FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

Feed the Future Nepal Knowledge-Based Integrated Sustainable Agriculture in Nepal (KISAN) II
Cereal Systems Initiative for South Asia (CSISA)
Government of Nepal

Technology Menu for Mechanical Grain Dryers (with Special Reference to Paddy and Maize)

May 2021

USAID
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CSISA

FEED THE FUTURE NEPAL KNOWLEDGE-BASED INTEGRATED SUSTAINABLE AGRICULTURE IN NEPAL (KISAN) II

CEREAL SYSTEMS INITIATIVE FOR SOUTH ASIA (CSISA)

GOVERNMENT OF NEPAL

TECHNOLOGY MENU FOR MECHANICAL GRAIN DRYERS (WITH SPECIAL REFERENCE TO PADDY AND MAIZE)

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Cover Photo: *The technical staffs of Nil Kamal Trader in Dang assembled the Matharu Grain Dryer and transported it to custom hiring center of Khushi Model Multipurpose Agro Farm Private Limited in Bodhipur, Dang for field verification. (Photo credit: Jyoti Rai for USAID)*

ABOUT USAID'S FTF KISAN II

USAID's Feed The Future (FTF) Nepal Knowledge-based Integrated Sustainable Agriculture in Nepal (KISAN II) is operating in twenty-five Hill and Terai districts in Lumbini, Bagmati, Karnali and Sudurpaschim Provinces to increase resilience, inclusiveness and sustainability of income growth through agricultural development, working closely with the Government of Nepal (GON). KISAN II works with the private sector to catalyze agricultural productivity, promote competitive market systems, ensure conducive enabling environment, and boost business and literacy skills for households in its zones of influence (ZOI).

ABOUT CSISA

The Cereal Systems Initiative for South Asia (CSISA) is a regional initiative to sustainably increase the productivity of cereal-based cropping systems, thus improving food security and farmers' livelihoods in Bangladesh, India and Nepal. CSISA works with public and private partners to support the widespread adoption of resource-conserving and climate-resilient farming technologies and practices. The initiative is led by the International Maize and Wheat Improvement Center (CIMMYT), implemented jointly with the International Food Policy Research Institute (IFPRI), the International Rice Research Institute (IRRI), and the International Water Management Institute (IWMI), and is funded by the U.S. Agency for International Development (USAID) and the Bill & Melinda Gates Foundation.

CENTER FOR CROP DEVELOPMENT AND AGRO-BIODIVERSITY CONSERVATION (CCDABC)

Centre for Crop Development and Agro-Biodiversity Conservation (CCDABC) is one of the six national centres under the Department of Agriculture. CCDABC is given the mandate to assist the Central Government in formulating and implementing the national policies and programs, technical standards, and regulations relating to cereal, pulse, oilseed and industrial crops, and in the area of agrobiodiversity conservation. The Centre is also entrusted for acquiring and disseminating the related technologies in the country in collaboration and coordination with lower-level governments. Two Agriculture Development Farms are also working under this Centre which are basically mandated for producing source seeds in a bid to increase the farmers' access to quality seeds.

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ACRONYMS

AC	Alternate Current
ACDI/VOCA	Agricultural Cooperative Development International/Volunteers in Overseas Cooperative Assistance
ADB	Agriculture Development Bank/Nepal
AEPC	Alternative Energy Promotion Centre
BAU	Bangladesh Agriculture University
BBN	Bideshi Binimaya Number
CA	Customs agent
CAIDMP	Center for Agriculture Infrastructure Development and Mechanization Promotion
CCDABC	Center for Crop Development and Agriculture Bio-Diversity Conservation
CDC	Collapsible dryer case
CGIAR	Consultative Group for International Agricultural Research
CIF	Cost insurance freight
CIMMYT	International Maize and Wheat Improvement Center
COO	Country of origin
db	Dry basis
DC	Direct current
DoA	Department of Agriculture
EMC	Equilibrium Moisture Content
FBD	Flat-bed dryer
FOB	Free-on-board
GoN	Government of Nepal
H	Height
ha	hectare
HDPE	High density polyethylene
hp	Horsepower
INRs	Indian rupees
IRRI	International Rice Research Institute
kg	kilogram
KISAN II	Knowledge-based Integrated Sustainable Agriculture in Nepal
KNUST	Kwame Nkrumah University and Science and Technology
KSU	Kansas State University
KVA	Kilo Volt Ampere
KW	Kilo Watt
L	Liter
L/C	Letter of Credit
LDPE	Low Density Polyethylene
LSU	Louisiana State University

m	meter
m^2	Square meter
m^3	Cubic meter
MC	Moisture content
MoALD	Ministry of Agriculture and Livestock Department
MOICS	Ministry of Industry, Commerce and Supplies
MT	Metric tonne
NARC	Nepal Agriculture Research Council
NPR	Nepalese Currency (equivalent: 1 USD= 115 NPR), and (1 INR= 1.6 NPR)
NRB	Nepal Rastra Bank
°C	Degree Centigrade
Pa	Pascal (unit of pressure)
PAN	Personal account number
PCC	Plain cement concrete
PMAMP	Prime Minister's Agriculture Modernization Project
PP	Polypropylene
PTO	Power take-off
PVC	Polyvinyl chloride
RCC	Reinforced cement concrete
RFBD	Reversible flow batch dryer
RH	Relative humidity
rpm	Revolution per minute
SBD	Solar bubble dryer
USD	United States Dollar
USAID	United States Agency for International Development
UV	Ultra-violet
V	Volt
VAT	Value Added Tax
wb	Wet basis

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DEFINITION OF TECHNICAL TERMS USED IN THIS DOCUMENT

Aeration: the process of forcing air through grain to reduce its temperature.

Batch: how much grain can be fed into the dryer at one time.

Dry-bulb temperature: air temperature recorded by a thermometer exposed to the air but shielded from radiation and moisture[1].

Dryer: a machine used to lower the water content of grain by using hot air.

Drying rate: the rate of removal of moisture from the grain, expressed in percent per hour.

Equilibrium moisture content: the moisture content in a drying process at which the grain neither gains nor loses moisture but remains constant.

Furnace: a heating unit (heater or boiler) attached to the grain dryer and used to produce hot air.

Horsepower: a unit of power equal to 746 watts of electricity.

Hygroscopic material: It is one which absorbs water from the (surrounding) air.

Moisture content: the amount of water content in the grain, usually expressed as a percentage (grams of water per 100 g of grain).

Relative humidity: the ratio of the actual vapor pressure relative to the vapor pressure of saturated air at the same temperature, expressed as a percentage[1].

Tempering: the process whereby the bulk of the grain is heaped, and the moisture content of any unevenly dried grain has a chance to equilibrate.

Wet-bulb temperature: air temperature recorded by a thermometer with its bulb wrapped in cloth moistened with distilled water. The rate of evaporation from the wet bulb (and thus the temperature it records) varies depending on the humidity of the air it is exposed to[1].

[1] Psychrometric charts, (https://www.designingbuildings.co.uk/wiki/Psychrometric_charts)

EXECUTIVE SUMMARY

Globally, one third of all food produced – 1.3 billion metric tons (MT) per year – goes to waste every year, an amount which could feed 37 million people for life[2]. In Nepal, post-harvest losses have been estimated to be 20-40% of the total agricultural production due to the lack of proper post-harvest technologies[3]. Ensuring proper drying techniques is one of the most effective methods of eliminating the losses. Post-harvest management of grain is also one of the prime activities to fetch an attractive selling price.

The traditional open sun drying method (drying on the stalk before cutting/harvesting, laying in the field after cutting/harvesting or threshing grain on a drying floor) is tedious, time-consuming and results in poor grain quality. Traditional drying systems are still practiced in many parts of the country because of their low cost and ease of management. To address this issue, high-performance mechanical dryers have been introduced in the country. Although initial costs are higher than sun drying, these are balanced by improvements to the grain and higher recovery rates.

Mechanical drying systems include dryers which are used to reduce moisture in wet grain by forcing ambient or heated air through the grain bulk to achieve a required moisture level for storage. In these systems, the drying temperature can be controlled and drying takes place within few hours, resulting in high quality grain. Heat energy from burning biomass, furnace oil or electricity is utilized by mechanical dryers to dry a range of agricultural products. These systems have been successfully adopted by farmers and entrepreneurs throughout the world and are scientifically accepted. This document introduces and discusses different types of high-performance mechanical dryers (both fixed and portable), and makes recommendations for consideration by Government of Nepal, investors from the farming community, the private sector, Development Partners (DP) and NGO/INGOs.

Rice is the principal food grain crop followed by maize and wheat in Nepal. Maize is the second most important staple food crop after rice. Winter crops (of which wheat is one) are harvested in the dry spring season and have low grain moisture. Spring rice (*chaite dhan*) is harvested at the beginning of the monsoon. It has a high moisture content, and the unpredictable weather at harvest time makes sun drying difficult, resulting in a large quantity of spring rice being lost every year. Summer maize is harvested at the end of monsoon and, like spring rice, its quality suffers greatly from high moisture content. Especially, in case of maize mycotoxin contamination is a big problem due to high moisture content which makes the food unsuitable not only for human consumption but also for animal feed.

In order to explore innovative drying technologies suitable to Nepalese farmers, this technology menu has been developed adopting secondary information, literature review, field observations and focused group discussion with concerned stakeholders.

This document discusses the range of grain-drying technologies which have been successfully adopted in Asia and worldwide, particularly in relation to post-harvest technologies/infrastructure associated with the drying of maize and paddy (particularly *chaite dhan*) suitable for Nepal. Of these, it lists the most commonly used types of dryer.

[2] Lipinski et al 2013, Reducing Food Loss and Waste. World Resource Institute
[3] FAO (2015) 'Global initiative on food loss and food waste reduction', United Nations, pp. 1– 8. Available at: http://www.fao.org/save-food/en/.

This document presents the most important information about the dryer, including types, benefits, working principles, features, specifications, source of supply, estimated cost, custom duties, special requirements, and examples of institutions/organizations which have been using the dryers successfully. It is published to introduce to the reader the various drying systems able to address the issue of post-harvest loss, specifically in spring rice and maize. It sets out to familiarize the reader with the various dryers on the market, and to facilitate the most appropriate choice of dryer for every level of farmer and entrepreneur, according to their needs and the funds they have. This document is expected to help policymakers, extension workers, rice millers and feed industries, machinery suppliers, farmers and co-operatives in decision-making, as well as to reduce post-harvest losses, particular those incurred in drying.

1. GRAIN DRYING

1.1. Introduction

One-third of all food produced globally goes to waste every year. Constituting 1.3 billion MTs annually, this would feed 37 million people for life[2]. In Nepal, post-harvest loss of cereal grains is estimated[4] at 15-20%, and about 20-40% of total agricultural products is lost due to the adoption of lack of proper postharvest management technologies. As limited agricultural mechanization is available to smallholder farmers in Nepal, almost all agricultural practices – including pre-harvest and post-harvest operations such as drying, de-hulling, shelling, winnowing and sorting, transportation and storage – are conducted manually. This leads to huge losses estimated to be 15% at the field level, 13–20% during processing and 15–25% in storage[5]. No data is available for Nepal specifically on the percentage of loss during the drying stages of post-harvest operations of paddy and maize in the grain production and supply chains; however, a recent study[6] carried out in neighboring Bangladesh shows that the proportion of loss is relatively higher during drying than at any other stage of the post-harvest process.

Rice is the principal food grain crop in Nepal, followed by maize and then wheat. It is a high energy, high calorie food, accounting for one-fifth of the global calorie supply. In Nepal it is the most important crop in terms of production and is often equated with the country's food security. Spring rice harvested during the monsoon has a high moisture content and a large quantity is lost every year, due to the unpredictability of the weather suitable for sun drying.

Maize is a staple cereal crop and as such, in Nepal, constitutes an important part of the staple diet and a major source (~36%) of daily calorie intake. A major threat to the country's maize production is mycotoxin contamination. This is a big challenge to agricultural production in general and especially in the case of maize, as it renders it unsuitable for either human consumption or animal feed. Worldwide, a large amount[7] (25-40%) of cereal grains are contaminated by mycotoxins produced by storage fungi and mold which generate dry matter loss, odor, and loss of nutritional value.

Grain drying is the process of reducing the grain's moisture content to a level which renders it ready for storage and is the most critical post-harvest operation. When grain is harvested, it contains moisture (up to 20% in paddy and 30% in maize) which, if retained during storage, can encourage the development of mycotoxins and molds, lead to grain discoloration and increase the likelihood of attack from pests[8]. It is vital, therefore, to dry the grain immediately after harvest (ideally within 24 hours) in order to protect it from physical contamination from pests, molds, and fungus. Delay in drying, or incomplete or ineffective drying, reduces grain quality and results in loss.

[4] KC, G. (1992). On farm level pre-harvest and post-harvest food loss preventive system in Nepal. Kathmandu.
[5] Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania, https://www.sciencedirect.com/science/article/pii/S0022474X1300101X
[6] Study report on Post Harvest Loss and Technical Efficiency of Rice, Wheat and Maize Production System: Assessment and Measures for Strengthening Food Security; Final Report CF # 6/08 , by B K Bala, M A Haque, Md. Anower Hossain, Shankar Majumdar submitted to National Food Policy Capacity Strengthening Programme EU/USAID, Bangladesh, August 2010.
[7] Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5296677/#B56-foods-06-00008
[8] It can also decrease the germination rate of the seed.

Traditional drying systems, including mat drying, pavement drying, field drying, and stacking are still practiced in many parts of Nepal because of their low cost and ease of management. However, these systems are tedious and time-consuming, and result in poor quality grain. To address this issue, a high-performance mechanical dryer has gradually been introduced into the country, although its cost is high compared to drying grain in the sun. Mechanical drying systems include dryers, which are used to reduce moisture in wet grain by forcing either ambient or heated air through the bulk grain to achieve the moisture level required for safe storage. With mechanical systems, the drying temperature can be controlled, and drying takes place within a few hours, resulting in high quality grain. These mechanical drying systems have been successfully adopted by farmers and entrepreneurs throughout the world.

Post-harvest management of grain is of prime importance to ensuring an attractive sale price, and a significant part of this is proper drying, the most effective method of eliminating post-harvest loss. This document introduces the salient features of both the fixed and portable types of high-performance mechanical dryer. Reducing post-harvest loss in Nepal would contribute for food security, improve farmers' livelihoods, and eliminate hunger.

1.2. Moisture levels for safe storage

After harvesting and before the grain is dried, the moisture content of paddy and maize tends to be as high as 24% and 32% respectively. High moisture content has been shown to be detrimental to grain in terms of weight loss and quality, particularly as it is used by insects and mold for survival and growth. To prevent moisture damage therefore, paddy and maize, like all cereal grains, must be dried as quickly as possible after harvesting to reduce the moisture content to the optimum level for safe storage.

For paddy and maize, international practice shows that depending upon the duration of storage and climatic conditions, the safe moisture content level is around 13% to 14%, as Table 1 shows. In Table 1, warm temperature may be referred to temperature above ambient temperature and cool temperature referred to temperature below ambient temperature.

Table 1. Optimum moisture content levels for short- and long-term storage[9]

Food grain	Long-term storage (1 year)	Short-term storage (30-60 days)	
		Warm temperature	Cool temperature
Corn (maize)	12%	12%	15%
Rough rice (paddy)	12%	12%	14%

Equilibrium moisture content

Hygroscopic material, including grain, has its own characteristic balance between the moisture content and the water vapor in the air. Moisture moves from the grain to the air (or vice versa) until a balance is achieved when food grain is exposed to the air, which is known as the grain's equilibrium moisture content (EMC). Table 2 presents the EMC values for maize, paddy and rice stored at 27 °C and 70 % relative humidity (the maximum acceptable levels for storage of any grain).

[9] Grain Drying Tools: Equilibrium Moisture Content Tables and Psychrometric Charts (https://www.uaex.edu/publications/pdf/FSA-1074.pdf)

Table 2. Equilibrium moisture content (EMC) values at 27 °C and 70% relative humidity[10]

Crop	EMC value
Maize	13.5%
Paddy	15%
Rice	13%

1.3. Drying process

The drying process requires a source of heat to evaporate moisture from the grain, with a flow of air helping to carry away the evaporated moisture. With mechanical drying methods, hot air is forced through the grain mass and:

1. Evaporates the moisture from the grain surface,
2. Increases the temperature of the grain, and
3. Carries the evaporated moisture away from the grain.

The increase in grain temperature also facilitates the rapid migration of moisture from inside the kernel towards the surface, as a result of the moisture gradient developed during the drying process. There are three stages to the drying curve (Figure 1)[11]: warming up, constant rate and falling rate (the warming up period is of little consequence in most cases because of its short duration; either the constant rate or falling rate period constitutes the major portion of the drying time). The exchange point at which the drying rate changes from constant to falling rate is termed 'critical moisture content'. During the constant rate drying stage, the rate of moisture removal from the grain is limited only by the rate of evaporation of water surfaces on or within the product.

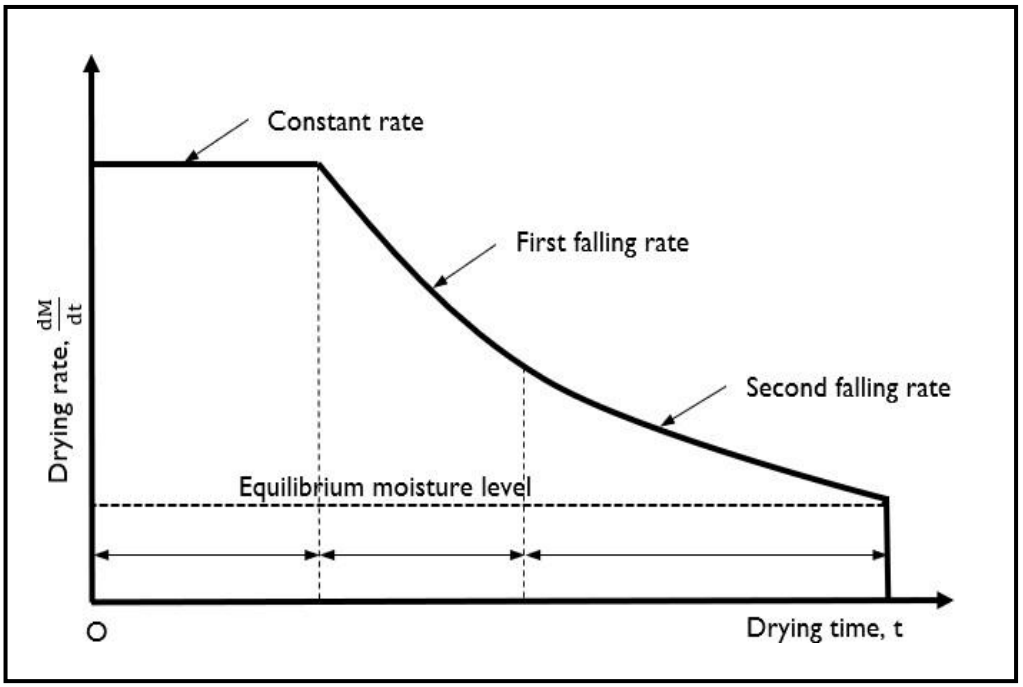


Figure 1. Drying Curve[12]

[10] Equilibrium moisture content (http://www.fao.org/3/i2433e/i2433e10.pdf)
[11] https://docplayer.net/161744315-Optimization-of-greenhouse-drying-process-for-white-button-mushroom-agaricus-bisporus.html
[12] IRRI (2020) and Authors Synthesis (2020) (http://www.knowledgebank.irri.org/)

1.4. Factors affecting drying

Several important factors affect drying and can be classified into three main categories:

1. **Grain parameters**, including initial grain moisture content, EMC of the grain, initial grain temperature, grain maturity and grain variety, and latent heat of water vaporization while removing moisture from the grain during drying.
2. **Air parameters**, including initial temperature, relative humidity of the air, and volume of air passing through the grains.
3. **Dryer factors**, including type of dryer and drying method, depth of grain through which the air moves, feed rate of the grain, dryer efficiency, airflow rate, and heat loss in the dryer as a result by radiation and convection.

1.5. Drying systems

Drying systems can be classified into two main groups, primarily according to their operating temperature ranges: high temperature and low temperature dryers. However, dryers are more commonly classified as traditional or mechanical dryers (Figure 2).

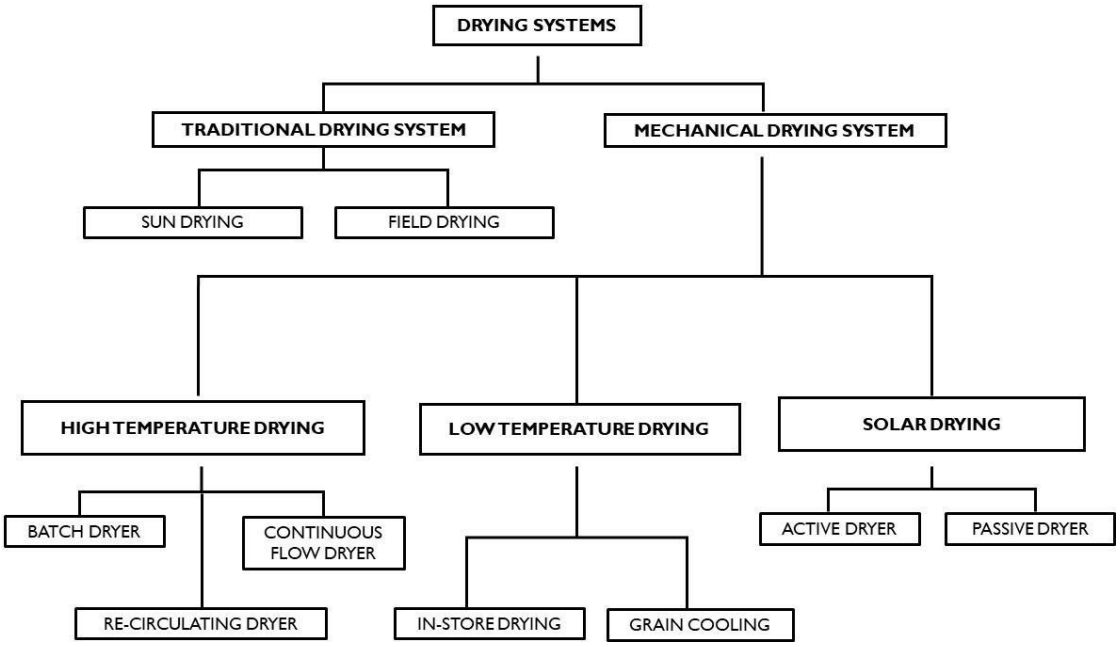


Figure 2. Drying Systems[13]

1.5.1. Traditional drying systems

Traditional drying systems are still practiced in many areas of Nepal because of their low cost and ease of management and are outlined in this section.

1.5.1.1. Sun drying

This involves spreading grain in the sun on mats or on purpose-built soil/brick or cement/concrete pavements.

- **Mat drying** is used in small-to-medium scale drying where threshed grains are placed on mats, nets or canvas.

[13] Authors' Synthesis (2020)

- **Pavement drying** is often used in large-scale drying for grain collectors and millers. Here, the grain is laid on pavements specifically made for drying.
- **Field drying and stacking** is a traditional method for pre-drying hand-harvested crops in the field where farmers cut rice panicles in the field and stack in small piles on top of the stubble with panicles inside to protect it from rain, birds and rodents (Photo 1).

Photo 1. Stacked paddy drying in the field (Photo credit: KISAN II project for USAID)

1.5.2. Mechanical drying systems

In these systems, mechanical dryers blow ambient or heated air through the bulk grain to remove moisture from it. This section outlines the different ways this can be performed.

1.5.2.1. Low-temperature or in-store drying

Low temperature drying (also referred to as in-store drying or near-ambient air drying) uses a fan to blow air at ambient or near-ambient temperature through a static bed of grain. This system controls the relative humidity rather than air temperature. This can be done using an in-store dryer which produces very high-quality grain but requires a long drying time ranging from four days to two weeks[12]. Low temperature dryers are generally used in silos or warehouses.

1.5.2.2. High temperature drying

High temperature drying involves heating the air to a high temperature to achieve rapid drying. There are many types of heated air dryers, but this document focuses on those which are currently commercially available in Nepal. These are:

- **Batch dryer.** Grain is fed into the dryer and laid out on a perforated screen. A fuel burner or biomass furnace is used to generate hot air, which is blown into the plenum chamber beneath the grain. The blower forcing the hot air upwards and through the grain to dry it is usually a simple axial flow fan, powered by a diesel engine or electric motor. The capacity of this type of dryer varies from 1-10 MT; it can be used by farmers, custom hiring centers small rice mills and cooperatives and can be either mechanically or manually loaded and unloaded. Most of the batch dryers described in this document are appropriate for adoption in the context of Nepal.
- **Recirculating batch dryer**. Grain is loaded into the dryer and recirculated to achieve even drying and the desired moisture content, thereby improving the grain quality and appearance. Both mobile and fixed types of recirculating batch dryer have been in use since the early 1990s in developed countries, and in Nepal various models and sizes are available for use by smaller and medium-sized commercial rice mills and cooperatives.
- **Continuous flow dryer**. Grain flows continuously through the dryer to the outlet in one cycle, decreasing drying time. This type of dryer is mainly used by larger automatic milling enterprises in Nepal and the South Asia region which handle large volumes of wet paddy, in particular for drying steamed rice. Examples of continuous flow dryers such as the horizontal and vertical Louisiana State University (LSU) dryers, which are popular in India and Nepal for steam rice.

1.6. Maximum recommended temperatures in and across different drying processes

Table 3 presents the different maximum allowable grain temperatures for drying different grains. Grain and seed for commercial use have quality attributes, such as whether they are uncracked and whole grain as opposed to grain which goes directly into animal feed. Maize is generally used as animal feed, so a higher drying temperature does not have adverse effect; for paddy, however, a higher temperature than that recommended will result in the rice breaking during milling. For seed, a lower temperature is favorable to maintain its viability.

Table 3. Maximum safe temperature (°C) of grain during drying for various end uses[14]

Crop	Maximum safe temperature (°C) of grain during drying for end use		
	Seed	Sold for commercial use	Animal feed
Ear corn (maize)	43	54	82
Shelled corn (maize)	43	54	82
Rice	43	43	-

Table 4 illustrates the maximum air temperatures recommended for drying maize using different types of dryer, which apply different temperature ranges for drying the same commodity. This is due to there being less variation in the moisture content of grain in a continuous/recirculating dryer than in the column/bin batch dryer. A higher temperature can be used with a continuous flow or recirculating batch dryer, as each individual kernel of grain is not exposed to the heated air for the entire drying cycle and as a result should not get as over-heated[15].

Table 4. Maximum recommended air temperatures for drying maize (°C)[16]

Grain	Dryer type				Seed
	Continuous flow	Recirculating batch	Column batch*	Bin batch	
Corn	93	93	82	48	43

1.7. Advantages and constraints of mechanical dryers

The mechanical dryer has several advantages and constraints:

1.7.1. Advantages

- Increases the quality of harvested grain by reducing crop exposure to weather.
- Leads to higher market prices due to increased grain quality.
- Secures income from minimizing weather risk and being able to process more grain.
- Reduces post-harvest loss, including head shattering (loss in the fields), due to timely drying.
- Reduces dependency on weather conditions to start harvesting.
- Creates labor savings and facilitates faster drying as a result of increased level of technology.
- Allows drying to be done day or night, thus achieving required moisture content quickly,
- Provides better control over temperature and moisture content.
- Reduces "in-field" drying time, allowing for earlier harvesting of higher-moisture grain.

[14] Preserving quality during grain drying and techniques for measuring grain quality (https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.501.899&rep=rep1&type=pdf)
[15] When drying seed, the temperature must not exceed 43°C to protect it from germination loss.
[16] NDSU (https://www.ag.ndsu.edu/publications/crops/grain-drying/ae701-grain-drying.pdf).

- Fields can be vacated earlier providing more time for post-harvest fieldwork, including the planting of a greater area of the next crop on time.
- Provides potential business opportunities for farmers, farmer associations and even commercial mills. Access to a dryer enables the offering of a mix of drying and storage services, with associations and cooperatives able to dry and store harvested grain off-farm.
- More even drying of grain; with paddy, this results in higher head rice recovery which leads to higher milling efficiency.

1.7.2. Constraints and Drawbacks

- Requires specialized equipment and machine, which is costly.
- Results in higher operating costs for fuel, electricity and skilled labor.
- Care is needed when using hot air as part of the drying process, as higher-than-recommended temperatures can cause damage to the grain/seed.

1.8. Guidelines to proper drying

Proper drying is crucial to achieve higher quality of grains, which can be maintained within 12-24 hours of harvesting paddy and maize[17]. The safe level of moisture content of the grain depends on the planned duration of its storage before further use (Table 2) even short-term storage of high moisture grain can cause deterioration in quality. The moisture content of grain depends on the relative humidity. For long-term storage of grain and seed in humid tropical climates, it is crucial to prevent humid air re-wetting the grain. The following points are important to consider for drying of paddy and maize grains:

- Ensure grain has achieved the correct moisture content through drying; this is critical for safe storage.
- When drying grain for milling, maintain the moisture content at 14% for both rice and maize so the grain weight and milling yield do not decrease.
- To avoid cracking, do not mix grains with different levels of moisture content.
- Monitor the grain temperature and moisture content constantly within the dryers to prevent grain from being exposed to excess temperature and over-drying. In the case of paddy, over-drying can cause excessive broken rice during milling, which ultimately reduces head rice recovery.

1.9. Heat sources and commercial drying

In Nepal, the energy required for drying grain currently represents a major portion of the total energy utilized for all on-farm grain-processing operations, and the cost of the energy source is by far the most expensive input cost. This means that for any actor offering commercial drying services (or simply the commercial grain enterprise overall), great attention is needed when considering the type of mill and its heat source needs when offering.

1.9.1. Agro biomass

If there is sufficient agriculture in the area where the drying is taking place, biomass (including rice husk, maize cob, wood dust, and different types of waste and by-products) should be readily available throughout the drying season, making it usually the least expensive source of fuel to burn and provide heat for the air in the dryer. While storing and drying biomass can be problematic, its

[17] Before drying, however, it is essential to clean the grain, to avoid uneven drying and wet spots (caused by dust, dirt and biomass). Cleaning facilitates proper drying which results in higher quality grain.

lower price is usually attractive to both small- and larger-scale agro-industries looking for fuel to use as part of the drying process. In many cases therefore, the source of heat for drying the grain comes from the crop itself. In the case of commercial rice mills and feed mills, by-products like rice husk or maize cobs are best utilized as the primary heat sources for their dryers. These fuels are burned in locally made furnaces of standard design, and can be used in:

- Direct flame heating, where in a clean burning, forced-air furnace all the heat and fumes from biomass burning is directed into the dryer,
- Indirect heat, again using a locally made, standard design, forced air furnace with an efficient heat exchanger,
- Steam boiler systems, using a heat exchanger to heat very large volumes of air.

1.9.2. Petroleum-based dryers

Petroleum-based dryers use a specially made furnace to burn various petroleum products, including natural gas/bottled gas (propane), diesel, kerosene, and fuel oil. While these are cleaner burning and provide a safe, secure energy source for heating, their prices are usually nearly twice as much as biomass source fuels. During the 2007-08 financial crisis, when in Nepal fuel prices nearly doubled and were in very short supply, many of the country's industrial boiler industries switched from fuel oil (which is slightly cheaper than diesel) to biofuels.

1.9.3. Electricity sources

Electricity from Nepal's hydroelectric system used for heating air is the cleanest energy source; however, it is also the most expensive than petroleum and agro-biomass, and unpredictable electricity supply.

1.9.4. Solar thermal and solar photovoltaic (PV) energy

The solar PV system using solar panels to generate energy to heat air is not commercially offered in Nepal; however, some companies are offering solar PV to run fans for small-scale dryers (with a capacity of 1-2 MTs/day), used to blow hot air through the grain. Although running costs are cheap, the investment costs of a solar PV are high in comparison to other heating sources, making solar panels much more expensive than electricity or diesel.

Similarly, in Nepal solar thermal energy is being offered in small-scale commercial systems, mainly for use in small-scale (<500 kgs/day) dryers for vegetables, as well as slightly larger (1 MT/day) walk-in poly tunnels, also used for drying vegetables. For drying grain, there are several solar tunnel methods on the market, but because of the high initial investment costs these are yet to be commercially viable in Nepal.

Of the four methods above, both small- and large-scale grain companies and farmer-producer associations prefer to invest in a dryer to choose agro-biomass fired furnaces as their heat source.

2. MECHANICAL DRYERS CURRENTLY USING IN DEVELOPING COUNTRIES

While there are many types of grain dryers in use globally, those mentioned below are chosen for discussion according to several criteria, and grouped together based mainly on their commercial availability, popularity, and use within the South and South East Asia regions, and African and European countries. Categorization is based on potential domains of purchase and use by farmers, small mills and cooperatives, larger mills and cooperatives, and large commercial milling operations. Some were piloted in Nepal in 2019; prototypes being tested at the time of writing in Nepal, Bangladesh and some African countries are also cited here.

Types of dryer discussed in this document:

- **Batch dryer,** including the Vietnamese flat-bed dryer, reversible flat-bed dryer, EasyDry M500 and ventilating dryer.
- **Recirculating batch dryer**, such as the Matharu grain dryer, K-series dryer, and columnar circulating dryer.
- **Continuous flow dryers**, including the LSU dryer.

2.1. Batch dryer

Chapter 1, section 1.5.2.2 ('High temperature drying') presents a general description of the batch dryer. Examples of batch dryers with different structural designs include the:

- Flat-bed batch dryer
- Reversible airflow flat-bed dryer
- Ventilating dryer
- EasyDry M500 dryer

The following sections describe these types of dryer and provide details of one or more dryers as examples.

2.1.1. Flat-bed batch dryers

There are several types of fixed, flat-bed batch grain dryers, where drying is accomplished by forcing heated air through the bulk grain. Here, the grain is kept stationary on a perforated screen until drying is complete. The capacity of a flat-bed dryer can vary according to requirements, with those in the global market able to handle up to 30 MT per batch.

The flat-bed dryer can also be made with locally available materials. Such dryers currently in use in South East Asia have been modified to make a reversible airflow flat-bed dryer; they can also be portable and are gaining popularity in the region, particularly in Vietnam, Cambodia and Myanmar. Following this principle, many dryers (fixed as well as portable) have been adopted successfully and are discussed in this document.

2.1.1.1. Flat-bed batch dryers – working principle

With conventional airflow, hot air is drawn up from the bottom of the flat-bed dryer, is distributed along its perforated bed and flows upward, as shown in Figure 3. The height of the side walls should be around 80 cm (as the maximum depth for drying rice is 60 cm). After drying for one-third of the required time, the grain in the bed is stirred to ensure even drying. To check whether the airflow is sufficient and even, a sheet of paper or dry leaf is placed on top of the grain; it should float lightly at

the top of the grain at all locations of the drying bin. In many countries, the dryers have been simply modified to allow both a conventional and reverse direction airflow to facilitate more even drying.

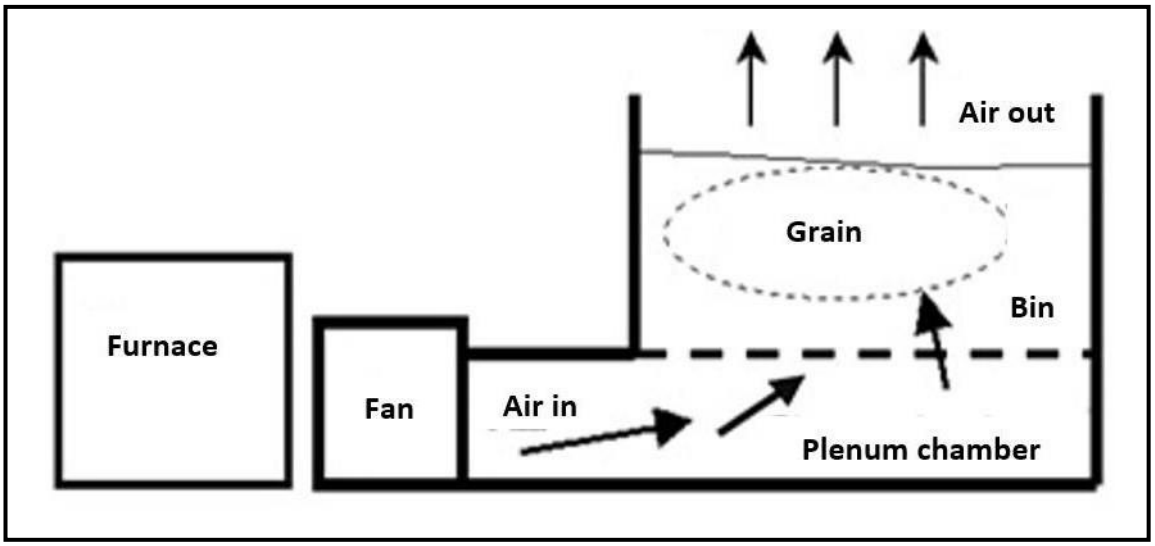


Figure 3. Schematic diagram of flat-bed dryer[18]

Flat-bed dryers are also a "batch" type of dryer. This is the simplest and least expensive dryer, and operates independently of weather conditions; however, the labor requirement is high. It is widely utilized for drying paddy, maize and other grain in Vietnam, the Philippines, Myanmar, Cambodia and Bangladesh. Toward the late 1990s in Southern Vietnam, a dryer with a capacity of 3 MT/batch was the minimum needed to achieve economies of scale. However, more recently in Vietnam, 10-20 MT/batch and even 30 MTs/batch dryers have become more common, providing better and faster returns on investment. The farmer or user selects the appropriate size, based on harvest season duration and also on whether the dryer is operated by a cooperative or private sector representative and the number of farmer-customers to be served. On average, drying time is 7 hours depending on the initial moisture content. Based on a working day of 18 hours duration therefore, a 1 MT/batch dryer can dry 2.5 MT per day or 100 MT per drying season of about 40 days; the 8 MT/batch dryer can dry 20 MT per day or 800 MT per drying season. With available labor, this dryer can be run 24 hours a day. Photo 2 illustrates two fixed-bed dryers in operation in Vietnam and Myanmar.

Photo 2. Flat-bed dryer in situ, Vietnam (left) and Myanmar (right)[18]

[18] IRRI (2020) and Authors' Synthesis (2020) (http://www.knowledgebank.irri.org/training/fact-sheets/postharvest-management/drying-fact-sheet-category/item/troubleshooting-a-flat-bed-dryer-fact-sheet)

2.1.1.2. Features of the model/type

- Simple design allows local production (except for the fan) and ensures easy maintenance and repair.
- It can be operated with a diesel engine where electricity is not available or is very expensive.
- The drying bin is usually made of brick and concrete (angle iron and sheet metal can also be used).
- The grain floor is a perforated steel sheet, 2.38 mm diameter and 0.76 mm thick.

2.1.1.3. Specifications of the model/type

The example provided here is a dryer with a capacity of 4 MT/batch, model SHG 4, developed by the Center for Agricultural Energy and Machinery, Nong Lam University[19]. Table 5 presents its important specifications.

Table 5. Specifications of a conventional flat-bed dryer (model SHG4)

Drying Parameters	Specification
Capacity	4 MTs/batch
Grain depth	0.25 m
Drying air temperature	43–45 °C
Drying rate	1.5% per hour
Drying bin	
Usually made of brick or concrete; angle iron and sheet metal can be substituted	
Grain floor	
2.38 mm-diameter perforated steel sheet, 0.76 mm thick	
Fan and heater options	
Fan	Axial vane type
Air delivery	1 ± 0.1 m^3 per sec per MT
Pressure creation	300 Pa
Rice husk consumption*	6.25 kg per hour per MT capacity
Drive options	
Diesel engine	3 hp
Fuel consumption	0.2-0.4 l of diesel/hour/MT/capacity
Electric motor	2 hp

*1 MT of paddy contains approx. 200 kg of rice hull.

2.1.1.4. Institutions/organizations where specific type/model has been successfully used

The flat-bed dryer has been successfully adopted in many developing countries due to its low cost and ease of operation; thousands are currently in use for drying paddy in Vietnam, Cambodia, the Philippines and Myanmar. This type of dryer is also manufactured and marketed in India and Bangladesh and is popular in these countries. A video of the operation and working of such dryers can be found on this YouTube website: https://www.youtube.com/watch?v=ax5kbwFMYB4

2.1.2. Reversible (air)flow flat-bed dryer

2.1.2.1. Introduction

This is a conventional flat-bed dryer which has been modified by adding a feature which enables the drying air to move in two directions (up and down) instead of just upwards. It was introduced in Philippines in 1994, as part of a collaborative project between Nong Lam University, Vietnam and the

[19] Center for Agricultural Energy and Machinery, Nong Lam University, NLU Thu-Duc District, Ho Chi Minh City, Vietnam.

Philippine Rice Research Institute (PhilRice)[20]. The reversible airflow flat-bed dryer is a modified version of the conventional flat-bed dryer and has a higher capacity; those with a drying capacity of between 15-100 MT/day are available in the market.

Figure 4 illustrates the principles which apply to both the conventional flat-bed dryer and the reverse flow flat-bed dryer. Grain is loaded on to a perforated floor in the drying bin, keeping a depth of 25-40 cm (for the conventional flat-bed dryer) and 50-60 cm (for the reversible flow flat-bed dryer). Air temperatures are generally maintained in both types of dryers in the ranges of 42°-45 °C for grain to be used for human or animal consumption and 40-43 °C for grain to be used as seed. An air velocity of 0.15-0.3 m/second is also recommended.

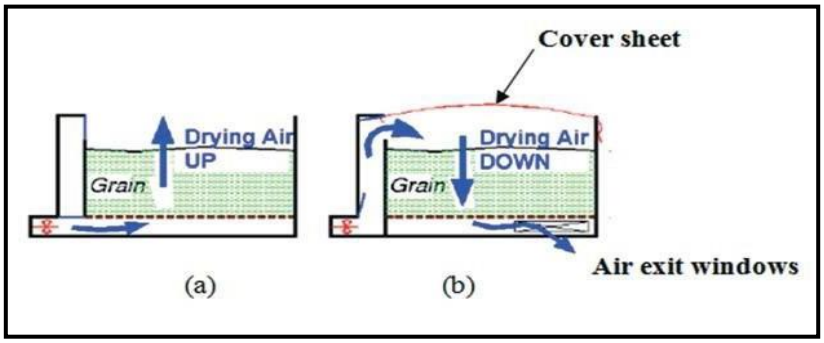


Figure 4. Reversible airflow dryer showing (a) first phase, and (b) second phase, direction of airflow reversed[21]

At the start of the drying process, hot air moves upwards from the bed of the dryer, drying the grain and absorbing moisture. During this phase, there is slight over-drying of the grain at the bottom and less drying at the top. As the air absorbs moisture from the grain on its way up through the grain bulk and drying capacity is reduced when it reaches the upper layer. To compensate for this, two-thirds of the way through the drying period the direction of the heated air is reversed, forcing it downwards and drying the grain on the way back down, resulting in increased drying overall. This reversed airflow is the main modification, with the dryer's other technical parts being very similar to those of the fixed-bed dryer.

2.1.2.2. Specifications of a typical model/type

Table 6 presents the specifications of a typical model of reversible flat-bed dryer with a drying capacity of 20 MTs of paddy per batch.

Table 6. Specifications of reversible flat-bed dryer[22]

Drying Parameter	Specification
Capacity, MTs/batch	20
Land area requirements, m^2/MT	8
Physical grain loss in drying, %	2
Electric consumption, kwh/MT	8.4
Rice husk consumption, kg/MT	48
Operating labor, h/MT	0.4
Life span, years	5
Drying depth, cm	50-60

[20] Phan-Hieu-Hien, Nguyen-Van-Xuan & Nguyen-HungTam, 2003.
[21] Adaptability of Vietnamese Reversible Airflow Flatbed Dryer in The Philippines, (http://maysaynonglam.com/upload/files/LeQuangVinh_SRA%20dryer%20in%20the%20Philippines.pdf)
[22] IRRI, http://www.knowledgebank.irri.org/.

2.1.2.3. Benefits

- Drying is more even than with a conventional flat-bed dryer.
- Head rice recovery is greater.
- Requires less labor than the conventional flat-bed dryer.
- Drying costs are less than with the conventional flat-bed dryer.
- For operation, installation and farmer feedback on the reversible flat-bed dryer in the Philippines, please see: https://www.youtube.com/watch?v=sZvB8b6vPro&t=328s.

2.1.3. Ventilating dryer

2.1.3.1. Introduction

The mechanical "ventilating" flat-bed batch dryer is made from angle iron and sheet metal and is suitable for smallholder farming households and community-based drying. It is used successfully in Bangladesh to dry agricultural products including paddy, maize and coffee.

Continuous direct hot air from the burner flows through the underlying grain layer (which is in a separate compartment), circulating uniformly through the grain until the desired moisture content is obtained. Features such as a thermal overload relay, combustion sensor, overheat sensor and pressure switch are available to ensure the process is smooth. In terms of design, the ventilating dryer is very simple; it is also easy to fabricate locally, and inspection and maintenance are easy. Figure 5 shows a small dryer manufactured in Bangladesh by Alim Industries Ltd.[23]. This dryer (model SKS-480D) has a capacity of 500 kg/batch and can remove 8-10% of the moisture per hour from the grain. It is affordable for small farmers as a low-cost dryer which provides a smooth drying process and can be moved relatively easily from one place to another.

Figure 5. Ventilating dryer, model SKS-480D[23]

2.1.3.2. Specifications of the model/type

Similar models of this type of dryer have been designed and manufactured in many countries including Japan, Korea, China, India, Myanmar, Indonesia, Turkey, Thailand, Iran and the Philippines. It is also manufactured and successfully marketed in Bangladesh by Alim Industries. The real time price of the ventilating dryer, model SKS-480 D (Table 7) in Bangladesh is estimated to be around USD 6,100(FOB)[24].

Table 7. Specifications of ventilating dryer23 (model SKS-480 D)[23]

Technical parameters	Technical specifications	
Type	Flat bed	
Fuel	Kerosene, premium diesel or fuel oil	
Method of heating	Low-temp direct heat type	High-temp direct heat type

[23] Alim Industries Ltd, (https://alim.com.bd/index.php/user/product/detail/27).
[24] All the prices cited in this document are FOB Prices.

Technical parameters	Technical specifications			
Approx. Maximum combustion, l/hr	3.3	4.4	5.6	6.6
Temperature range, °C	10-36	22-48	30-55	40-65
Safety devices	Thermal overload relay, air pressure switch, abnormal combustion sensor, control fuse, overheat sensor, pressure switch			
Electricity	1P/3P, 220V/380V/415V/440V, 50/60Hz			
Power consumption, kW	0.75			
Dimensions (length x width x height), mm	3810 x 2465 x 870			
Approx. net weight kg	455			
Drying bin	3.5 m^3, 5.84 m^2			

2.1.4. Easy Dry M500 maize dryer

2.1.4.1. Introduction

The portable shallow-bed batch maize dryer (the EasyDry M500) was designed, developed and tested by the AflaSTOP project[25] to meet the needs of Kenyan smallholder farmers, with funding from USAID and the Bill and Melinda Gates Foundation. It was designed to make manufacture possible at the local level, utilizing locally available materials. Now it is available for piloting and commercialization in different parts of Africa (including Kenya, Rwanda, Tanzania, and Ghana) as well as in Nepal.

As this is an open source technology, a Nepalese company, Krishi Tech Nepal Pvt. Ltd. has been able to manufacture the EasyDry M500 dryer. It can dry maize in batches of 500 kg, lowering the moisture level from 18-20% to approximately 13.5% in three hours, with the aim of drying three batches per day in one location[26]. In collaboration with USAID's KISAN II project, the dryer has been demonstrated in Dang and Pyuthan districts in western Nepal.

The EasyDry M500 dryer[27] is a modified form of movable flat-bed dryer, incorporating a furnace with a heat exchanger and a fan. It utilizes maize cobs as its main heat source. The heat and smoke produced from burning the cobs passes through the dryer's heat exchanger and exits through a chimney. A second fan, powered by petrol generator, pushes clean air through alternative channels in the heat exchanger. This dry, hot air is then pushed through the maize bed, which is suspended on a table-like structure, placed within a canvas bag making up the side walls of the dryer. Within three to four hours, up to 500 kg of 'wet' maize (with a moisture content of approximately 19%) can be dried to a level closer to 13.5%, allowing for its safer post-harvest storage[28].

The EasyDry M500 is simple to understand and operate. Biomass including rice husk, wood chips, as well as wooden pallets can be used as fuel to provide the heat source. As it can be made from local, low-cost materials, and the by-product of the maize crop (that is, maize cobs) utilized to provide the source of heat, this dryer could be promoted for sustainable use by small farming households.

[25] ACDI/VOCA (https://www.acdivoca.org/)
[26] ACDI/VOCA (http://www.acdivoca.org/wp-content/uploads/2017/03/AflaSTOP-Innovations-in-Drying-Brief_finalA4.pdf)
[27] ACDI/VOCA (https://www.acdivoca.org/easydry-m500-maize-dryer-overview-and-information-hub/).
[28] ACDI/VOCA (http://web.archive.org/web/20201204075740/http://www.acdivoca.org/easydry-m500-maize-dryer-overview-and-information-hub/)

Photo 3. Demonstration of EasyDry M500 dryer, Pyuthan, Nepal (Photo credit: Krishi Tech Nepal (2019))

The following table provides the technical specifications of the EasyDry M500 dryer, when using maize cobs as fuel.

Table 8. Specifications of the EasyDry M500 dryer, used to dry maize[29]

Dryer Parameters	Specifications
Capacity (kg)	500
Drying time (hours)	3-4
Size operation, length x width x height (m)	2.4 x 3.3 x 1.8
Size transportation, length x width x height (m)	1.5 x 1.5 x 0.9
Weight (kg)	190
Power requirement	12-15 kg maize cobs + 0.45 l petrol/hour
Durability (years)	5

As Krishi Tech Nepal Pvt Ltd has only recently initiated local manufacture of the EasyDry M500 dryer model in Nepal, its price is comparatively high, at around NPR 350,000 (USD 3,045) including taxes. Working together with USAID's KISAN II project, the company has conducted further demonstrations in Makwanpur, and the EasyDry M500 has been adopted by cooperatives in Nuwakot for seed drying, and Dang, Banke and Pyuthan districts for grain drying. In response to suggestions from farmers, Krishi Tech Nepal Pvt Ltd is making modifications to the dryer to make it lighter, more portable, and cost-effective by replacing the heating source of firewood with LPG or electricity. The working and operational features of the dryer can be found at https://www.acdivoca.org/easydry-m500-maize-dryer-overview-and-information-hub/.

[29] Krishi Tech Nepal Pvt Ltd (2019).

Photo 4. Demonstration of EasyDry M500 dryer, Pyuthan district, Nepal (Photo Credit: Krishi Tech Nepal Pvt. Ltd.)

2.2. Recirculating dryer

2.2.1. General description of recirculating batch-type dryers

Chapter 1, section 1.5.2.2 provides a general description of the recirculating batch dryer. Introduced and tested in South East Asia during the 1990s, the increased use of this type of dryer by rice processors in India and Pakistan is a recent phenomenon. This type of dryer is increasingly being used by the private sector with the aim of producing better quality grain and for handling large amounts in the peak season safely. The recirculating batch dryer (which has a variety of designs/models and capacities, particularly the mobile types) is popularly used by smaller and medium commercial rice mills and cooperatives, and to provide custom services to farmers.

2.2.2. Mobile dryers

Numerous manufacturers and suppliers from Italy, UK, Spain, Finland, Turkey, India and China are currently marketing a wide range of mobile types of dryer globally, which are used to dry paddy, maize and other food grains with different degrees of automation and ease of mobility. The current capacity of mobile dryers available in the market is as high as 50 MT/batch, able to dry up to 100 MT/day of paddy or maize. Some mobile dryers are designed to dry quantities of grain as high as 750 MT/day.

2.2.2.1. General working principles of mobile grain dryers

- Most mobile paddy or maize dryers are recirculating circular bin batch types of grain dryer.
- Generally, drying capacity ranges from 1 MT/batch to 50 MT/batch.
- Its heating source is generally a diesel-fed furnace, through which hot air is produced and forced to the drying plenum with the help of a centrifugal fan.
- Loading of the grain can be done manually or mechanically, with the grain carried up and into the drying bin with the help of elevator.
- Hot air is forced through the plenum at the center of the dryer, passing upwards and sideways through the grain and out of the bin. The grain is then recirculated using an elevator so as to achieve even drying and higher drying efficiency. Unloading is done automatically by an auger.
- A tractor or truck powers the blower, agitator and auger grain elevator (for loading, mixing and unloading) and a small generator for controlling the furnace. The furnace uses light diesel oil as fuel to provide a heat source.

2.2.2.2. General features of mobile dryers

- A simple structure, small volume, convenient operation, no auxiliary equipment, and convenient transportation and movement.
- Compact body, easy operation, especially designed for small and medium-sized farmer and companies.
- Uses hot air as the drying medium, adopts a circulating drying process; the grain is heated uniformly and until it reaches the optimum moisture content.
- Uses coal, rice husk or straw as fuel, and is converted into clean hot air through combustion and heat exchanger. Many mobile dryers have supplementary facilities of using electricity for drying, which conveys no pollution to the dried grain.
- Mobile grain dryers are fitted with digital temperature and moisture measuring devices due to which drying uniformity is improved.
- Easy to clean, inspect and maintain.
- Farm-to-farm service due to its portability.
- Electric controller to regulate temperature and airflow.
- High drying efficiency, easy to transport, saves space; it can be moved between farms and from one place to another, to be used for drying wherever required.
- Machine can be easily assembled and disassembled and is easy to transport using a tractor or pickup.
- Automatic control system for temperature and moisture.

2.2.2.3. Benefits of mobile dryers

- Mobile dryers are considered best suited for field use and custom hiring. They can be moved easily using a small four-wheel tractor or on a trailer and are easy to operate. Almost all mobile dryers can be operated using tractor power (making use of gas or diesel) and/or by electric motor.
- Takes less time to dry grain as compared to conventional dryer.
- Small investment, low cost of use, automated work process, automatic shutdown, appropriate for the needs of small and medium-sized farming households.
- Farm-to-farm service due to its portability.
- Widely used for various crops, including corn, paddy, wheat and sesame.

Photo 5 provides some examples of small-scale mobile dryers for paddy and maize currently in the market. Table 9 presents the important design characteristics of these mobile dryers available from India, China, Italy and Turkey and their indicative prices. The dryers as mentioned in the table are shown in the Photo 5.

Table 9. Comparison of different mobile grain dryers

Parameters		Essar ENOCH'S*	Matharu* Industries	TKM Series**	Agrex s.p.a***	Mecmar spa***	Hanzhong Burt Machinery Co Ltd**	Zhengzou Tianze Environmental Protection**
Model		ED-200	MEP-20	TKM 10	AGD 10	CPT 7/61F	MD-2	T-2D
Capacity (MTs/batch)	paddy	2.5	2	8		5.8	2	2
	maize	3.5	3	7		7.5		
Daily output (MTs/day)	paddy			31	28	26.4		
	maize			48	35	45.6	16	20
Operating temperature (°C)	paddy		Varies, from min of 25°– 100 °C	45-55	45	45		45-60
	maize			100-120	90	120		100-130
Power requirements	tractor size (hp)		35	50	50	30		
	motor drive (kW)		15	30.4	22.5	11 to 17	8.5	8.5
	fuel consumption (diesel, L/hr; coal, kg/hr)		13				8.5 kW; coal, diesel	8.5 kW and 7.5 l diesel/MT
Bin capacity (m^3)		4	4.6	10	10	10	2.8	3.8
Operating height (m)			4.5	3.8	5.5	5.65	3.46	3.46
Loading rate/ time		20 MTs/hr	20 min 9 MTs/hr	18 min	20 min	18 min		8-10 min
Emptying time (min)				9	20	15	8-10	8-10
Drying time (hr/batch)			2.5-3				3-4	3
Cost (USD-FOB)		~10000	~ 12000	USD 43,740 (solid burner);	40,000	30,000	10,000	6,000

Parameters		Essar ENOCH'S*	Matharu* Industries	TKM Series**	Agrex s.p.a***	Mecmar spa***	Hanzhong Burt Machinery Co Ltd**	Zhengzou Tianze Environmental Protection**
				USD 24,300 (diesel burner)				
Company		Essar Environmental Air Systems, Hyderabad, India	Matharu Industries Pvt Ltd, Faridkot India	Ozsu Machine Import Export Foreign Trade Company, Turkey	Agrex SPA Villafranca, Italy	Mecmar SPA, Minerbe, Italy	Hanzhong Burt Machinery Co Ltd, Hanzhong City, China	Zhengzhou Tienzen Environmental Protection Technologies Co Ltd, Henan, China
Notes: *as per the website, Indiamart.com[30]; **as per the website, alibaba.com[31] and ***communication with companies								

[30] Indiamart (https://www.indiamart.com/).
[31] Alibaba (https://www.alibaba.com/).

(Photo Credit: Matharu Industries (P) Ltd).

(Photo Credit: Essar Environmental Air Systems).

(Photo Credit: Mecmar SPA, Italy).

(Photo Credit: Ozsu Machine Import Export Foreign Trade Turkey).

(Photo Credit: Hanzhong Burt Machinery Co Ltd).

(Photo Credit: Zhengzhou Tienzen Environmental Protection Technologies).

Photo 5: Examples of mobile dryers manufactured and available in the market.

In Nepal, a mobile dryer was recently introduced in Dang district by Nepal Pasuahara Pvt. Ltd. This company had procured a dryer unit of model MEP-20 from Matharu Industries of India with the support of the Maize Super Zone office of the Prime Minister's Agriculture Modernization Project (PMAMP) in Dang. Completed trial runs found the dryer performs well and has been used for custom hiring services.

2.2.3. Fixed type of recirculating dryer

Many fixed types of recirculating dryer are also commercially available in Nepal and used by granaries and mills**.** Two such types of dryer and their different designs are presented here: the Presun grain dryer manufactured in China and the Bio-M6 dryer in India.

2.2.3.1. Presun grain dryer

The drying section of this dryer covers only 30% of space compared with the storage section, while the remaining portion is for cooling and tempering. Raw paddy and many other types of grain benefit from the tempering process; with the help of an elevator the grain is circulated repeatedly, so its moisture content reduces quickly even at the lower temperature. Tempering requires a longer time to finish the processing, but it protects and improves the quality of the grain (paddy, maize, soybean) and reduces the likelihood of cracking, which in turn results in fewer broken grains during the milling process.

In the Presun dryer, the more expensive steam boiler system is not required. It has options for using a small gas/diesel/oil burner furnace or a biomass furnace to generate the hot air, which circulates from the bottom to the top. The Presun dryer is currently marketed with the capacity of 15-35 MTs/batch. In this system, the temperature needed for drying is less than required with the LSU type of dryer, which can increase the quality of the rice grain.

This type of dryer has been successfully adopted in East Asia; at the time of writing, installation of a unit in Nepal is in progress. Photo 6 presents the dryer's design, while Table 10 provides some of its features and technical details.

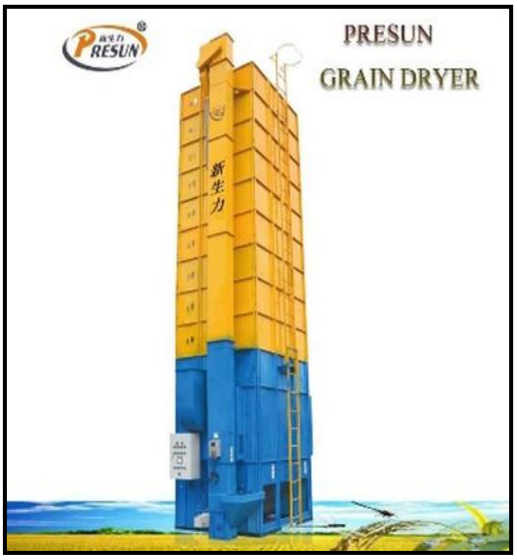


Photo 6. Presun grain dryer (Photo Credit: Anhui Xinshengli Agricultural Machinery Co Ltd)

2.2.3.2. Bio-M6 dryer

Manufactured by Matharu, portable batch grain dryers (of which the Bio-M6 is one) are used for drying both small and large quantities of grain. Simple to use, reliable and easy to install, the Bio-M6 dryer has an inbuilt biomass furnace which provides clean and ash-free hot air to the drying chamber and makes the drying cost up to 70% cheaper compared to using diesel or gas as fuel. It is designed for drying grains including maize, paddy, wheat, soybean, barley and rice, and marketed with the capacity range of 0.5-27 MT/batch.

In this design of dryer, hot air is generated by the husk furnace and forced to the drying plenum where the grain gets ample air to dry. The grain's temperature and moisture content are displayed on the control panel. As the desired moisture content is reached, the process stops, as it is equipped with fully automatic temperature-controlled features. Photo 7 provides an image of the Bio-M6 dryer and Table 10 summarizes some of the technical details and features of the two designs of fixed recirculating dryer outlined above.

Photo 7. Bio-M6 dryer with biomass furnace (Photo Credit: Matharu Industries Pvt Ltd)

Table 10. Technical details and features of two fixed recirculating dryers (Presun grain dryer and Bio-M6), when drying paddy

Capacity	Bio-M6	Presun
Dryer capacity (paddy)	6 MTs/batch	15 MTs/batch
Performance		
Loading time, mins	40*	60-90
Cooling	Variable, dependent on condition	
Emptying time, mins	20*	60-90
Power requirements		
Electric motor drive	15 kW, 3-phase, 50 Hz	9.6 kW, 3-phase, 50 Hz
Biomass husk furnace		
Power requirement	1 hp+2 hp, 3-phase, 50 Hz motors	2.2 kW
Fuel type	Rice husk, 50-80 kg/hr*	Rice husk, wood, straw, anthracite
Husk feeding	Automatic	Manual/automatic
Temperature control	Automatic, as per set values	Indirect hot air heating and auto-temperature control
Ash removal	Manually	Ash exhaust system

Overall		
Set	Loading hopper, loading bucket elevator, agitating drive (chain/gear); perforated screen, centrifugal fan; biomass husk furnace	Body of grain dryer, housing electric control cabinet, moisture meter, inlet of paddy, elevator, dried layer, ladder, auger, outlet for grain, centrifugal fan
Overall dimensions, mm	N/A	2583 × 4321 × 10,000
Safety devices	Temperature control, horst circuit protection, dust-proof control panel temperature and moisture display	Low temperature automatic alarm, high temperature automatic control. feeding system, smoking exhaust system, hot-air supply system, ash exhaust system, temperature control system
Materials suitable for drying	Maize, paddy, wheat, soybean, barley, rice	Paddy, corn, wheat and other cereal crops
Manufacturer	Matharu Industries Pvt Ltd, India	Anhui Xinshengli Agricultural Machinery Co. Ltd, China
Price estimated	USD 16,700	USD 26,500

2.2.4. Columnar circulating batch dryer

2.2.4.1. Introduction of dryer

During operation of this low temperature dryer, if the grain does not reach the target safe moisture content level during the first cycle, the conveying system recycles it back into the dryer and the process is repeated. Moisture content is measured at the outlet of the dryer and given in real time. When the grain reaches the optimum moisture content level, the discharge valve opens, discharging the grain out of the dryer.

This type of dryer uses coal, and biomass such as straw as fuel for a hot air furnace, creating an airflow which is evenly distributed ensuring uniform drying of the grain. Current designs in the market are well-automated, with a temperature controller and facilities enabling operation in manual mode. It also provides multiple emergency grain discharge ports for easy maintenance and troubleshooting. It is considered well-suited for drying both paddy and maize and is available with capacities varying from 2.5-30 MT/batch.

2.2.4.2. Specifications of an example columnar circulating batch dryer

Photo 8 shows the columnar circulating dryer (model 5HH-10) manufactured by Zhengzhou Wangu Machinery Co Ltd[32], China and widely used for large-scale drying of paddy and maize. Table 11 provides selected specifications of the dryer.

[32] Zhengzhou Wangu Machinery Co Ltd, (http://www.grain-dryermachine.com/).

Photo 8. Columnar circulating batch dryer (Photo Credit: Zhengzhou Wangu Machinery Co Ltd.)

Table 11. Specifications of small circulating grain dryer32 (model 5HH-10)

Parameter	Specification	
Model	**5HH-10 batch grain dryer**	
Capacity, MTs		10 per batch
Overall dimension (length × width × height), mm	Dryer body Overall dimension	2400 × 2060 × 7040 2860 × 4515 × 9095
Drying rate, %/h		0.7～0.9
Hot air temperature range, °C		50～85
Dryer motor, total power		10.3 kW
Auxiliary power	Grain discharge motor power, kW	0.4
	Elevator motor power, kW	2.2
	Conveyor system motor power, kW	2.2
	Fan speed	1450 rpm/min
	Air pressure of hot air fan	1100 Pa
	Hot air fan flow	12000～14000 m³/h
	Motor power	5.5 kW
	Fuel	biomass
	Fuel consumption	80 kg rice husk/hr
	Heat exchanger model	tube type
	Induced draft fan	
	Speed	2840 rpm
	Air flow	3500 m³/hr
	Power	2.2 kW
Elevator capacity	20 MTs/hr	
Performance	Grain feed time, mins	40～45 paddy/wheat
	Grain discharge time, mins	35~40 paddy/wheat

This type of dryer is reported to be in use in India and the Philippines. The cost estimate for this model of dryer set, including the biomass burner, is around USD 21,400.

2.3. Continuous flow dryer

Chapter 1, section 1.5.2.2 provides a general description of the continuous flow dryer. The grain passes through this type of dryer in a continuous flow at a controlled rate. It is kept in a thin layer approximately 100–150 mm deep and hot air blown through it[33]. The air temperature is generally substantially higher than in bulk dryers. The rate of throughput can be controlled, and hence the length of time exposed to the hot air, which is adjusted according to the amount of moisture to be removed. The final part of the path through the dryer is an ambient air section to cool the grain. Continuous flow dryers are high in cost and their use is only economically viable in highly mechanized situations.

2.3.1. Vertical-type LSU dryer

2.3.1.1. Introduction

The LSU dryer is a vertical, continuous flow type of dryer, developed at Louisiana State University[34] (LSU), USA in the late 1940s. In a continuous flow dryer, the grain flows without stopping from one end to the other, re-emerging with a 12-13% moisture content and ready for storage or milling. The LSU dryer was developed specifically for rice to ensure gentle treatment, good mixing, and the provision of consistent air-to-grain contact.

Photo 9. LSU dryer installed in a rice mill, Jhapa district, Nepal (Photo Credit: KISAN II Project for USAID)

The vertical LSU dryer consists of:

- Vertical rectangular drying chamber fitted with (1) airports, and (2) a holding bin with loading mechanism
- Air blower with duct
- Grain discharging mechanism with hopper bottom
- Air heating system

The operating system conveys the grain continuously by means of an elevator to the holding bin, where the grain receives hot air generated by the rice husk-fired furnace or boiler. Usually, there is a single pass of continuously flowing grain; however, some models are fitted for the recirculation of grain to ensure even drying. At the bottom of the drying chamber, a temperature-monitoring gadget

[33] Grain Drying Sourcebook (https://catapultdesign.org/files/2016/03/ASI-Grain-Drying-Sourcebook.pdf)
[34] Louisiana State University (https://www.lsu.edu/).

records the grain moisture content. Generally, airflow rate is 60-70 m^3/min/MT with an air temperature of 60-80 °C (for paddy) and up to 120 °C (for maize).

Due to the very high investment costs associated with the dryer unit and the heating furnace or boiler and cooling bin, as well as the high degree of automation required, this type of dryer is considered best suited to large-scale rice mills, flour mills and feed mills.

2.3.1.2. Specifications of the model/type

Photo 9 above presents an example of a vertical LSU dryer, manufactured and marketed by SLV Food Processing Industries, Karnataka, India. Table 12 presents some of the dryer's technical specifications.

Table 12. Technical specification of the LSU dryer, SLV Food Processing Industries, used to dry paddy

Parameter	Specification
Dryer capacity, MTs/hr	40
Bucket elevator capacity, MTs/hr	18
Centrifugal blower capacity, ft^3/min	33,000
Firing chamber volume, ft^3	300
Hot air fan, cfm	600
Drying time, hours	8
Drying rate, %/hr	1.5-2
Total power required, hp	29.5
Minimum area required (length x width x height) in ft.	10 x 8 x 70
Rice husk consumption, kg/hr	250-300

The vertical type of continuous flow LSU dryer is reported to have been used by many large-scale rice mills in India; the particular model of dryer referred to here has also been installed by large-scale rice mills in Nepal. The estimated cost of procurement of such dryers from India and China with the full complement of facilities (dryer, furnace, bulk-grain handling equipment and control gadgets) results in combined costs of anywhere between USD 60,000 to USD 100,000.

2.3.2. Horizontal LSU dryer

2.3.2.1. Introduction of dryer

The LSU dryer is a horizontal-type, continuous flow dryer. It consists of a feed bucket conveyor assembly, a dryer body housing, three conveyors, a cyclone and furnace assembly. The dryer also has a feeding inlet and outlet, two exhaust air fans and a dust removal fan. The clean hot air produced by the furnace is forced with the help of blower to the bed (or drying plenum) of the horizontal dryer, where the grain is fed in from the top with the help of a bucket conveyor assembly. Inside the dryer body, the grain is exposed on three conveyor belts in succession, where it gets the abundant heat energy, resulting in even drying. The temperature can be controlled for different commodities as required. The dried grains are expelled from the outlet at the base of the dryer's third conveyor.

Because of its horizontal alignment, the LSU dryer can be used for drying multiple products in addition to cereal grains, including tea, coffee and spices. In addition, its power/fuel requirements are relatively low compared to the vertical type of dryer. Its horizontal alignment also provides ease of maintenance and makes it less risky in terms of vulnerability to damage from natural disasters, such as high winds and earthquake.

2.3.2.2. Specifications of the model/type

An example of the horizontal type of continuous flow dryer has been supplied by Vista Equipment & Machines Pvt Ltd, Tamilnadu, India to business in Nepal, subsidized by provincial government[35]. Table 13 presents some of the dryer's technical specifications in regard to maize drying.

Photo 10. Horizontal type of continuous flow dryer (Photo Credit: Vista Equipment & Machines Pvt Ltd.)

Table 13. Specifications of horizontal, continuous flow LSU dryer

Parameters	Specifications
Dryer capacity, MTs/day	40
Processing capacity MTs/hr	2.5
Feed bucket conveyor capacity, MTs/hr	3
Furnace capacity, kg/hr	750
Volume flow of hot air fan, cfm	2500
Hot air temperature, °C	60
Drying time per batch, mins	~40
Drying rate, %/hr	8-10
Total power required, hp	55.5
Minimum space required (length x width x height), m^3	70 x 30 x 15
Durability, years	5-10
Rice husk consumption, kg/hr	60-80

The estimated total price for a complete set of dryers at place of origin is around INR 3.9 million (USD 33,915) in 2019 excluding foundation work which is built locally.

[35] GON, Province 1, (http://molmac.p1.gov.np/.)

2.4. Some small-scale dryers: prototypes/models

This section examines types of dryer which are in the demonstration or prototype testing phase, with the aim of providing the reader with more knowledge, and which can be used as reference material. Of particular interest are dryers which can be built locally.

2.4.1. Solar drying

Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized[36]. In broad terms, there are two major groups:

- active solar energy drying systems (often termed as 'hybrid solar')
- passive solar energy drying systems (conventionally termed as 'natural circulation solar').

Various models of large and small solar tunnel dryers have been constructed for grain drying. They have been tested and demonstrated since early 2000 and can dry 1-3 MT of grain over a period of 1-2 days. The Alternative Energy Promotion Centre[37] (AEPC) of the GON is promoting different solar dryers for drying different commodities, some of which are especially for drying grain in ultra-small batches (±200 kg).

2.4.1.1. Introduction of the solar/electric bubble dryer

The solar bubble dryer (SBD) is a drying technology designed to protect against rain, dust, and frost/mist during drying to mitigate post-harvest loss and the effects of climate change. It is the latest low-cost drying technology to be developed jointly by IRRI, the University of Hohenheim/Germany and GrainPro Inc.

Photo 11. Solar bubble dryer (Photo Credit: GrainPro Inc.)

The solar bubble dryer shown in Photo 11 was originally designed in the form of a plastic drying tunnel made of UV-resistant, water-repellent inflatable plastic material, with a cover made of UV-LDPE and a drying floor of reinforced PVC. At the time of writing, GrainPro Inc is marketing four models of solar bubble dryer as collapsible dryers for drying 0.5 MT and 1 MT of grain and utilizing solar panels or electricity as the heating source.

[36] G. L. Visavale -Principles, Classification and Selection of Solar Dryers (https://docplayer.net/28556846-Principles-classification-and-selection-of-solar-dryers.html)
[37] A GON unit under the Ministry of Energy, Water Resources and Irrigation. (https://www.aepc.gov.np/).

The working principle used in solar bubble dryer technology is simple. It uses energy from the sun in two ways[38]. Firstly, the drying tunnel serves as a solar collector to convert energy to heat from the sunlight entering the transparent top of the tunnel. Secondly, it has a photovoltaic system consisting of a solar panel, a deep cycle rechargeable battery and a controller, generating electricity to provide power to a small fan/blower. This moves air through the drying tunnel, inflating it and removing the water inside the tunnel as it evaporates from the grain. Two small ventilators facilitate drying, driving out grain moisture and keeping the bubble inflated. A simple roller dragged on ropes attached to its ends underneath the tunnel is used to turn the grain over without the need to open the tunnel. A rake is also available to turn the grain manually inside the tunnel.

Modified versions of the solar bubble dryer are also available, enabling the use of electricity as a power source instead of solar panels. The major advantage of this dryer is that in the case of sudden rain, the grain being dried is protected from re-wetting. In addition, the solar bubble dryer is mobile, and because it operates either completely or at least partially independently from the need for fuel or connection to the power grid, its operating costs are very low. It comes in different sizes, with current models having capacities of 0.5 MT and 1 MT/batch. It is built of collapsible materials and its components are detachable (making it easy to transport and assemble on any flat surface), and its operation does not require skilled labor. It is thus considered one of the most appropriate dryers for food grain, including *chaite dhan*. Its two limitations are (1) it needs a large area (minimum 25 m^2) of flat, even land, and (2) the investment cost is high.

2.4.1.2. Specifications of the dryer

Table 14 presents some technical details of four models of bubble dryer (including the one described above) operated by solar panel and electric power.

Table 14. Specifications of horizontal, continuous flow LSU dryer

Parameter	SBD25 Solar	SBD25 Electric	SBD50 Solar	SBD50 Electric
Top cover	UV-LDPE, transparent	UV-LDPE, transparent	UV-LDPE, transparent	UV-LDPE, transparent
Drying floor	reinforced PVC, black	reinforced PVC, black	reinforced PVC, black	reinforced PVC, black
Rake mixer	plastic rake with wooden handle (length: 2.2 m)	plastic rake with wooden handle (length: 2.2 m)	plastic rake with wooden handle (length: 2.2 m)	plastic rake with wooden handle (length: 2.2 m)
Ventilator	12 V DC ventilator, 1 unit	220 V AC ventilator, 1 unit	12 V DC ventilator, 2 units	220 V AC ventilator, 2 units
Solar panel	100 W, 1 unit	N/A	100 W, 2 units	N/A
Battery**	absorbed glass mat (AGM) 12 V, 70 AH	N/A	AGM 12V, 70 AH	N/A
Dimensions, m (length x width)	15 x 2	15 x 2	26 x 2	26 x2

[38] IRRI (2021) (https://rkbodisha.in/index.php/drying)

Parameter	SBD25 Solar	SBD25 Electric	SBD50 Solar	SBD50 Electric
Drying area, m^2	25	25	50	50
Capacity (based on paddy), kg	500	500	1,000	1,000

The solar bubble dryer is manufactured solely by GrainPro Inc[39] and is available in Nepal. At the time of writing, its estimated cost in Nepal is NPR 300,000 (USD 2,610).

With support from IRRI and the Renewable Energy for Rural Areas[40] (RERA) programs in Nepal, in June 2019, Nepal Agriculture Research Council (NARC) conducted a pilot test of a 1 MT-capacity solar bubble dryer at its premises at Khumaltar, Lalitpur, for spring rice. Some of the observations made were as follows:

- In view of the space requirements, an SBD with a drying capacity of 500 kg is preferred.
- The solar panel, roller mixture and blowers can be made locally to reduce costs.
- Intensive training and coaching are necessary to utilize and scale up this technology.

2.4.2. GrainPro collapsible dryer case

2.4.2.1. Introduction

The GrainPro collapsible dryer case (see Photo 12) is a portable case used to dry various agricultural commodities, including paddy and maize, safely and conveniently.

This is easy-to-install solution made from woven coated polyethylene (PE), which is twice as strong as ordinary tarpaulin and lighter than reinforced PVC, with inflatable PE sidewalls which keep commodities from spilling out of the dryer. The grain is spread on the dryer case where it absorbs energy from the sun during a major part of the day. Some of the energy is reflected and the remainder is absorbed by the surface, depending upon its color. The absorbed radiant energy is converted into thermal energy, increasing the temperature of the materials of the dryer which eventually dries the grain. As this system uses sunlight, thus it is the cheapest method of grain drying. The main advantage of the CDC is that the grain can be protected from re-wetting, as the drying floor can be easily folded and closed at night or in the case of sudden rain, preventing moisture re-absorption[38].

Some of the salient features and benefits of the dryer case are that it (1) is collapsible, (2) is lightweight and easy to transport, (3) is fast and easy to install by inflating the side walls, (3) closes conveniently and quickly in the case of sudden rain by using the pulling straps, heavy-duty zipper and flap cover, and (5) has nominal operational costs.

[39] GrainPro Inc, (https://www.grainpro.com/en).
[40] AEPC (https://www.aepc.gov.np/renewable-energy-for-rural-areas-rera).

Photo 12. CDC in use (Photo Credit: GrainPro Inc.)

2.4.2.2. Product specification

Table 15 presents the specifications of three different versions of the collapsible dryer case.

Table 15. Specifications of the CDC[39]

Parameters	CDC II – 25	CDC II – 44	CDC II – 75
Materials	Woven coated polyethylene		
Color	Black		
Thickness, mm	0.5		
Weight, g	320		
Drying area, m^2	25	44	75
Dimensions (length x width), cm	895 x 280	1575 x 280	1305 x 575
Capacity, kg	500	900	1550
Packed weight, kg	16	27	36
Packed volume, (length x width x height), cm	105 x 85 x 5	105 x 85 x 9	105 x 85 x 15

The GrainPro collapsible dryer case is manufactured by GrainPro Inc and is currently supplied in Nepal. At the time of writing, its estimated cost in Nepal is between NPR 100,000 (USD 870) and NPR 150,000 (USD 1,305) (inclusive of taxes). This type of dryer case has been utilized in Nepal for demonstration purposes by Forward Nepal in Chitwan and PMAMP[41].

Photo 12. CDC, details (Photo Credit: GrainPro Inc.)

[41] PMAMP (https://pmamp.gov.np/).

2.5. Large-scale dryers

Other models of large-scale dryer include the in-store dryer (in-bin, in-silo, in-warehouse), rotary dryer and two-stage dryers (where the bulk grain passes first through a fluidized bed dryer and then through batches of recirculating column dryers).

These types of dryer are popularly used by many countries which produce and export grain, including the US, China, India, Thailand, Vietnam and Argentina, for the large-scale drying/storage of maize and paddy. As the initial cost of a continuous drying system is very high, and economically viable only where large-scale drying and storage is combined, these dryers are not currently appropriate for Nepal. This publication therefore does not provide technical descriptions for them.

3. ECONOMICS OF GRAIN DRYING

Grain dyers, whether batch flow or continuous flow, are designed to reduce grain moisture content quickly by heating air which is then passed through the grain. As the drying rate and heating energy efficiency both increase by increasing the drying temperature (which must, nevertheless, keep within the recommended range), the design and management of the dryer, including sources of heat energy, are very important factors in achieving efficient, cost-effective drying.

The use of heat source devices for grain dryers, including biomass-burning stoves and diesel-fired hot air furnaces, has increased in recent years. Similarly, the use of diesel or electric energy for to power a fan to blow hot air into the grain and for conveying grain is increasing. Ways to optimize the use of these resources and the associated costs are therefore equally important aspects to keep in mind when considering the economics of drying.

As a wide range of dryers is available, and drying technologies have evolved and become more diverse and complex, it is becoming increasingly difficult to select the right type of dryer, even after examining their advantages and constraints. It is important, therefore, to be aware of what is available in the market, as well as the key criteria in the dryer selection process. Chapter 5 outlines the key criteria/aspects that potential investors and support projects should consider when choosing a mechanical dryer for installation in Nepal.

Costs of drying

- International Rice Research Institute (IRRI) has published a web-based information source book[42], "Rice Knowledge Bank, Your Information Source for Rice Farming". As the publication indicates, to ensure the success of introducing mechanical grain dryers, the cost of using them should not be higher than 5% (in the case of paddy) of the grain value. In many South East Asian countries, drying costs tend to be less than 5%. However, there is no study data available for the different dryers presented here; it would also be ineffective to list costs, as these depend upon many location/country-specific factors, such as capital investment requirements, fuel/electricity/labor costs, and the total quantity of grain dried during the drying season. Each potential buyer should draw up a separate business plan to include a cost-benefit calculation for each individual drying system, taking all these factors into consideration.
- Drying costs comprise fixed costs (depreciation, cost of interest, repair costs and opportunity costs) and variable costs (consisting mainly of fuel, labor and electricity costs).

[42] IRRI (http://www.knowledgebank.irri.org/).

The drying cost calculation is generally stated in cost per unit weight, usually as the cost per MT of paddy or maize. This is essential for making a comparative assessment of different drying systems.

To calculate costs requires an understanding of each particular dryer system, and should take into consideration technical information, including:

- Capacity (kg or MT) per batch (or MT/hr for continuous dryers)
- Drying temperatures (these differ for maize and paddy in each type of dryer)
- Drying time
- Labor requirements (for loading and unloading)
- Cost of repairing and maintaining the dryer
- Salvage value (depreciation)
- Dryer service life

And, information specific/local to the farming household/community/cooperative, including:

- Dryer utilization (in terms of crops/seasons)
- Grain to be dried (maize or paddy)
- Price of rice husk or maize cobs to be used as biofuel for heating furnace
- Price of electricity required for fans and conveying systems
- Cost of day labor
- Initial moisture content of the grain to be dried
- Expected final moisture content of the dried grain
- Weight of grain after drying
- Market price difference between dry and wet paddy
- Capital investment and credit cycle
- Interest rate

In 2019, case studies examining best practice for paddy drying in four South East Asian countries (Vietnam, Cambodia, the Philippines and Myanmar) were conducted under the Rice Flagship Project 2 of CGIAR in order to grade rice value chains. These presented an economic analysis of rice drying systems (drying in the sun, solar bubble dryers, conventional flat-bed dryers, reversible airflow flat-bed dryers and the recirculating columnar dryer)[43]. Table 16 presents the comparative results of the economic parameters and drying costs these studies used for different drying systems.

Table 16. Economic parameters of paddy drying (unit cost/labor/material per MT)

Parameters	Unit	Drying in the sun	Solar bubble dryer	Conventional flat-bed dryer	Reversible airflow flat-bed dryer	Recirculating columnar dryer
Capacity	MT/batch	1	1	4	20	30
Land area requirement	m^2/MT	40	28	12.5	8	6.7
Total investment	USD/MT	25	1855	1250	833	1317

[43] Nguyen-Van Hung, Tran Van tuan, Pyseth Meas, Caesar Javentino M, Myo Aung Kyaw and Martin Gummert (2019): Best Practices for Paddy Drying: case studies in Vietnam, Cambodia, Phillipines and Myanmar, Plant Protection Science Vol 22 No. 1, pp. 107-118.

Parameters	Unit	Drying in the sun	Solar bubble dryer	Conventional flat-bed dryer	Reversible airflow flat-bed dryer	Recirculating columnar dryer
Electricity consumption	kWh/MT	0	0	10.5	8.4	7.5
Rice husk used as fuel	kg/MT	0	0	48	48	60
Operating labor	hr/MT	16	4	2	0.4	0.3
Solar cell	w/MT	-	200	-	-	-
Plastic HDPE	kg/MT	10	31	-	-	-
Maintenance cost	% of investment	0	50	50	50	50
Life span of dryer	years		5	5	5	5
Physical loss during drying	per cent	5	2	2	2	2
Cost of drying	USD/MT	10-25	12-18	7-12	5-8	7-10

Table 17. Drying systems matched with capacities of different rice production systems in South East Asia

Capacity (MTs/day)	Drying system	Post-harvest system		
		Subsistence farming, own consumption	Surplus farming, local market	Surplus farming, premium market and export
Less than 2	Solar bubble dryer (batch)	***		
4-10	Conventional flat-bed dryer (batch)		***	*
11-30	Conventional flat-bed dryer (batch)		***	**
11-30	Recirculating columnar dryer (batch)		***	**
Higher than 30	Recirculating columnar dryer (batch)		*	***

Note: *not suitable; ** suitable; ***most suitable.

The findings and recommendations from the case studies were based on scenarios in South East Asian countries; nevertheless, these can be used as reference for our purpose, namely, to facilitate the selection of the most appropriate drying system for specific target groups (cooperatives, community groups, millers and other potential dryer operators) in Nepal. Some points of note are:

- Currently, the investment cost of solar bubble dryers is high. On the plus side, they could be utilized at the farm level, provided the investment cost could be made affordable and certain modifications made (for example, introducing electrical fans instead of solar panels).

- Conventional flat-bed dryers with a drying capacity of 4-10 MT/day would be most useful and appropriate for cooperatives and community-based operators interested in providing custom drying services on a fee-paying basis.
- The conventional flat-bed dryer and recirculating columnar dryer with a capacity of 11-30 MT/day are the most appropriate for cooperatives and community-based operators, as well as for the small-to-medium category of millers who intend to produce and sell high quality rice. Any dryer with a capacity of above 30 MT/day is not appropriate for Nepal in its current context.
- The introduction of mobile dryers could also be considered for drying paddy and maize at both the farm and off-farm levels.

4. OTHER DRYER ACCESSORIES

4.1. Selection of blowers/fans

Air is the medium used to carry moisture away from the paddy or maize during drying and conditioning. Hot air is typically forced into the bottom section of a bin (the plenum) under a perforated floor supporting the moist grain, using one or more fans.

Two types of fan – the axial flow and the centrifugal flow – are used to blow hot air into the grain bins during the drying process. Table 18 presents the characteristic uses and differences of these two types of fan/blower.

Table 18. Characteristic uses and differences of axial and centrifugal fans/blowers

Type/characteristics	Axial type	Centrifugal type
Design	Blows air in an axial direction, parallel to the shaft about which the blades rotate, flow is axial at entry and exit, fan is designed to produce a pressure difference.	Blows air from one end of the impeller, parallel to the shaft, which exits perpendicular to the shaft. It has backward-curved blades[44]
Performance	The axial fans could provide adequate airflow for aeration of rice already dried, which required much less airflow than when drying This type of fan is suitable for grains that create low static pressure, less than 4 inches of water[44].	These are most efficient type of fans when static pressure is more than 4 inches of water and are typically capable of generating much greater pressure than the axial fan[44].
Airflow rates	Higher airflow rate created at lower pressure, therefore more suitable for shallow-bed batch dryers with low resistance to airflow.	Ideal for use with deeper bed-drying operations because of high resistance to the airflow generated by rough rice (lower airflow rates)
Construction and overloading	Structurally very sturdy and non-overloading type.	Structurally sturdy and tends to overload if forward curved blades/rotors are used. To avoid overloading, backward curved blade/rotors should be preferred.

[44]Selection, Performance and Maintenance of Grain Bin Fans, (https://www.uaex.edu/farm-ranch/crops-commercial-horticulture/Grain_drying_and_storage/rice_drying_and_storage.aspx)

Type/characteristics	Axial type	Centrifugal type
Noise level	Very noisy during operation; not suitable for urban areas	Less noisy than axial fans, so should be considered when locating drying facilities near residences.
Cost	Cheaper than centrifugal fans	More expensive
Typically used in	Aeration; recirculation batch dryers; batch dryers	In-store dryers; other dryers

The optimum location of the fan is very essential to facilitate the even distribution of air flowing through the grain, which allows even drying and avoids "hot spots" that eventually increases drying efficiency and quality of grain. Grain producers or drying service providers should select the fan according to their needs. If the fan/blowers are oversized, it consumes unnecessary energy (in the form of electricity to power the fan motor, and gas or electricity to power the air heater) which increases the unnecessary cost.

The greater the airflow rate, the more energy is required to heat the air to the specific required temperature. Both the airflow rate through the grain and the air temperature directly control the drying rate of the grain[44]. Selecting the appropriate fan is important to achieve balanced airflow rates through the grain to ensure efficient drying, and to avoid higher running costs and a higher-than-necessary investment in the fan.

Farmers/investors should select an appropriately designed dryer (including careful consideration of appropriate fan/blower), to optimize the balance between airflow rate and air temperature, optimizing moisture content, and maximizing quality while minimizing overall costs. More information on the selection, performance and maintenance of grain bin fans can be available at website[44].

4.2. Grain cooling

Rather than drying the grain, grain cooler systems reduce its temperature so it can be stored safely and thus conserved for longer periods. The grain is first placed in a storage silo and then cooled to a level where grain with higher moisture content can be safely stored and conserved for much longer periods than grain with a higher moisture content kept at higher ambient temperatures.

Low temperature drying avoids common problems, including heat dissipation and moisture re-absorption by dried grain (normally that with a higher-than-ambient temperature), insect activity, product fermentation, molds, toxins, weight loss due to grain metabolism, and water condensation. Grain chilling also permits the retention of higher grain moisture without the associated risks. This cooling procedure also avoids the potential need for expensive, dangerous chemical fumigations, while at the same time reducing drying costs and energy consumption. However, the initial investment for buying and installing grain coolers tends to be very high. Photo 13 shows two examples of popular types of grain cooler.

Photo 13. Examples of grain cooling equipment (Photo Credit: FrigorTech and grainTECHNIK)

4.3. Moisture meters

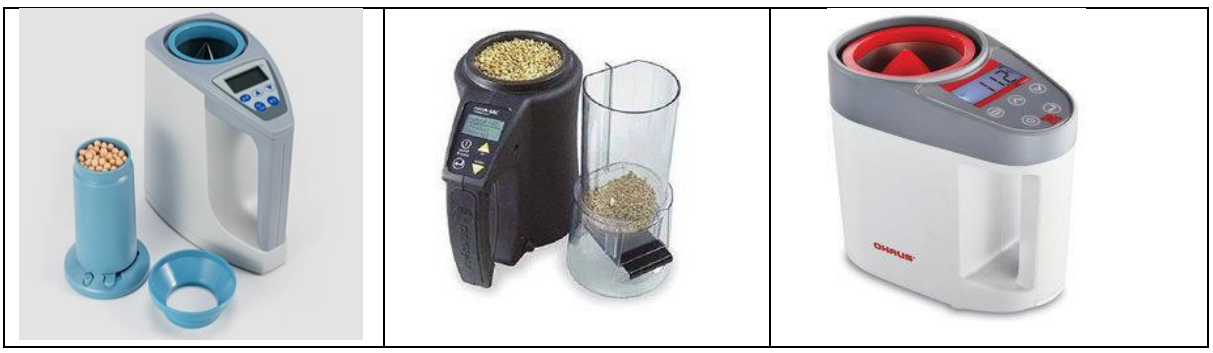
Most of the more expensive commercial dryers come with a built-in automated grain moisture meter, thermometer, anemometer and hygrometer. Conversely, many of the inexpensive, locally fabricated small dryers[45] are lacking these devices, which they need to measure different parameters such as moisture content, temperature, airflow rates/wind speed and humidity.

Digital moisture meters are commonly used in Nepal to determine the moisture content of grain digitally to get a quick result digitally to within a fraction of a second. Some of the commonly available moisture meters are mentioned below.

Along with built-in instruments to monitor/test the moisture content of the grain, and the ambient relative humidity, many commercial grain dryers monitor and regulate temperature and airflow rates. In many small capacity or locally fabricated dryers, these instruments are not built in, and therefore need to be selected and procured separately. As a wide range of instruments for varied applications are available, it is important to ensure that those procured are suitable for the purpose of drying cereal grains, especially paddy, rice and maize.

Many different makes of grain moisture meters are available from US, UK, Japan, India and China. Common types of moisture meter used with the dryer include the portable handheld, cup type, digital probes, halogen or infrared moisture analyzers, as well as laboratory moisture meters.

Note: It is essential to select a meter with a range able to determine moisture content of up to 35%. Photo 14 presents examples of moisture meters currently available in the market.



[45] Including the flat-bed dryer, EasyDry M500 maize dryer, ventilating dryer, solar/electric bubble dryer, GrainPro collapsible dryer case, Bio-M6 dryer, hybrid dryer, reversible flat-bed dryer, BAU-STR dryer and the solar biomass hybrid dryer, discussed elsewhere in this document.

Photo 14. Examples of moisture meters in the market, suitable for grain drying[46]

Most digital grain moisture meters cost between USD 100 and USD 1000, a wide range reflecting their ease of operation, accuracy in measurement, and country of origin.

4.4. Hygrometers

A hygrometer is an instrument used to measure air humidity. Photo 15 provides examples of the humidity measuring devices currently in wide use for drying grain.

[46] Amazon, Indiamart and Alibaba.com (2020)

Photo 15. Examples of relative humidity measuring devices suitable for use in grain dryers[46]

The cost of hygrometers currently available ranges from USD 10 to USD 200, depending upon ease of operation, accuracy in measurement and country of origin.

4.5. Thermometers

For measuring grain and air temperature inside the dryer, the different types of thermometer or temperature probes include bimetallic, bin and digital thermometers, temperature sensors, and temperature recorders/transmitters. The majority of these read temperatures below 200 °C. Photo 16 presents examples of thermometers generally used in grain dryers.

The cost of such thermometers and temperature probes/sensors ranges from USD 20 to USD 150, depending upon ease of operation, accuracy in measurement and country of origin.

Photo 16. Examples of thermometers and sensors suitable for use in grain drying[46]

4.6. Anemometer

The airflow rate must also be adjusted during grain drying, and for this an airflow meter (or anemometer) is essential. Photo 17 presents some of the hand-held types of anemometer available in the market and suitable for this operation.

Photo 17. Examples of airflow meters available suitable for monitoring airflow rates during grain drying[46]

4.7. Grain handling devices

As any drying system requires the frequent loading and unloading of grain and labor costs are increasing, more and more grain is being handled by mechanical conveyor during the drying and storage processes. With the use of Conveyors, hand labor is reduced which reduces the labor cost and saves a significant amount of operation. Many grains dryer manufacturers supply grain-handling devices as inbuilt components of the dryers and in some other cases as per the choice of the buyer. In the case of mobile dryers, these conveyors are designed as integral parts. At the point of purchase therefore, if the conveyor needs to be procured separately, it is essential to ensure that the right type and size of conveyor is ordered. To make the correct decision, therefore, it is essential to have a good understanding of the types of grain handling device, particularly conveyors.

Commonly used types of conveyors are:

- Screw conveyors (augers) move grain horizontally or up small inclines
- Belt and bucket elevators and flat-belt conveyers move grain horizontally, up small inclines, or lift grains vertically
- Flat-belt conveyors.

4.7.1. Screw conveyors

This type of conveyor is used to move grain horizontally which comprises a conveyor screw in a trough, supported by end and hanger bearings. Rotation of the screw pushes the grain along the trough. In a standard conveyor screw, the distance from the center of one thread to the center of the next which is known as Pitch is equal to its diameter. However, conveyor can also be used in an inclined position but there will be a corresponding reduction in capacity.

There are many manufacturers which produces a special screw conveyor or "auger", used to move grain intermittently for short distances, for example, from a tractor-trailer into a dryer or from a dryer into a storage bin. Two types of auger are utilized for different purposes: horizontal and vertical[47].

A horizontal auger is generally used for horizontal unloading and conveying grain on or under the floor of a dryer/storage bin generally known as sweep auger. Being light duty, this type of auger is less expensive than heavy duty types and more attractive to operators who do not require continuous heavy-duty operation.

A vertical auger is designed to move grain discharged from the dryer to a truck, or into a mill or storage facilities. It has the same type of trough and screw flight construction as the horizontal auger, with adjustable height and angle so as to meet the customers' requirements[47]. However, operating this type of auger in a vertical position that greatly reduces its conveying capacity.

Both types of auger are available in a wide range of lengths and capacities and are usually powered by an electric motor. Longer augers may be mounted on wheels for easy transportation. The angle of operation is adjustable but the capacity declines as the auger is raised; high moisture content also reduces capacity.

4.7.2. Belt-and-bucket elevators

This is a belt operating between two pulleys with its load supported on idlers. It can be flat (for moving bags of grain) or V-shaped (for moving bulk grain). The carrying capacity depends on the belt width, angle of trough, and belt speed. The belt and bucket elevator consists of a belt, drive and end pulleys, idlers, a drive and tension mechanism, and loading and discharging devices. In practice, this type of conveyor is used horizontally, although an inclination of up to 15° is possible. Some elevators have ribs which enables the angle to be increased up to 30°. The factors which affects the angle of inclination at which a belt conveyor will convey a bulk material include its particle size and shape, moisture content, angle of repose, and flowability. It's carrying capacity is high because relatively high speeds, and grain can be conveyed several hundred meters long. In addition, grain can be loaded or unloaded anywhere along the belt, causing no damage to the crop and raising little dust. The initial cost is high for short-distance belts and relatively low for long-distance belts compared to other types of horizontal conveyor. For these reasons, belt conveyors are widely used to move paddy in many installations in Nepal. They range from 30-100 cm in width and can be used up to several hundred meters long[48].

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[47]Technical Handbook for the Paddy Rice Postharvest Industry in Developing Countries James E. Wimberly (http://homedocbox.com/Appliances/74672391-Technical-handbook-for-the-paddy-rice-postharvest-Industry-in-developing-countries-james-e-wimberly.html)

[48] Conveying (http://www2.hcmuaf.edu.vn/data/dh04cc/file/Conveying.pdf)

Several designs of bucket elevators are available in the market to handle different products. Most commonly used elevators are the centrifugal discharge-type for conveying grains like maize and paddy. A bucket elevator consists of a crowned pulley at the top and bottom of the casing and runs between them. Small buckets or scoops are fixed to the belt at regular intervals to hold grains and carry the grain from the bottom of the elevator to the top. Carrying capacity of the elevators depends upon the width of the buckets, spacing and belt speed[49].

Elevators can be up to 20 m in height and with a capacity as high as 50 MT per hour. A properly designed bucket elevator driven at the correct speed will make a clean discharge, ensuring only slight grain damage, and little or no backlogging or down legging.

4.7.3. Other types of conveyors

Other types of conveyor like shaker (which operates by vibrating), chain (which drags) and pneumatic conveyors are occasionally used to move paddy and maize. However, these types of conveyors are rarely used because of the limited capacity of shaker conveyor and very short life of chain and pneumatic conveyors due to the extreme abrasiveness of paddy and maize as compared to other grains. As a result, these type of conveyors are seldom used for moving paddy/maize[48].

5. SELECTION OF MECHANICAL GRAIN DRYERS

In Nepal, very few mechanical dryers have been installed by large-scale mills for drying grain which they utilize for milling purposes, particularly for production of parboiled or steamed rice. A few other small mobile, solar bubble dryers are in the demonstration stages for grain drying. Thus, Nepal is yet to take advantage of mechanical drying systems and their potential for reducing post-harvest loss of cereal grain. As a developing country producing paddy and maize as major cereal grains for food security, it is important that Nepal considers promoting the adoption of commercial scale drying systems, as is being done in India, Bangladesh and many other Asian countries.
A large number of manufacturers of dryer machineries exist in the global market, supplying different types of mechanical dryers with a wide range of drying capacities, from very small to very large capacity.

Differences in drying cost, dried grain quality, specific initial capital cost, and varying degrees of automation, all result in differences in economic and social benefit to the user. It is extremely important, therefore, to provide potential investors (farmer groups, cooperatives, the private sector) with information on opportunities and knowledge about multiple market choices of dryer technologies, for use in Nepal in a range of situations and for different purposes.
It is likely that providing potential investors with this knowledge and information and thus facilitating them to make an informed choice would be one of the best programmatic outcomes which will push them closer to taking advantage of mechanical drying systems to reduce post-harvest loss of cereal grains. At this stage, it would be extremely worthwhile for the potential investor to inform themselves about the following basic criteria/aspects and general requirements to consider when selecting the most appropriate grain dryer.

Technical aspects

- Type of grain for which the dryer can be used (including paddy, maize and wheat).
- Drying capacity requirements (MT/day, MT/batch or MT/hr).

[49] FAO (http://www.fao.org/3/s1250e/S1250E0x.htm)

- Maximum allowable moisture removal while maintaining grain quality.
- Drying quality, breakage ratio, discoloration, pollution (changes in taste) to grain, burnt kernels.
- Adaptability of dryer to heating source/fuels (biomass, diesel/heating oil, electricity).
- Ambient temperature suitable for operation (varies between types of dryer, and for paddy and maize).
- Fuel and electricity requirements.
- Level of automatic control (control of grain level, control of grain level and temperature, measurement of moisture content and through-put, computerized control and process monitor).
- Adaptability and ease of system to be used with additional automation.
- Reliability (breakdown probability, safety).
- Adjustment of temperature and humidity, waste heat recycling system.
- Available space required for dryer arrangement and operations.
- Air pollution (altitude and intensity of smoke [fume] emission), dust and noise emissions, whether it conforms to local and central government labor safety and "smokestack" regulations.

Economic aspects

- Reasonable equipment price and initial investment requirement for all the machinery, equipment (electric motors, furnaces, fans, conveyers/material handing devices and measuring/monitoring instruments).
- Operating cost including drying cost.
- Service life.
- Reliable operation.
- Ease of maintenance services.

In the context of the initial stage of introduction of mechanical dryers in Nepal, investors and support projects should consider the following points before selecting a machine in which to invest:

For consideration by investors

- Location of dryer needs to be chosen to avoid flood areas and with easy access to central roads/paths.
- It is very important to install dryers close to farmers, to (1) cater for the needs of target crops (e.g. *chaite dhan*), and/or (2) to facilitate the development of custom hiring services to provide drying services to farmers.
- It is also important to ensure an assured biomass supply to supply a heat source where the dryer is to be installed. Other energy sources can be used at the beginning and in emergencies, but biomass use will greatly reduce operating costs.
- In terms of dryer investment, investors should take care not to cut corners leading to, for example, the wrong selection of blower fans designs, heating furnaces and conveyors. Over time, this would be likely to increase operational costs and reduce efficiencies.
- Investors should consider the design of the different dryers and the possibility each provides to switch over easily from a biomass fuel-based heating furnace to an electric power source whenever this is cheaply available.

- The potential of a dryer to provide multi-crop drying needs to be considered to facilitate the year-round operation of the selected dryer to reduce the cost of drying.
- Any proposed dryer business should seriously consider offering additional services such as milling, feed milling and warehouse services, avoiding the need for famers to transport twice.
- To provide drying services to small-holder farming households, a choice of mobile dryers would be useful.
- The prospect of using basic semi-automatic grain handling devices (like conveyors) for loading and unloading could also be considered when an electric power source is available.
- Availability of sufficient land and building space needed to house the dryers (for mobile and fixed-bed dryers) should be considered, along with the future possible expansion of drying capacity and provision for conveying devices.

For consideration by support program/projects

When extending program support to facilitate the establishment of dryers by farmers, community, cooperatives and the private sector, GON and development partners should consider the following points prior to either short-term or long-term investment:

- Federal government (CAIDMP and CCDABC under DOA and PMAMP), provincial and local governments, as well as donor partners (such as KISAN-CIMMYT) involved in post-harvest technology need to monitor and support farm-level micro drying, and study/gain a better understanding of the industrial-level drying business model. Of urgent need, however, is the targeting, through two or three PPP programs, of "middle path" business models for smaller private mills and farmer marketing association/cooperatives and using the 3 - 20 MT/day mobile and flat-bed dryers. Support could be in the form of grants, cost-sharing or subsidies, as well as some longer-term business development inputs and, very importantly, strong agri-rural engineering inputs.
- It is also important to assess the cost-benefit situation alongside the constraints faced by large-scale private sector millers who have already invested in drying. This assessment will help identify the lessons to be learned by potential investors, big or small, including farmers.
- On a long-term basis, GON and donor partners need to create a reduced risk investment environment, including policies to offset private sector investment risk.
- GON and support projects should also develop multi-year support programs to provide long-term engineering and business mentoring, with the aim of reducing risk for investors.

6. CUSTOM DUTIES/EXCISE DUTIES, OTHER TAXES AND VAT ON DRYER IMPORT

In Nepal, the import of machinery/equipment and instrument spare parts is subject to differential custom duties depending upon the supplier's country of origin (categorized as India, Tibet, SAARC or 'other country'). Value added tax (VAT) is levied at the customs point itself.

Import tariff. In the case of plastic materials and cooling devices, excise duty is also levied, with tariff rates varying according to the GON's annual program and policies.

Table 19 presents the integrated tariff rates applied to dryers, furnaces, fans, material-handling devices and test instruments by GON in Fiscal Year 2019/20.

Table 19. Integrated tariff rates[50] applied to dryers and associated equipment and instruments in Nepal, FY 2019/20

HS Code	Item	Import Duty % of Value		Excise Duty	VAT	Total tariff rate % of Value			
		SAARC	Others			SAARC		Tibet	Others
						India	Others		
39.20	Plastic sheets PE/PP/PVC	15	15	5	13	35.56	35.56	35.56	36.45
84.19.31	Drying machinery for agriculture products (other than for domestic purposes)	5	5			4*	4*	4*	4*
84.19.90	Spare parts for dryers	exempt	exempt		13	13	13	13	13
84.19.31; 84.19.50	Heating furnaces	5	5			4*	4*	4*	4*
84.28.10; 84.28.20 and 84.37.80	Material handling equipment, conveyors and spare parts	5	5		13	18.37	18.65	19.37	18.65
84.14.80	Industrial fans	6	10		13	21.19	21.19	29.10	29.95
84.18	Cooling devices	15	15	5	13	35.56	36.45	35.56	36.45
90.18	Scientific equipment for measuring temperature, humidity, moisture etc.	5	5		13	18.37	18.65	18.35	18.65

*Reduction in the tariff is as per provision in the Financial Act, 2077, GON Nepal. This is applicable only to those machineries imported under schemes approved by the Department of Industry.

7. ACCESS TO FINANCE AND INTEREST RATES ON DRYERS

Until October 13, 2020, there was no special mechanism enabling easy access to funds for installing dryers. However, the following two types of loan for drying facilities have been considered under the "deprived loan" category, as specified in the Unified Directives 2077 of Nepal Rastra Bank (NRB):

[50]Integrated Custom Tariff 2019/20, published by Department of Customs, Ministry of Finance, Nepal, 2019. (https://customs.gov.np/storage/files/1/Custom%20Tariff/01_inti.pdf).

- Any loan proposal for solar dryers requiring an investment of NPR 200,000 or less
- Any loan proposal up to NPR 10 million by rural cooperatives for post-harvest services

For these types of loan proposal, the banks and financial institutions of Nepal will have to consider for priority lending. Details of the loan procedures and terms and conditions to be followed for deprived sector loans can be found in the Nepal Rastra Bank (NRB) Directives[51] 17/077.

Until very recently in Nepal, grain drying was not generally considered a separate industry and therefore could not receive any concessional loans for capital investment under priority sector lending. Thus, as of September 2020, normal interest rates for bank term loans for capital investment apply, at around 14.5% (base rate plus 5%, depending on the bank). However, the recently revised integrated Working Guidelines for Interest Subsidies on Concessional Loans (Third Amendment), 2077, passed by GON on September 24, 2020, provisioned the grain storage industry as an additional enterprise entitled to receive concessional loans, with interest subsidies of up to NPR 50 million. GON will provide 5 percentage points of the interest charged by the banks and financial institutions as an interest subsidy to the borrower of loans for capital investment in grain storage.

The current interest rate for loans which fall into the agriculture and livestock enterprise category remains at the individual bank's base rate plus up to 5% points (actual interest rates remain within the range of 9% to 14.5%). The current subsidy provision will allow borrowers to obtain loans at a rate of between 4% and 9.5%, depending upon the bank providing the loan. At the time of writing, interest rates continue to fluctuate widely, depending upon the financial situation of Nepal's banks and GON's monetary policy.

Details of loan eligibility, loan application procedures, and other terms and conditions can be obtained from the website: https://www.nrb.org.np/.

8. SUBSIDIES/INCENTIVES AVAILABILITY AND RECEIVED ON DRYERS

Up to the time of writing, approximately 15 - 20 food grain dryers have come into existence in Nepal as an integral part of grain/feed mills, with no separate industry registered solely for drying. In the purview of GON policy, grain drying has yet to be listed as a priority industry and as such there is no clear established policy in terms of monitoring or providing subsidies and incentives for the establishment of dryers in Nepal. However, from fiscal year 2018 - 19, different federal and provincial government agencies have begun to include subsidy programs to provide support to establish small numbers of dryers for grains and cereals, particularly in regard to the Spring Rice Initiative.

In financial year 2019/20, the Ministry of Agricultural, Land Management and Cooperatives in the country's Province 1 launched a program to support farming households, entrepreneur farmers' clubs and co-operatives to establish five dryers for *chaite dhan*, announcing a maximum 75% subsidy on the cost of the dryer, with a maximum limit of subsidy of NPR 8.0 million[52].

[51] Nepal Rastra Bank (NRB) Directives 17/077, (https://www.nrb.org.np/contents/uploads/2020/09/Unified-Directives- 2077.pdf.)
[52] GON, Province 1, (http://molmac.p1.gov.np/node/140).

Similarly, in the same year, the Center for Agriculture Infrastructure Development and Mechanization Promotion (CAIDMP), under the Department of Agriculture of the Federal Ministry of Agriculture and Livestock Development (MOALD) also provisioned a 50% subsidy (with a maximum limit of subsidy of NPR 10 million) for the procurement of dryers for drying *chaite dhan* and spring maize.

In August 2020, MOALD developed an operational procedure for an agriculture infrastructure development program to be implemented by local government under a conditional grant from federal government. The program includes the provision of grants for the purchasing and establishment of grain dryers. Detailed information about dryer subsidies can be found on the CAIDMP website: http://caidmp.gov.np/.

As indicated in the recently revised (Third Amendment 2077) Integrated Working Guidelines for Interest Subsidies on Concessional Loans, any loan to be provided for capital investment in grain dryers will be considered under the category of a privileged loan. This has cleared the way for entrepreneurs wanting to invest in mechanical drying methods to obtain a subsidized loan from any bank or financial institution.

9. INSURANCE POLICY

As per the Asset Insurance Directives 2075 of the Nepal Insurance Committee (the GON regulatory agency), dryers come under a medium risk category, with the premium rate set at NPR 3 per NPR 1,000 of the asset value. The terms and conditions of insurances are as set in the Directives[53]. There is currently no scheme for any premium subsidies for the dryers available.

10. IMPORT PROCEDURES

Nepal has an open and porous trade regime with India. The GON Ministry of Industry, Commerce, and Supplies (MoICS) and along with the Department of Customs under the Ministry of Finance, governs the rules and regulations relating to the import of drying equipment. When importing drying machineries and ancillary gadgets/components associated with the dryers, the following rules and procedures have to be observed.

Rules related to import

- Except for prohibited and quantitatively restricted items, no licence is required for imports.
- Nepal customs does not require any pre-shipment inspection and there is no generalized system of such inspections.
- A customs valuation provides a basis for the declaration of value by an importer on the Nepal Customs Declaration Form for the calculation of applicable duty and tax.
- Customs duty on imported goods is assessed on the basis of their transaction price. The owner of the goods is required to submit to customs bills and invoices showing their price, as well as other necessary documents relating to imports, as demanded by the customs for verifying their transaction price.
- No demurrage is charged on imported goods until they are valued for the purpose of assessing customs duty.

[53] Property Insurance Directives, 2077, (http://nib.gov.np/wp-content/uploads/2018/12/Property-Insurance-Final.pdf.)

Paying for imports

- Imports from India are normally paid in Indian rupees.
- For imports from a third country, GON does not allow advance payments for goods and separate payments for freight. In addition, with the exception of prohibited and quantitatively restricted goods, there is no restriction on the release of foreign currency for importing any type and quantity of goods. However, to obtain foreign currency from a commercial bank, the importer has to get a letter of credit (L/C) issued on fulfilment of the bank's requirements.
- An irrevocable L/C is the commonly used documentary credit for the settlement of payment in imports from third countries.

Import procedure

- Most of Nepal's international trade takes place via transit in India. Nepali cargo is mostly routed through Indian ports at Haldia and Kolkata in West Bengal, and Vishakhapatnam port in Andhra Pradesh.
- From the respective ports, goods are trans-shipped by rail or road to Nepal's border customs. Importers can also use airfreight to deliver their goods to Nepal via Tribhuvan International Airport in Kathmandu.

Importing from India

1. The following documents and procedures are required for importing dryer and its parts. Custom agent authority letter
2. Delivery order of the terminal management company (TMC) in case of inland clearance depots (ICDs) at Biratnagar, Birgunj and Bhairahawa
3. Invoice
4. Nepal's customs declaration (white)
5. Packing list
6. Additional documents for the specific cargo as applicable (including plant quarantine/health/phytosanitary certificates for plants, a laboratory test report for food products, analysis report for chemicals, health certificate for raw wool, veterinary certificate for animals).

Upon submission, the customs office processes the application, imposes the appropriate tariffs, and sends the commodities for clearance.

Importing from a third country via India

a. Entry into Nepal

- When cargo reaches the Nepal border, the importer or customs agent must go to Nepal's customs with the following documents:
    1. BBN 4 form of the Nepal Rastra Bank (Central Bank of Nepal)
    2. Bill of lading/delivery order
    3. Certificate of Insurance
    4. Certified copy of L/C or advance payment
    5. COO (this is not strictly required except where imported goods are subject to a special tariff concession on account of their place of origin
    6. Combined transport document (CTD) (original)
    7. Delivery order of TMC, in the case of Inland Container Depots (ICDs) at Biratnagar, Birgunj and Bhairahawa

8. Enterprise registration certificate
9. Invoice
10. Customs agent authority letter
11. Nepal's customs declaration (white)
12. Packing list
13. VAT registration certificate/PAN
14. Wool specification test report if applicable
15. Additional documents for specific cargo, such as plant quarantine/health/phytosanitary certificates for plants, lab test report for food products, analysis report for chemicals, health certificate for raw wool, a veterinary certificate for animals, where applicable.

- The requirement of a Certificate of Insurance by customs is only for customs valuation: any insurance document submitted by the importer is acceptable to the customs for valuation purposes.
- Customs verifies the BBN 4 document issued by a commercial bank with BBN 3 received previously from the same bank at the time of opening L/C. After the goods are cleared, customs certify the BBN 4 and hands it over to the importer for delivering to the issuing bank.
- After all the submitted documents have been checked. Customs assess the applicable duty and VAT for payment by the importer before releasing the cargo. When the goods are cleared after the payment of customs dues, the Nepalese customs officer endorses the original and third copy of CTD, and the original is returned to the importer who sends back the third copy with a covering letter for delivery to the corresponding Indian border customs.

The importer is required to submit the original CTD to the corresponding Indian border customs within 15 days of the date on which the goods were released at the Indian port of entry (or such extended time as the concerned Assistant Commissioner of Customs House may allow).

NOTE: *Information such as procedure for opening and paying L/C in a commercial bank, import licensing permits & per shipment inspection, procedure at the seaport at entry, procedure at the Indian border and entry into Nepal can be found from the https://staging.nepaltradeportal.gov.np/guide-to-importing and details of the custom clearance procedures is given by the Departments of Customs in its website: https://www.customs.gov.np/page/customs-procedure.*

11. DRYER CHOICES IN THE CONTEXT OF NEPAL

Typical types of mechanical or heated-air dryers used for paddy and maize drying across South East Asia and South Asia are the flat-bed dryer (both the fixed and the reversible airflow types), the recirculating batch columnar dryer, the continuous flow dryer and the two-stage drying systems referred to in chapter 2, section 2.5 of this document).

A wide range of dryers for paddy and maize is available in the Asian markets (see for example those listed by indiamart.com and Alibaba.com), with more than 900 suppliers and a similar number of types/models of grain dryer. Suppliers are predominantly located in India and China, and to some extent in Taiwan. Some companies in Thailand, the Philippines, Bangladesh and Vietnam are also manufacturing and marketing the flat-bed and other types of dryer. Thus, with the advent of multiple E-commerce websites, there has emerged over the last five years or so a large choice of technology and an increased chance of obtaining suitably priced dryers with the highest efficiency, accuracy, operational ease, compactness, mobility and multi-functionality. Prices (FOB) vary widely, mainly from USD 2,000 to USD 50,000 per unit, depending upon factors such as dryer type, capacity, machine materials (mild steel/stainless steel), heating and airflow devices, type of material conveying systems, degree of automation/safety, and movability. Some low-cost dryers have also been designed and manufactured at the local level in countries such as Vietnam, the Philippines and Bangladesh. Many popular models of dryer are also available from developed countries including the US, Canada, Italy, Turkey, UK, Finland, Denmark and Japan. Manufacturers include Agrex, Andrew Fletcher, Buhler, Dancorn, ESMA, Fratelli, GT Dryer, Hillsboro, HKB, Masters, Mepu, Moridge, NECO OZSU, Peddrotti, TECO, Mecmar, Shivvers, Strahl and Zafrrani. Of these dryers, most have either a higher drying capacity or higher degree of automation and safety measures than those available in Asia. Compounded by high freight charges, the cost of these dryers is relatively high, making their affordability a likely major concern for investors in Nepal.

In the context of Nepal, two different approaches should be considered when selecting the type of mechanical dryer most appropriate for introduction and dissemination, to (1) farmers'/community groups and cooperatives, and (2) grain storage owners, rice millers and feed millers.

As a large number of dryer manufacturers and a variety of technologies are available, coupled with very little current use in Nepal of mechanical dryers for drying cereal grains, it is very difficult to provide recommendations regarding dryer type and capacity on the basis of a cost-benefit analysis. However, in an attempt to facilitate choice of dryer type, Table 20 provides general indications of dryers most suitable for farmers groups/community, cooperatives, custom service providers, and rice/feed mills and storage operators.

Table 20. Types of dryer, based on capacity and use options (indicative)

Capacity (MTs/day)	Dryer/ Drying system	Farmers groups/ community-based services	Cooperative ownership	Custom drying services	Grain storage operators; rice/feed mills
Up to 2	Solar bubble (batch) dryer	***	**	*	*

Capacity (MTs/day)	Dryer/ Drying system	Farmers groups/ community-based services	Cooperative ownership	Custom drying services	Grain storage operators; rice/feed mills
0.5-1	EasyDry M500	***	*	*	*
2-3	Locally fabricated conventional flat-bed dryers	***	**	*	*
4-6	Reversible airflow flat-bed (batch) dryer	*	***	***	*
4-6	Mobile type of reversible airflow dryer	*	***	***	*
4-0	Reversible airflow flat-bed (batch) dryer	*	***	***	*
11-30	Conventional flat-bed (batch) dryer	*	**	**	**
11-30	Recirculating columnar (batch) dryer	*	**	**	***
Above 30	Recirculating columnar (batch) dryer	*	*	**	***
Above 30	Continuous flow dryer, vertical LSU type	*	*	*	***

Note: *not so suitable; ** suitable; ***most suitable.

a. Most appropriate dryer for (1) farmer/community groups or cooperatives and (2) custom drying services

Land-holding sizes in Nepal are very small (0.68 hectare on average)[54] and there are large number of farmers for whom direct drying services would be appropriate. Based on the experience of other countries, the following three options could be usefully considered when introducing and disseminating mechanical dryers for the benefit of farmers:

1. **Farmer groups/community-based services**. Appropriate here would be the promotion of low-cost, small-scale, multiple-grain and multi-use mobile dryers, utilizing a solar or biomass/electrical heating source (in contrast to high capacity dryers needing a high initial investment and greater operating skills). The locally fabricated, modified, conventional flat-bed

[54] As per the National Sample Census of Agriculture 2011-2012 (CBS, 2012).

dryer, following a Vietnamese design and with a capacity of 1 MT/batch (around 2-3 MTs/day is highly suitable for Nepal.

Alongside this, a smaller version of dryer (such as the EasyDry M500, a portable maize dryer designed in Kenya, discussed in detail in Chapter 2, section 2.1.4) could be manufactured and adopted in Nepal. This can dry batches of up to 500 kg, three batches a day. It has already been tested by Krishi Tech Nepal.

In addition to these, as it is portable and also usable in emergencies, the solar bubble dryer, initially designed and developed by IRRI and manufactured by GrainPro Inc, could also be considered for promotion at the community level, provided the cost of the dryer can be reduced and complementary energy sources (solar and electricity) used to facilitate longer drying hours.

II. **Cooperative ownership**. Cooperatives (including farmer cooperatives) own the dryer and provide drying services to groups of farmers and community-level agencies. This entails a lower upfront cost and a higher utilization of the dryers, especially if there is a large number of farmer members – rice or maize drying is seasonal in nature, and this option avoids the dryer sitting idle for at least six to eight months. A cooperative might realize its return on investment after three to four years, depending on the scale of dryer usage. Maintenance of the dryer could be an issue of not operating at the optimal level as the farmers are not trained to proper handling such equipment and machineries.

III. **Custom drying services provided by a group of farmers/cooperatives or private company/firm**, either at a specific location or on a mobile (door-to-door) basis. These charge farmers a service/rental fee (varying according to location) for custom service provision. The main advantages of this option include the farmer being a user of the dryer as well as a possible service provider, renting it out to other farmers. This option has the potential to be sustainable because the individual farmer is not required to invest in the dryer, can access trained operators, and are not responsible for maintenance services. In addition, the dryer can also be moved from one location to another to take opportunity of seasonal variation in demand. The only disadvantage is the high investment cost associated with buying and installing a new mechanical dryer with the most appropriate capacity (that is, small), which is likely to necessitate access to financial support.

Based on the experience of South East Asian countries, for the latter two options (cooperative ownership and custom drying services), the small capacity, fixed flat-bed dryer (specifically, the reversible airflow type) or mobile recirculating dryer are highly suitable for providing drying services directly to farmers in Nepal. A typical cooperative comprising about 100 small farming household members, with an aggregate farm area of 20 ha per cooperative and yields of 3-4 MTs of paddy or maize/ha, will produce 60-80 MTs of paddy (or maize) per harvest which will require drying. Farmers would be expected to harvest collectively, on average, 4-6 MTs/day over a harvesting period of about 15 days. To dry this quantity of grain, a dryer with a capacity of 2-3 MTs per batch is sufficient. If the drying process needs to be hastened or the crop yield is unexpectedly high, the dryer capacity might also need to increase; it is therefore safe to consider a drying capacity requirement of up to 3-4 MTs/batch (or 6-8 MTs/day). To ensure economy of scale, this should be considered the minimum capacity when investing in a flat-bed dryer.

b. Owners of grain storage, and rice and feed millers

In Nepal, rice mills with a milling capacity of less than 4 MTs/hour currently do not consider it essential to use a paddy drying unit; those with a greater capacity than this and producing steamed rice do use mechanical drying facilities as integral parts of the mill. Most of the country's millers use continuous LSU dryers, with their dryer requirements synchronized with the batch operation of the steaming process and the conditioning bins. The maximum milling capacity of mills in operation in Nepal at the time of writing is around 8 MTs/hr.

However, any rice mill or agency planning to procure paddy or maize during the harvest season to store in bulk in silos or warehouses for future processing/trading should also install drying facilities. This is particularly important in the case of *chaite dhan* (spring paddy) because of the difficulty the country's farmers face in drying the harvested grain due to adverse seasonal weather conditions such as poor sunshine or the high chance of rain. In Nepal, very few mills and no storage agencies have considered the option of mechanical drying facilities, even though these would enhance their economic efficiencies in terms of reducing storage loss and maintaining the quality of stored grain. Any initiative by GON to encourage the use of mechanical drying facilities as an integral part of business operation will encourage grain millers and storage operators in installing and utilizing dryers. This report recommends the recirculating columnar dryer as the most suitable for batches up to 30 MTs/day; for drying requirements of over 30 MTs/day, the continuous flow dryer (for example, the vertical LSU dryer) would be the most appropriate.

The operational capacity of Nepal's larger feed mills is 5-10 MTs per hour. Their prime raw materials are maize and soyabean, which they buy and store in bulk as stock to process. Consequently, demand for large-scale drying exists in these mills but almost none have drying facilities. If these larger mills decide to establish dryers for multi-crop drying (mainly for maize and soyabean), they could also opt for similar choices to those reflected in above Table 20 for rice mills and grain storage.

As the use of mechanical dryers is quite new to Nepal and is in the demonstration phase at the farm level, greater efforts are needed to raise awareness among farmers about the economic advantages of their use, in terms of reduced labor requirements, time savings, and reduced quantitative and quality losses of the grain they produce. At this initial stage, considering what option to choose (with particular reference to the possible minimization of post-harvest loss), GON needs to extend financial support to investors wanting to provide farm-level drying services. With this in mind, GON has recently articulated its intention to provide financial support in the form of capital subsidy or interest subsidies (as discussed in Chapter 8) for those interested in establishing and providing grain dryer services.

However, before selecting the most appropriate manufacturer/supplier and model of dryer, it is essential that any potential investor refer to the technical and economic aspects specified in Chapter 5. Alongside this, in the context of this being the initial stage of mechanical dryers being introduced in Nepal, it is equally important to factor in some of the critical points that Chapter 5 raises, before investors, bankers, GON support projects and development partners make the important decision to invest their time, money and commitment in contributing to the mechanization of the nation's agriculture and increased food security for its country's citizens.

12. POLICY RECOMMENDATIONS

Adoption of the appropriate drying technology at the farming communities is very essential to reduce the post-harvest loss and eventually that could contribute to reduce the grain import trend in the country. Based on the discussion in the previous sections, following policies are recommended to be considered by the three tires governments, development partners, private sectors and concerned stakeholders.

i. In order to promote dryer to the farmers, the federal government is recommended to formulate and enact policy to reduce the import tariff for the dryer appropriate to the smallholder farmers and farmers' cooperatives.
ii. The government is advised to encourage manufacturers, entrepreneurs, traders to establish dryer assembling and maintenance centres in the country.
iii. The Provincial governments and the local governments are suggested to promote appropriate dryer suitable for the specific crops through subsidizing the price of the drying machineries and promote custom hiring services at the farming communities.
iv. The government and the development partners should invest on research and performance testing of dryer because the same dryer performing efficiently in neighboring countries may not perform well in local conditions. Collaboration among the development partners and stakeholders is crucial to have integrated approach to avail such drying technologies to the smallholder farmers. For example, KISAN II collaborated with Krishi Tech Nepal to promote EasyDry M500 maize dryer. Demonstration and performance testing had been done in Makwanpur district as indicated above. The price of this dryer is very high as compared to other manufacture countries. This is due to first time introducing in Nepal.
v. Researches or studies to be carried out to find out and explore the innovative and appropriate technologies on post-harvest management to be appropriate for the smallholder farmers or farmers' cooperatives to reduce the post-harvest losses.

13. SOME IMPORTANT LINKS FOR DRYERS

- Matharu maize grain dryer, https://youtu.be/mgzP6qemH3A
- Matharu rice mill paddy dryer, https://youtu.be/U49aj1xUowE
- Matharu bio-mass multi-grain dryer, https://youtu.be/sDPqVmpyYSE
- PEDROTTI grain dryer: https://youtu.be/zFsz4uwlJM8
- Flat-bed dryer (diesel operated), 6 MTs capacity, https://youtu.be/lmmAdG9RUQw
- FAO Grain storage techniques: Evolution and trends in developing countries, http://www.fao.org/3/t1838e/T1838E00.htm#Contents
- IRRI Drying Basics and Principles, http://www.knowledgebank.irri.org/images/docs/drying-basics-presentation.pdfTamil Nadu Agricultural University initiated E-learning notes on dryers and drying, http://eagri.org/eagri50/AENG252/pdf/lec05.pdf
- FAO. Drying of high moisture grains, http://www.fao.org/3/x5427e/x5427e0d.htm#drying%20of%20high%20moisture%20paddy
- Reversible two-way airflow dryer, https://www.youtube.com/watch?v=Wuxy6BE7O6Q
- Agrimec grain dryer, https://www.youtube.com/watch?v=bAua8Egf0qQ
- Suncue grain dryer, https://www.youtube.com/watch?v=0H7-KXG3cIE

14. ANNEX

Annex I: List of referred manufacturers and suppliers of Grain Dryers

Company Name	Address	Contact telephone:	Email address/Website/Product video link
AGREX S.p.A	Via Balla, 55-57 35010, Villafranca Padovana (PD), ITALY	+39 049.50.00.000	E-mail: info@agrex.com Website: www.agrex.com
Alim Industries Limited	BSCIC, Industrial Estate, Gutatikor Kodomtoli, Sylhet 3100	09611969696 (hotline) +880821 840662840664 (office)	Website: www.alimindustriesltd.com E-mail: info@alimindustriesltd.com
Anhui Xinshengli Agricultural Machinery Co Ltd	The Cross of Tangkou and Yanqiao Road, Taohua Industrial Zone, Hefei City, Anhui Province, China	+86-551-63430788/15395023670	E-mail: sales@presungraindryer.com Website: www.graindryermachine.com
Essar Environmental Air Systems	Survey No. 198/U, Gagillapur Village, Quthubullapur M, R. R. District Hyderabad 500043, Telangana, India	+91-04020000730	E-mail: essareng777@gmail.com Website: https://www.essarairsystem.com
FrigorTec LP	602 Sawyer Street, Suite 460 Houston (TX) 77007	(832) 730-1894	E-mail: nfo@frigortecamericas.com Website: www.frigortecamericas.com
GrainPro Philippines Inc **Local supplier: Mero Agro Pvt Ltd**	Subic Bay Industrial Park Phase I Subic Bay Freeport Zone 2222 Philippines Shree Krishna Sadan 7th floor, New Baneshwor, Kathmandu, Nepal	+977-1-4786329	Website: www.grainpro.com E-mail: info@meroagro.com Website: www.meroagro.com
Grain Technik Pvt Ltd		+91 11 4608 9500	Website: http://www.graintechnik.com/ E-mail: info@graintechnik.com
Hanzhong Burt Machinery Co Ltd	No. 1#, Hope Road, Xinyuan Development Zone, Hantai District, Shaanxi, China (mainland)		E-mail: kentlssone@gmail.com Website: http://hzburt.com, http://www.botejx.com
Krishi Tech Nepal Pvt Ltd	Maharajgunj, Kathmandu, Nepal	+977 9851109997	E-mail: Info@krishitechnepal.com
Matharu Industries Pvt Ltd	Ferozepur road, Faridkot 151203 (Punjab), India	+91 935 775 0573	E-mail: matharuservice@gmail.com Website: http://www.matharugroup.com/ Video: https://youtu.be/FUhHGNSQdJc

Company Name	Address	Contact telephone:	Email address/Website/Product video link
Mecmar SPA	Copparo 29, 37046 Minerbe VR, Italy	+39 442 99229	E-mail: info@mecmargroup.com Website: https://www.mecmargroup.com/en Video: https://www.youtube.com/user/MecmarGroup
Mepu Limited	Mynämäentie 59, 21900 Yläne, Finland	+358 2 275 4454	E-mail: erkki.jokela@mepu.com Website: www.mepu.com Video: https://www.youtube.com/channel/UCfyQJVR1iuyzDVEU-PXqpCQ
Ozsu Machine Import Export Foreign Trade Company	Kurtuluş Neighbourhood Cumhuriyet Boulevard No. 33 Gonen, Balıkesir, Turkey	+90 266 762 1594 | +90 266 762 5151	E-mail: export@ozsu.com.tr; Website: http://ozsu.com.tr/en/welcome/ Video: https://www.youtube.com/channel/UCYhDLkSNtC4ljdtYHSyEkMg
SLV Food Processing Industries	Sy. No. 157, Dommasandra, Mallanayakanahalli (PO), Mulbagal 563136. Kolar (dist.), Karnataka, India	+91 96555 56881 +91 94808 58974 +91 94446 54448	E-mail: slvpaddydryers@gmail.com Website: www.slvpaddydryers.com
Vista Equipments & Machines Pvt Ltd	SF No. 17, Thillai Nagar Extension, Pollachi Main Road, Eachanari, Coimbatore 641021, Tamilnadu, India	+91 98431 77300 +91 94862 91119	Website: https://www.vistaequipments.com/ E-mail: info@vistaequipments.com, sales@vistaequipments.com
Zhengzhou Tiannze Environmental Protection technologies Co Ltd	Zhoucun Industrial Park Huanyu Avenue, Muye District Henan Province, China	+86 15838219777	E-mail: michael@tzepress.com Website: www.tzepress.com
Zhengzhou Wangu Machinery Co Ltd	No.113 Anyang Road, Shangjie District, Zhengzhou City, Henan, China	0371-56507987 0371-56507999	Website: www.zzwgjx.com E-mail: zzwgjx@163.com