6) Reversible plate (7) Screen floor (8) Middle slap (9)Upper air inlets (B connected) (10) Lower air inlets (A connected); A: upward drying (1st drying period), B: downward drying (2nd drying period)

a diesel engine and a steel-type and open-type shed, the initial investment was ~ USD 19,820 (including labor, taxes and insurance) [8]. The estimates are based on data from The Philippines in 2011. Costs can vary widely across countries and regions. To save expenses, the bin can be made out of metal sheets.

Operating cost:

Table 4. Operating costs calculated from an 8 ton batch of newly harvested long grain paddy in Philippines, 2011 [4]

Rice husk consumption rate (kg/h)	45
Rice husk cost (USD/kg)	0.017
Diesel fuel consumption rate (L/h)	1.6
Diesel fuel rate USD/L	0.65
Labor cost for operator USD/h	0.72
Labor cost for loading and unloading (USD/ton)	3.82

Values converted from PHP to USD. USD 1 = PHP 53

Economic analysis:

Table 5. Source [4]

Drying cost (USD/ton)	14.08
Payback period (years)	2.4

Table 5. Source [4]

Internal rate of return (%)	33.1
Breakeven point, (batches/year)	53
Annual net income at 120 batches per year (USD)	7,245.56

Values converted from PHP to USD. USD 1 = PHP 53

Similar variability applies as for a conventional bed dryer. The additional profit that could be obtained from less broken heads (9.2% in SRA and 9.4% in IRRI) and better germination rates (91.5% in SRA and 79.9% in IRRI) is not taken into consideration. Its applicability in drying of other grains has also been tested in a laboratory scale reversible air dryer and the results are as follows:

Table 6: Test results from laboratory reversible air dryer [5]

	Paddy	Whole coffee	Whole coffee	Coffee bean	Pulped coffee	Pulped coffee	Peanut
Input grain (kg)	27	88	38.6	NR	NR	NR	NR
Initial MC (%)	22.8	66	66	20	64	62	47
Final MC (%)	13.9	21.4	20	13.5	31.3	12.8	11.9
Grain layer depth (cm)	70	180	80	100	60	70	100
Drying temperature (°C)	49	50	55	61	75	68	43
Superficial velocity ($m.min^{-1}$)	16	14	14	14	10	12	12
Drying time (hours)	5	53	22	5.5	7.5	11.5	26
Timing for reversing air (after) (hour)	4	23	12	3.5	5	5 & 8	16
Max MC differential (%)	1.2	10.0	4	4	28	17.3	5.5

NR - Not reported

General comments:

Advantages:

- The reverse airflow dryer eliminates manual mixing and accordingly saves labor compared to conventional flatbed dryer.
- The SRA dryer has furnace design which reduces ash coming in contact with the grains.
- Uses half the area of a conventional flatbed dryer for the given volume of grains.
- Good uniformity of moisture content.
- Can handle the drying of fragile products, since no mixing is required.

Fig. 6: Three ton per batch mobile dryer SRA - 3M [9]

Disadvantages:

- Requires a relatively more sophisticated plenum and fan drive design.
- May lose efficiency and generate extra dust if the tarp is not properly fastened when in the downward flow drying period.
- Grains still come in contact with some ash from combustion.

Troubleshooting:
Visit http://www.knowledgebank.irri.org/training/fact-sheets/postharvest-management/drying-fact-sheet-category/item/troubleshooting-a-flat-bed-dryer-fact-sheet

For information regarding fabrication or in general, email postharvest@irri.org or call +63 2 580 5600.

3. Collapsible flatbed dryer (Easydry M500)

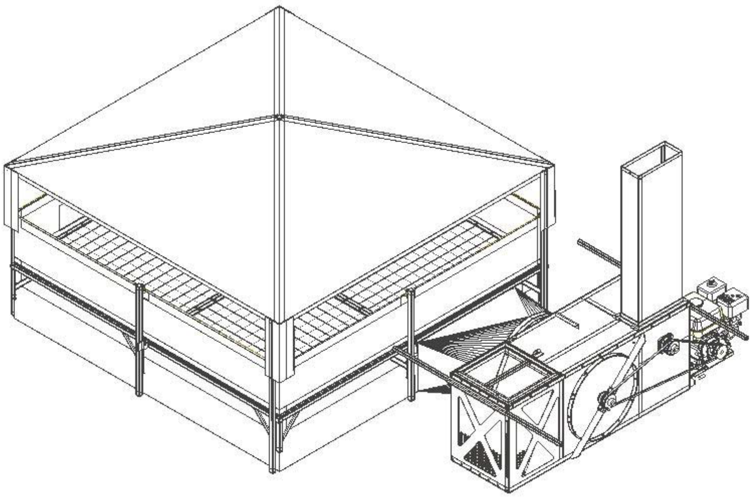


Fig. 7: Images of the collapsible flatbed dryer. Top left image shows the collapsed version mobile enough to be carried on motorcycles. Top right image shows the assembled version. Bottom image shows the dryer with the weather guard. [11]

The Easydry M500 dryer is a small collapsible flatbed dryer designed to be portable, unlike the conventional flatbed. In addition to portability, it differs from the conventional flatbed dryer by using a heat exchanger after the blower, so that clean air is blown through the grains to be dried.

Characteristics:

Capacity: With the intention to keep it portable, the capacity is limited to either 500 kg or 1000 kg. When drying 1000 kg, the drying time is roughly two times, with 2.7x fuel requirement, in order to increase the static pressure required to increase the air flow with the same blower.

Drying performance: Using a 450 mm diameter axial flow fan with an linear air velocity through maize bed of 0.24 m/s, a 500 kg batch of maize can be dried from 17% to 13% moisture content in 2.5 hours. This gives an average moisture reduction rate of 1.6% per hour. In order to make the dryer of different capacities, it may be necessary to experiment with different airflow rates in order to optimize the heating time without compromising dried grain quality.

Economic feasibility:

Components required for fabrication: Metal sheets to create the furnace, housing for the blower, plastic for the plenum chamber and canvas for the bin and weather guard, an axial flow blower (can be either made or bought from the market), fine wire mesh or perforated metal to place over the plenum, tarpaulin cover attached to the bin and a diesel generator (or connection to the electrical grid) to power the blower.

Capital cost: The dryer is designed in a way that it can be easily fabricated by local artisans with the instructions provided in the manuals. It was manufactured in Kenya at USD 850; in Tanzania at USD 1,100; in Rwanda at USD 1,660 and in Uganda at USD 1,100. These costs are inclusive of profit margins of the artisans.

Operation cost: Here, labor cost is excluded, since it is assumed that it will the farmer himself/herself who would be doing the work of loading and unloading the grains.

Table 7. Operating costs calculated from a 500 kg batch of maize in Kenya, 2015 [7]

Corn cob consumption rate (kg/h)	16.5
Corn cob cost (USD/kg)	0.06
Petrol fuel consumption rate (L/h)	0.5
Petrol fuel rate USD/L	1.03

Economic analysis:

Table 8. Source [7]

Drying cost (USD/500 kg batch)	9.70
Payback period (years)	2
Breakeven point, (batches/day)	3
Annual net income at 120 batches per season (USD)	280

The Easydry dryer was developed for use on maize in Africa. It has been tested for groundnuts with little variability in drying time. It is intended for use by either a small-scale farmer or a local service provider. If owned by a local service provider, the developers suggest that, it would be the most economically feasible when the service provider would not have to travel more than 1.6 km with the unassembled dryer on two motorbikes.

Advantages:

- Highly collapsible, therefore, easily portable on two motorcycles.
- Flue gases don't come in contact with the grains because of the heat exchanger.

Disadvantages:

- Fabrication requires skill.
- Labor intensive, as someone needs to mix the grains frequently.

For information regarding fabrication, operation, troubleshooting or in general resources for prospective owners/operators, visit http://www.acdivoca.org/easydry/

4. Flatbed Drying Wagon

The Flatbed Wagon Dryer is a completely self-contained mobile flatbed dryer, which is commercially available by Scoring-Ag Inc, USA. The unique feature about this dryer is that this 5.5 ton capacity dryer can be shipped into a standard 20-foot shipping container anywhere in the world. It is designed for precision drying, in the sense that it contains a thermo-humidistat, which regulates the heater to bring the product to the desired moisture content.

Fig: 8: Drying wagon for seeds [10]

Characteristics:

Capacity: It comes in two sizes; 315 bushel (8 ton) and 215 bushel (5.5 ton) per batch. The 215 bushel version can be shipped into a standard 20-ft container.

Drying performance: For a 5% moisture reduction for any given grain, the smaller dryer takes 1 hour per 1.8 tons of corn. This corresponds to a drying time of roughly 3 hours per batch for 5% moisture reduction. This gives an average of 1.67% moisture reduction per hour of batch.

Advantages:

- Portable
- Uses electric heating, therefore, there is no production and subsequent contact of ash with grains.
- In bigger farms, it can be used simultaneously while harvesting with combine tractors.

Disadvantages:

- Difficult to use in areas with poor electricity supply.
- May be difficult to load grains manually because of high height (~ 9 feet).

For more information, contact ScoringAg at +1 941 926 3400, or email bmerker@scoringsystem.com or visit http://scoringag-equipment.com/products.cfm#foodcrop

Further Information

For more information on drying see:

http://www.knowledgebank.irri.org/step-by-step-production/postharvest/drying

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[11] http://www.acdivoca.org/easydry/