Short Communication
Range Mgmt. & Agroforestry 38 (1) :143-146, 2017
ISSN 0971-2070

Drying characteristics of berseem in a solar dryer with supplemental heating system

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Received: 20th December, 2015 Accepted: 24th December, 2016

Abstract
A solar dryer developed at ICAR-Indian Grassland and Fodder Research Institute, Jhansi was used for berseem hay making in the month of March 2014. During drying, average ambient temperature was observed as 29.5 ^{0}C, while in the solar chamber it was 39.8 ^{0}C. Chopped samples at 4.444 kg/m^2 loading density dried in the solar dryer took an average drying time of 14 hrs which was 4 hrs lesser than the drying time of unchopped samples under open sun drying. The major part of drying took place in falling rate period with the exception of some initial acceleration period. The capacity of the dryer for berseem crop was 100 kg per batch at 5.555 kg/m^2 loading density and the cost of processing per quintal was Rs 360.

Keywords: Berseem, Drying rate, Drying, Moisture content, Solar dryer

Owing to the abundance of solar energy in a tropical country like India, it is easy to establish solar greenhouses with little technological intervention. During monsoon, the production of forages is in abundance which could be utilized during lean period for animal feeding. But this requires application of proper conservation methods (Das *et al*., 2013). Conventionally, the grasses are harvested when they are self dried. Similarly, the pastures/cultivated legumes are not appropriately dried. The legumes like berseem, if dried under natural sun shine loose leaves and lead to production of poor quality hays. But berseem is one of the major *Rabi* forage crops occupying maximum area during winter season in India and has the potential for quality berseem hay making (Zayed *et al*., 2011).

Earlier many studies were directed towards the role of solar dryer in drying process. The effect of different drying methods viz, sun drying, shade drying, solar drying and mechanical drying on the quality characteristics of products were evaluated. It was observed that shade drying took maximum time for drying, followed by solar drying, hot air drying (40^{0}C), sun drying and hot air drying (50^{0}C) (Rayaguru *et al.,* 2007). Rathore *et al.* (2009) also designed and developed a low cost walk-in-type solar tunnel dryer for bulk drying of farm and agro-industrial products. Studies on techno-economics of solar tunnel dryer were carried out, which indicated that the solar dryer is techno-economically viable option than the mechanical dryers (Seveda *et al.,* 2004; Jain *et al.*., 2004). Samual and Anap (1980) designed a 5 tonne capacity portable hay drier consisting of a fan unit, welded iron mesh floor and slatted floor duct to dry hay from 40% moisture content (MC) to a safe limit of 20% within 3 days. However, heating temperature, duration of heating, particle size and moisture conditions were found as responsible factors governing the drying process for hay making (D'Mello and Acamovic, 1989). Guodao *et.al*.. (2004) observed that though the high temperature drying is costlier due to expensive machinery used and the operational cost, the additional cost of drying could be compensated by the high price of the quality product. They recommended slow drying at low temperature (50-60°C) over two to three hours and quick drying in kilns (10 to 20 seconds) at temperatures above 60°C for drying stylo crop commercially. Keeping in view, the advantages of solar dryer, performance evaluation of a newly developed solar drier was carried out in comparison to open sun drying technique in berseem. The drying kinetics of the crop was also carried out.

The present investigation was undertaken at Central Experimental Farm of ICAR- IGFRI, Jhansi (78^0 35' E longitude, 25^0 27' N latitude and 271 m (above mean sea level) during the month of March 2014. An east west oriented solar dryer shown in Figure 1 was developed and used for experimentation. The features of the dryer include solar air heaters with ETC tubes, insulated hot air carrying pipes upto drying chamber, blower with electric motor matching with air heaters and air regulator system for varying air speed, control panel indicating temperature gauges, temperature control system and regulators, etc as per requirement.

Fig 1. Solar dryer for hay making

The experiments were conducted to evaluate the performance of the solar dryer and to characterize the drying behaviour of berseem crop under both the drying conditions viz solar dryer and open sun (Table 1). Two levels for loading density (4.444 and 5.555 kg/m^2) and treatments of berseem namely chopped and unchopped with three replications were fixed. The samples were dried from an initial moisture content of 76.5% to a final moisture content of 9- 12.5%. Drying was started at 9:00 AM and terminated at 5:00 PM. The loaded trays were weighed every 1 hr until the end of the drying period. At 5:00 PM, the samples were collected and kept in air tight plastics covered to induce uniform moisture distribution. The samples were again dried in the next day until the final moisture content was attained (i.e. until no further changes in their weight were observed). Weighing of loaded trays in both the methods took 20 sec for each sample while removing the tray from the dryer as well as from open sun. Hourly measurement of environmental parameters i.e. ambient and inside the dryer temperature and relative humidity were also made. The method recommended by Ranganna (1986) was used to determine the initial moisture content (MC). Moisture content of the samples during drying was computed through mass balance following standard procedure.

The chopped and unchopped samples loaded at different densities were subjected to different drying methods. The change in moisture content with drying time for the samples as shown in Fig 1 to 4, exhibited a non linear decrease of moisture with drying time. Initially the moisture content decreased for the first 3 hrs, because of low temperature in the morning hours. This was followed by a rapid moisture decrease due to increase in solar temperature. Initially material surface was saturated with water, and therefore, with increase in air temperature, faster drying took place between 3 to 7 hrs. In the falling rate period, the material surface was no longer saturated with water and drying was controlled by diffusion of moisture from the interior of the material to the surface. As expected, the drying time varied with drying method and loading density. The drying time ranged from 14 hrs (chopped berseem at 4.444 kg/m^2 under solar dryer) to 20 hrs (unchopped berseem at 5.555 kg/m^2 under open sun), being generally lower at higher drying temperatures. Comparing the curves between the Fig 1 and 2, the moisture removal was found greater for chopped samples than those for the unchopped samples. This was because of more surface area exposed for drying in chopped samples and also facilitating the pore structure to be opened. Therefore, it resulted into more absorption of heat, increase in water vapour pressure inside the pores and rapid mass transfer with the samples. Similar results were reported earlier in green bean (Rosello' *et al.,* 1997).

It was observed that drying time increased with loading density e.g. under open sun drying (16 hrs at 4.444 kg/m^2 and 17 hrs at 5.555 kg/m^2 for chopped samples). Again, it was observed in case of solar dryer that chopped samples took lesser time (14 hrs at 4.444 kg/m^2) as compared to unchopped samples (16 hrs at 4.444 kg/m^2). Similar trend was also observed in case of open sun drying. The final moisture content varied from 9.0 to 12.5%. The decreased moisture content was attributed to increased evaporation of water both on the surface of and inside structure of berseem due to increasing temperatures by solar heating. It was observed that the drying was faster at higher temperature (i.e. solar dryer), as normally expected. But at few points there was unexpected interactions of curves and this was due to experimental variations.

Table 1. Experimental plan for drying of berseem crop

Variable Parameters	Range/particulars	Levels	Observations
Treatments	Chopped and unchopped	2	• Measurement of environmental parameters i.e. ambient and inside the dryer temperature and relative humidity
Loading density	4.444 and 5.555 kg/m^2	2	
Drying methods	SD: Solar drying	2	
	OSD: Open sun drying		• Measurement of mass of the samples

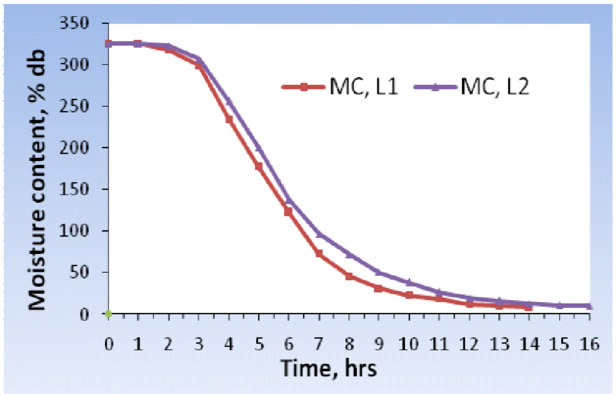

Fig 1. Variation of MC with time under SD for chopped samples during 12-14 March 2014

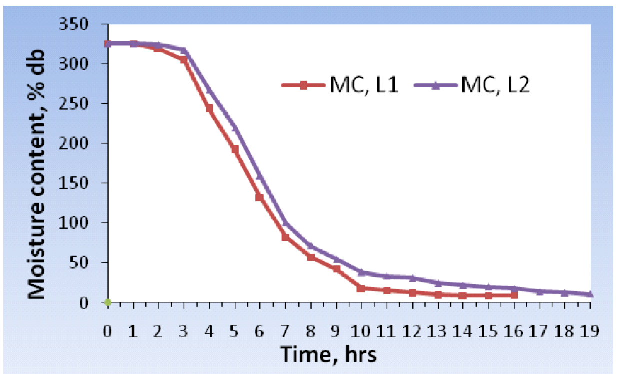

Fig 2. Variation of MC with time under SD for unchopped samples during 12-14 March 2014

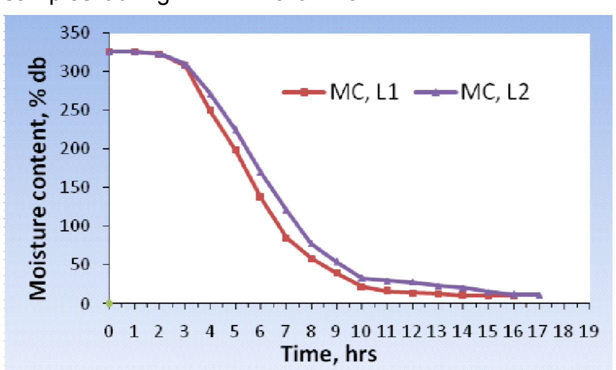

Fig 3. Variation of MC with time under OSD for chopped samples during 12-14 March 2014

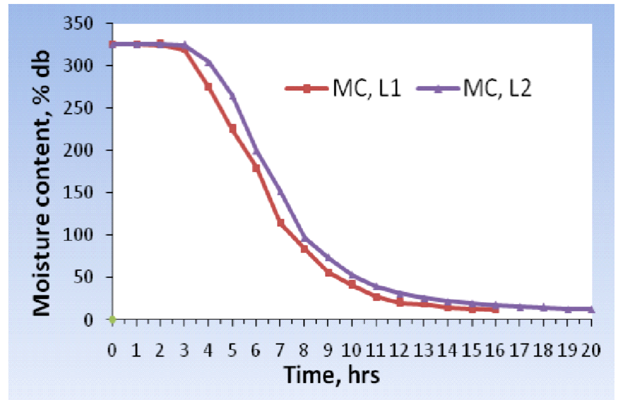

Fig 4. Variation of MC with time under OSD for unchopped samples during 12-14 March 2014.

The overall drying rate varied from 15.65 to 22.6% /hr for the total range of variables of the study. As expected, the overall drying rate was higher at higher temperature (Table 2). Overall drying rate was increased with increase in average temperature from 29.5 ^{0}C (OSD) to 39.8 ^{0}C (SD). It was seen that the overall drying rate decreased with increase in loading density in each drying methods. However, the overall drying rate was slightly lower for unchopped samples than for chopped samples. The reason for various drying times for berseem crops was attributed to the different drying conditions such as temperature, air velocity, relative humidity and drying methods. Based on the cost incurred towards labour, fresh produce (berseem), chopping and final recovery of dried produce, economic analysis of the solar drying system was done. It was observed that cost of processing per quintal was Rs. 360/- under solar dryer.

Conclusion

It was concluded that the solar dryer is an appropriate means for drying of berseem as it considerably reduced

Table 2. Overall drying rates at experimental drying conditions

Drying methods	Loading density (kg/m^2)	Treatment	Initial MC (%)	Final MC (%)	Drying time (hrs)	Overall drying rate (%/hr)
SD	5.555	Unchopped	325.5	11.1	19	16.55
(39.8^{0}C)		Chopped	325.5	10.3	16	19.70
	4.444	Unchopped	325.5	9.2	16	19.77
		Chopped	325.5	9.0	14	22.60
OSD	5.555	Unchopped	325.5	12.5	20	15.65
(29.5^{0}C)		Chopped	325.5	11.3	17	18.48
	4.444	Unchopped	325.5	10.8	18	17.48
		Chopped	325.5	9.9	16	19.72

MC: Moisture content

the drying time as compared to open sun. Drying characteristics showed that major drying took place in falling rate period except some accelerating period initially. Chopped samples at 4.444 kg/sqm loading density dried under solar dryer took average drying time of 14 hrs which was 4 hrs lesser than drying time of unchopped samples under open sun drying.

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