Study of solar dryer technology for agricultural produce

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Overview

Importance of drying

1. Reduces weight
2. Enhances the shelf life
3. Reduces the volume
4. Make it more disease resistant

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- Wet basis (M_w) : $M_w = (w - d)/w$
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- Internal parameters
  - Moisture content (M)
  - Equilibrium Moisture content (M_e)
  - Sorption isotherm

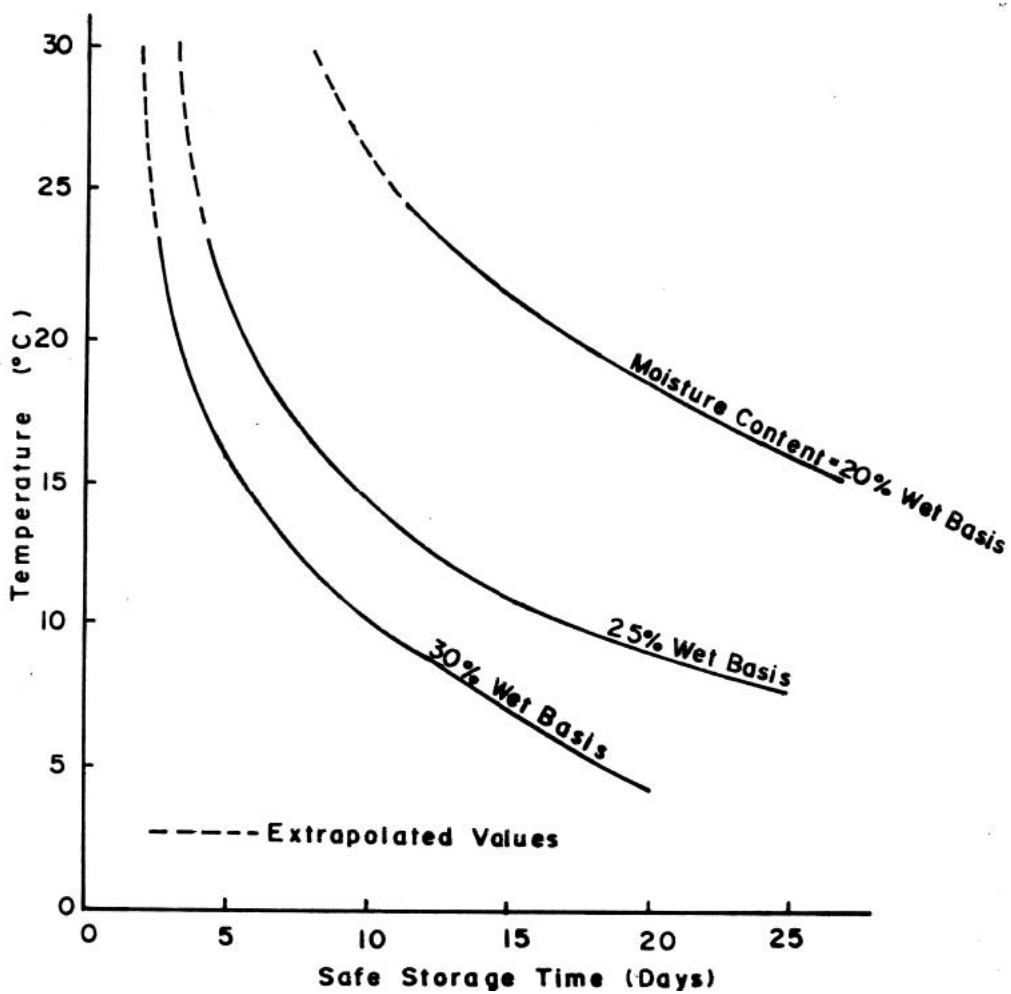

Figure: safe storage period for corn[1]

[1] OV Ekechukwu (1999). "Review of solar-energy drying systems I: an overview of drying principles and theory". In: *Energy conversion and management* 40.6, pp. 593–613.

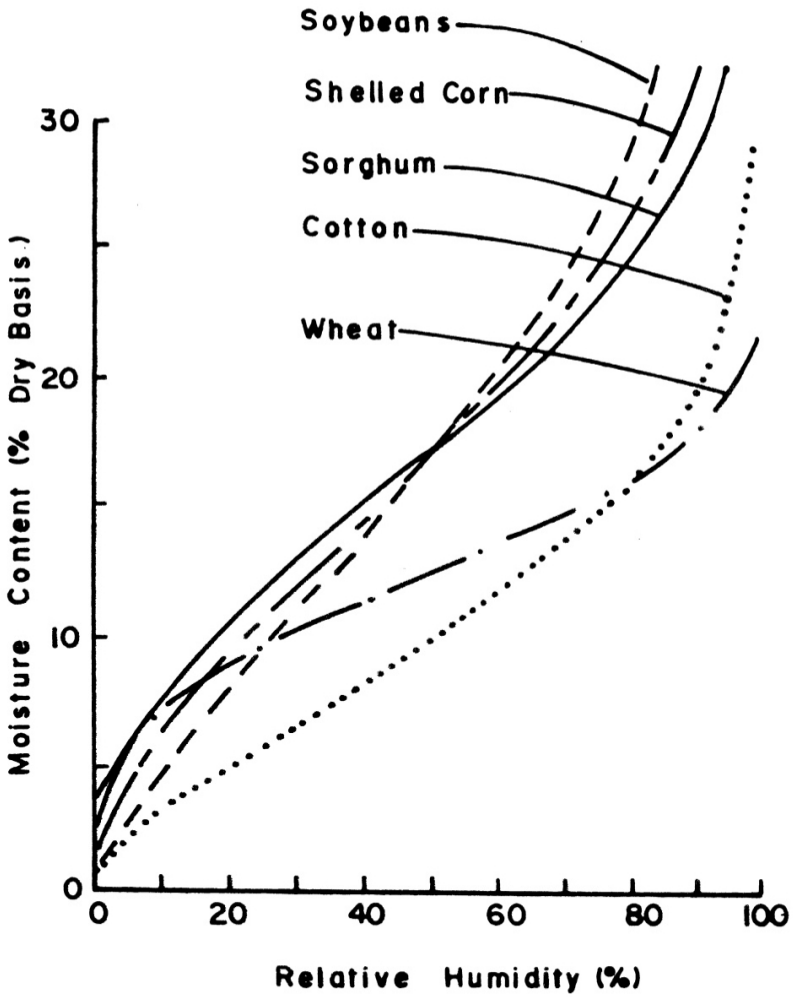

Figure: Sorption isotherm[2]

[2] OV Ekechukwu (1999). "Review of solar-energy drying systems I: an overview of drying principles and theory". In: *Energy conversion and management* 40.6, pp. 593–613.

Pshychrometry

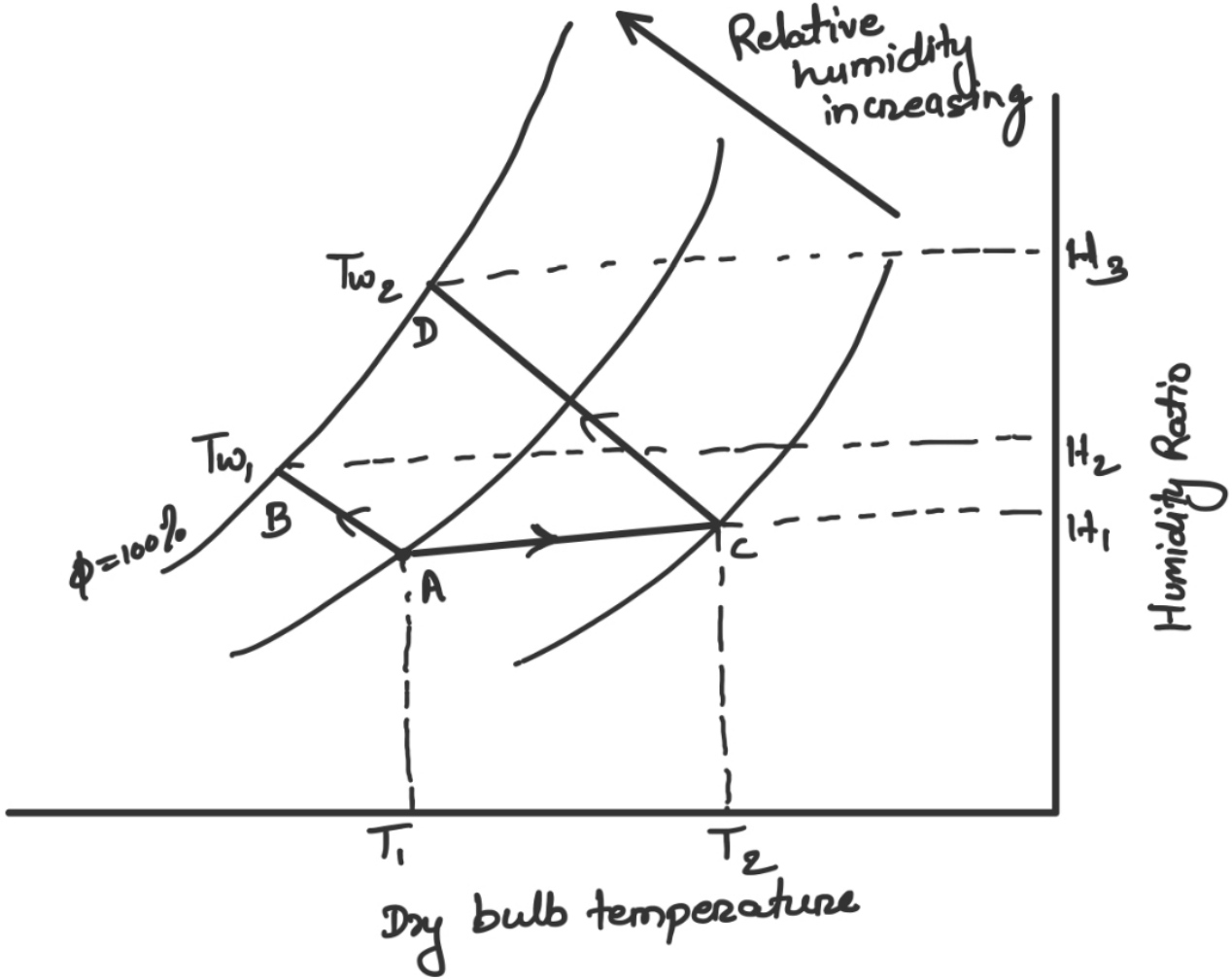

Figure: Pshychrometric chart

Classification of crop dryers

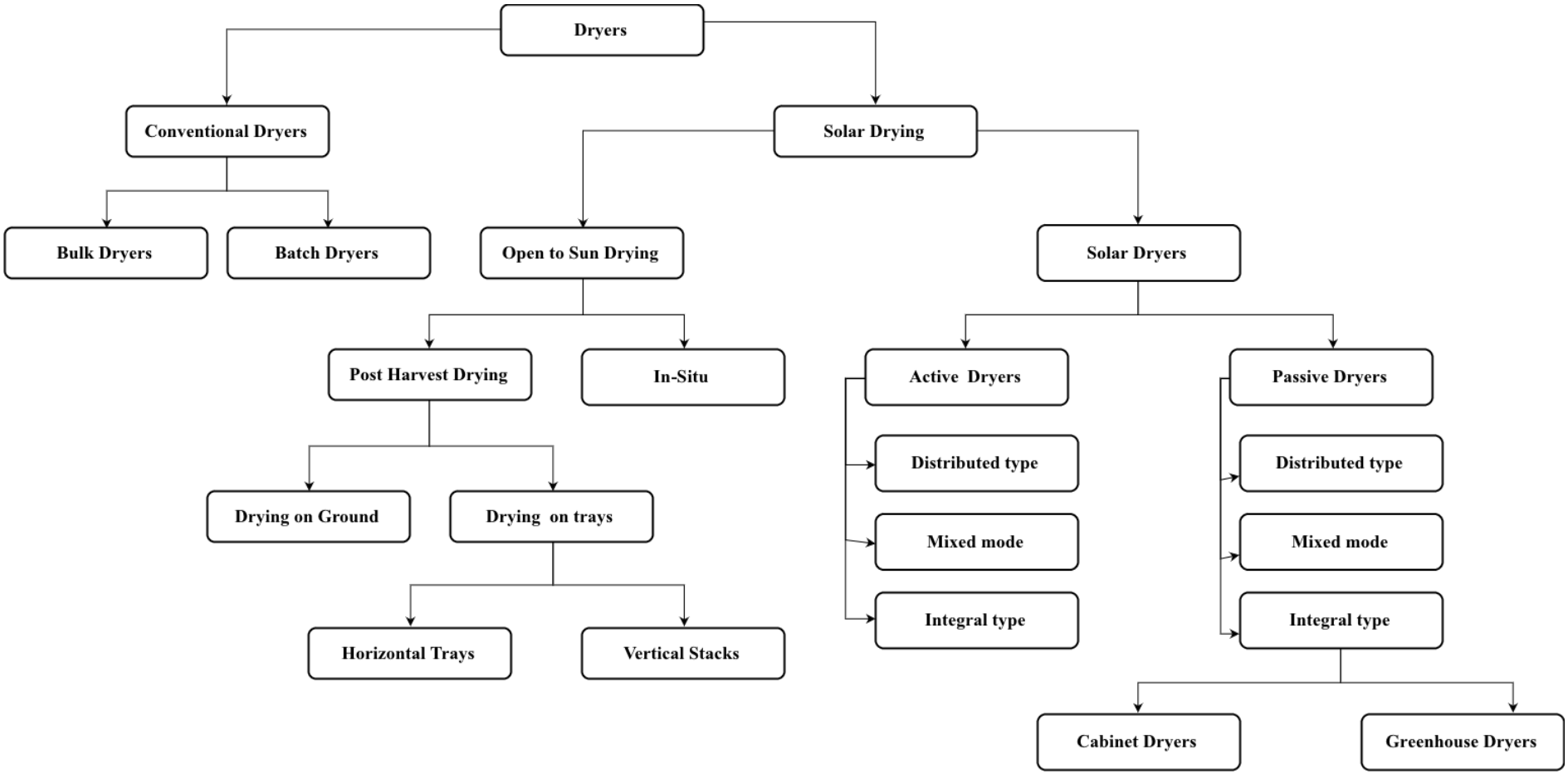

Figure: Classification of Solar dryers

Designs of dryers

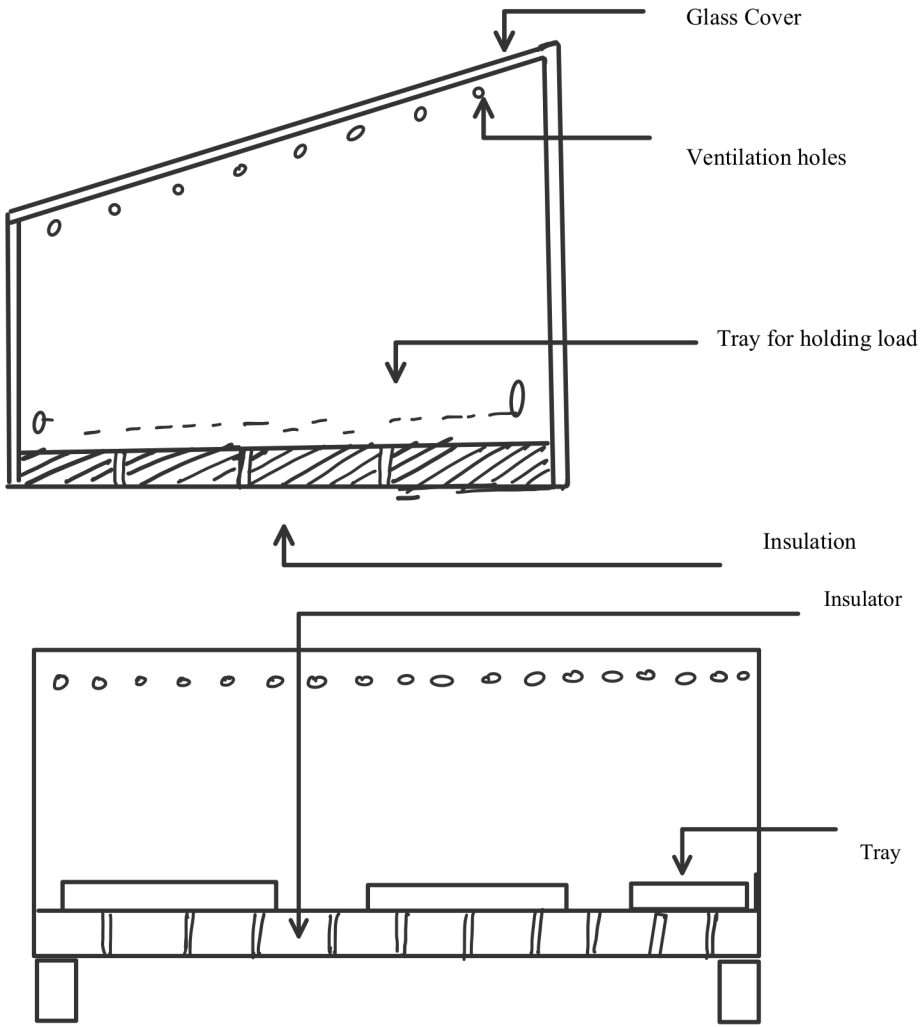

Figure: Cabinet dryers

Designs of dryers

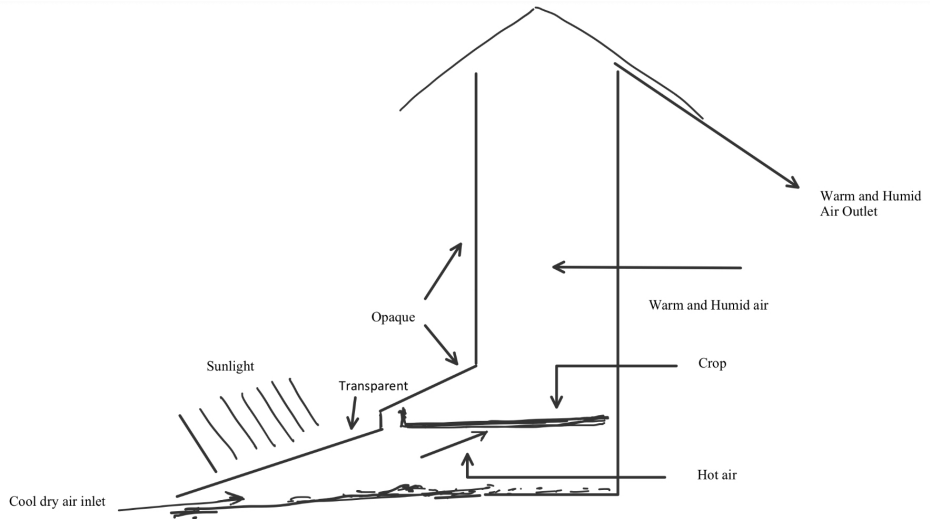

Figure: Indirect dryers

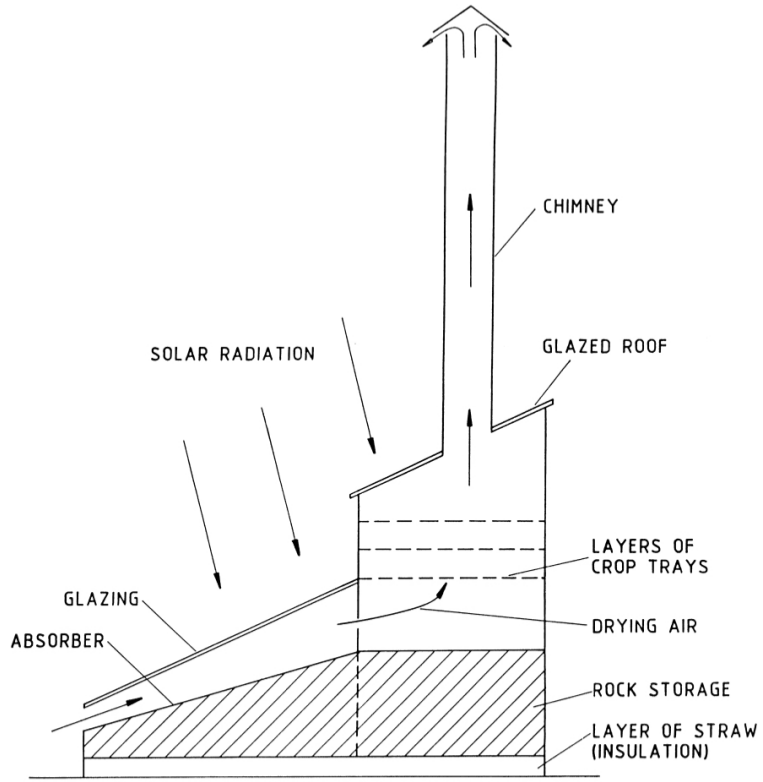

Figure: Mixed dryers

Designs of dryers

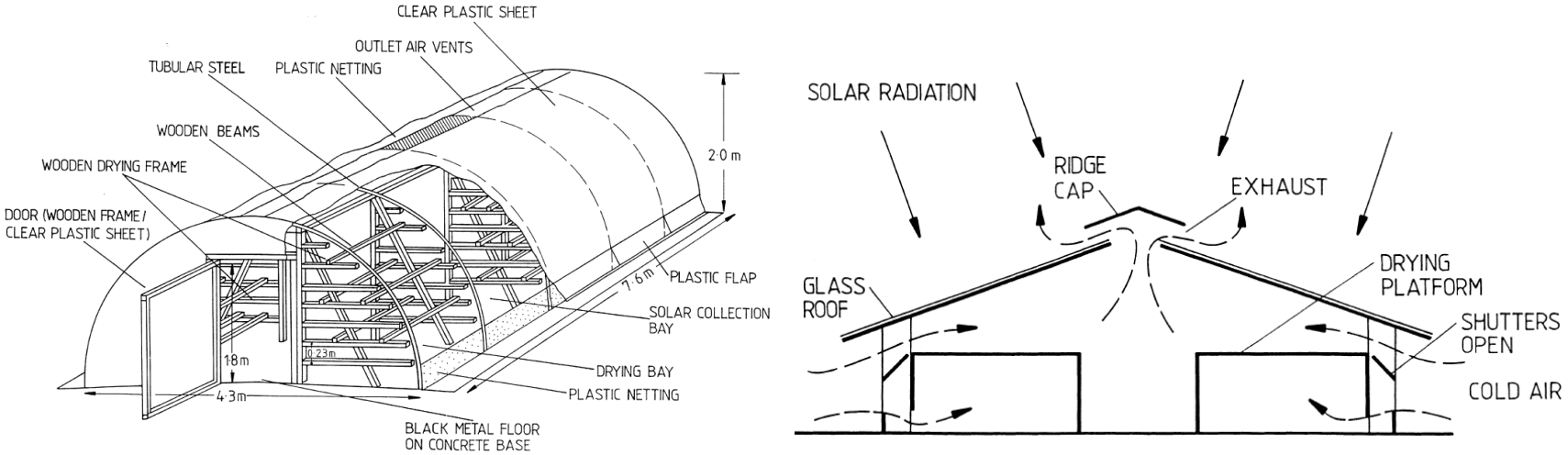

Figure: Greenhouse dryers[3]

[3] O Va Ekechukwu and Brian Norton (1999). "Review of solar-energy drying systems II: an overview of solar drying technology". In: *Energy conversion and management* 40.6, pp. 615–655.

Marketability

Sensory qualities

This is an important aspect of marketability of the produce. It includes colour, texture, odour, taste, shape, size, uniformity, flavours etc.

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Rehydration

The quality of a product to regain its original quality such as flavour, texture and appearance after addition of water.

Crop parameters

Crop	Moisture		Max. Temp (in degree C)	Drying time(h)
	Initial(%)	Final(%)		
Onions	85	6	55	48
Tomatoes	95	7	60	36
Green peas	80	5	60	9
Grapes	80	15-20		32-40
Apples	82	11—14	65-70	24-26
Bananas	80	15	70	15
Chilies	80	5		48
Ginger	80	10		168
Cabbage	80	4	65	48
Turmeric	80	10		120
Potato chips	75	13	70	72
Paddy. raw	22-24	11	50	

Table: Moisture content (w.b.) of several agricultural produce for solar drying.[4]

[4] Ahmad Fudholi et al. (2010). "Review of solar dryers for agricultural and marine products". In: *Renewable and sustainable energy reviews* 14.1, pp. 1–30.

Quality of dried produce

Fruits and vegetables	Type of solar dryer	Major findings
Wild coriander	Direct cabinet solar dryer and indirect cabinet solar dryer	- The highest retention of natural colour and absence of browning were observed from samples using indirect solar dryer. - Essential oil from samples dried in the indirect solar dryer was closer in its composition to those obtained from oven or the fresh one.
Olives leaf	Indirect forced convection solar dryer	- The values of L* parameter of the solar dried olive leaves increase compared to the fresh one. - The luminance of the leaves was improved by solar drying but the greenness of the leaves reduced. - The olive leaves dried at 40°C (1.62 m^3/min) exhibited the lowest DPPH radical scavenging activities.
Coffee	Solar dryer with black transpired air solar collector	- Coffee beans dried faster in the solar dryer with acceptable quality and no serious defects. - No OTA (Ochratoxin) forming fungi was found in solar dried sample.
Grapes and figs	Indirect and direct solar dryers	- Vitamin C content of solar dried fruits was low due oxidation, especially when the samples were either scalded or sulfurized. - The colour of solar dried grapes showed high acceptance as compared to the natural dried sample (medium acceptance). - The texture and colour of figs dried using mixed solar dryers showed better acceptance than the sun dried samples.
Vanilla	Solar greenhouse dryer	- Export quality standard (Grade A) with vaniline content of 2.36% was obtained. - Average drying time for vanilla pods was between 49 to 53.5 hr with drying temperature ranging from 33°C to 65°C and RH of about 34% during day time.
Pistachio nuts	Direct solar dryer	- Both solar and sun dried samples showed splendid taste as compared to hot air dried sample. - No aflatoxin was found in both sun and solar dried pistachio nuts.
Sweet potato	Green house solar dryer	- Solar dried sample showed negligible losses in total carotenoids as compared to sun and hot air dried samples. - Sun dried sample showed the lowest retention value.

Figure: Quality of solar dried products[5]

[5] Anupam Tiwari (2016). "A review on solar drying of agricultural produce". In: *Journal of Food Processing and Technology* 7.9, p. 623.

Seasonal parameters

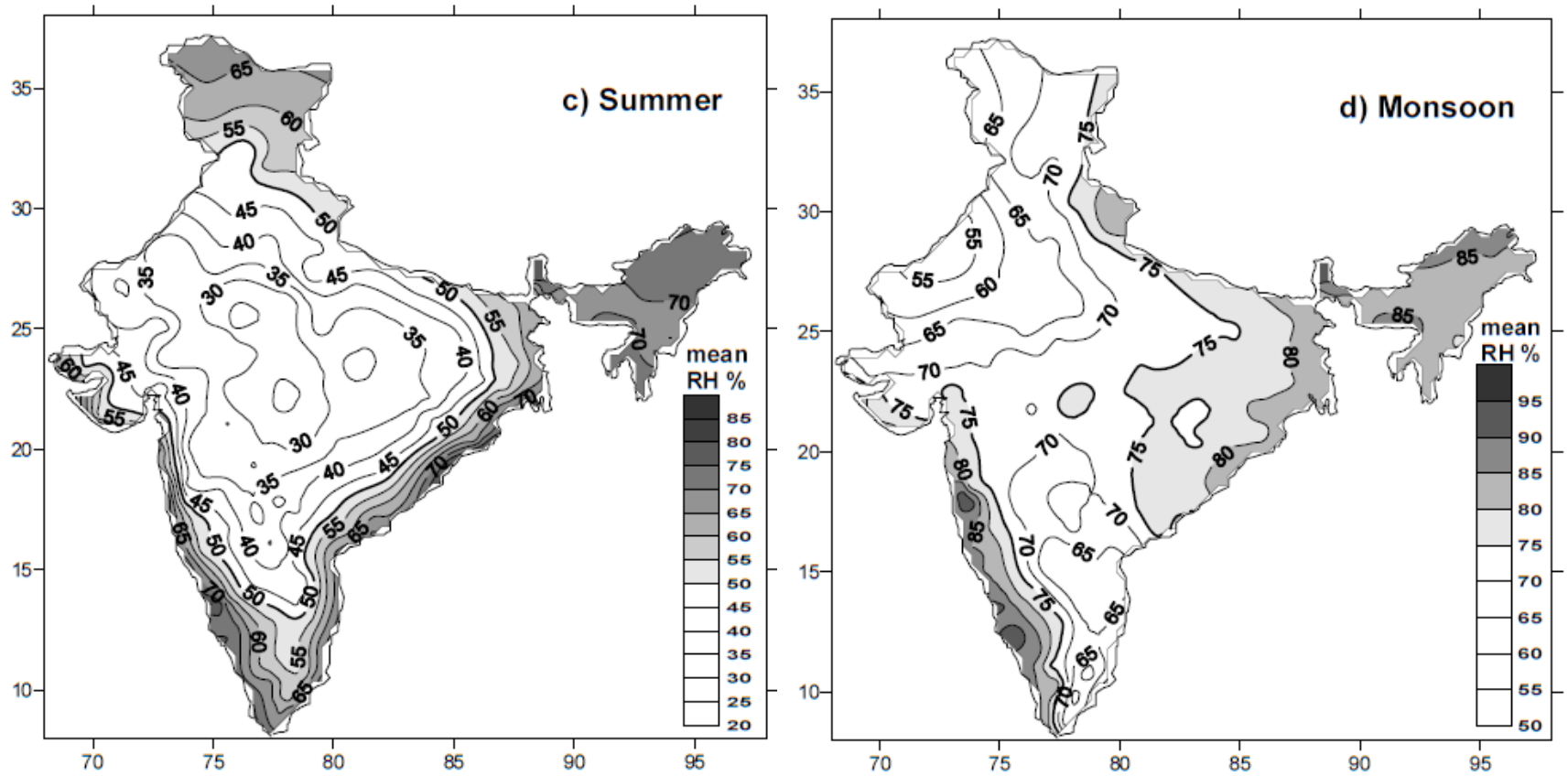

Figure: Spatial distribution of average absolute and relative humidty for period between 1971-2000[7]

[6] AK Jaswal and AL Koppar (2011). "Recent climatology and trends in surface humidity over India for 1969-2007". In: *Mausam* 62.2, pp. 145–162.

[7] AK Jaswal and AL Koppar (2011). "Recent climatology and trends in surface

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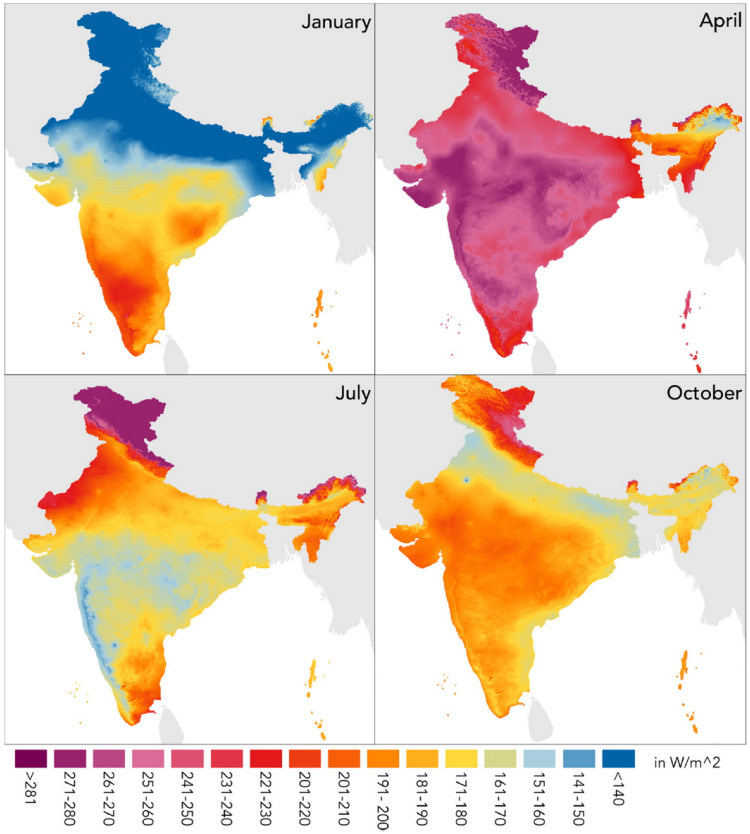

Figure: Mean Solar irradiance (GHI) for 1994 to 2014[8]

[8] Jana Müller et al. (2017). "Towards building solar in India-A combined mapping and monitoring approach for creating a new solar atlas". In: *Energy for Sustainable Development* 40, pp. 31–40.

Spatial Distribution of crops

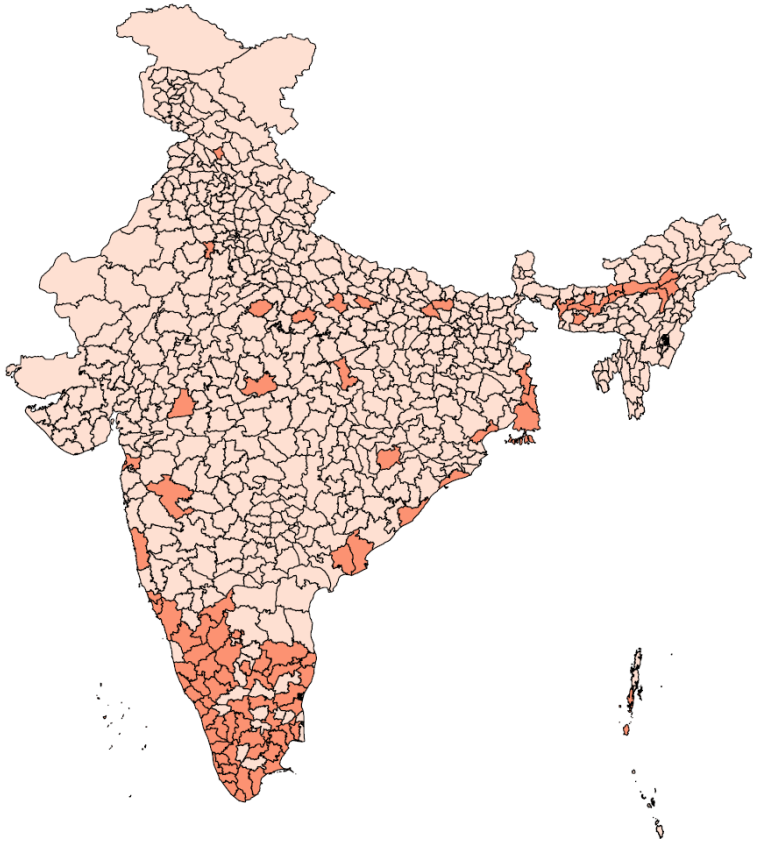

Figure: Spatial Distribution of coconut cultivation[9]

[9] GOI MOSPI M/o Statistics & Programme Implementation (2013). *Situation Assessment Survey of Agricultural Households, January - December 2013*. NSS 70th Round, http://microdata.gov.in/nada43/index.php/catalog/133/study-description.

Current issues

Design

- Temperature fluctuation
  - Over drying
  - Harmful for the temperature sensitive crops
  - Inadequate drying
  - Requirement of active dryer
- Storage
  - Rehydation
  - Longer drying time

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Literature

- Designs are not specific
- Effects of seasons
- Heat storage solution
- Storage solutions for crops post drying

Drying comparision

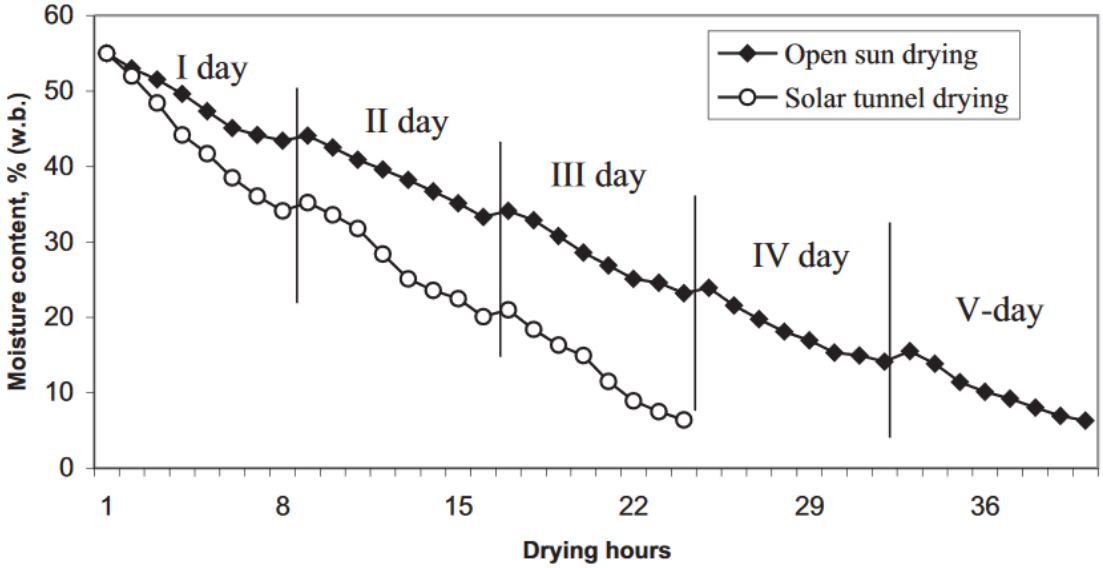

Figure: Variation of moisture content in coconut[10]

[10] S Kulanthaisami et al. (2009). "Drying characteristics of coconut in solar tunnel dryer". In: *Madras Agric. J* 96.1/6, pp. 265–269.

Solutions

Integration of heat storage

- Provides longer drying time
- Reduce fluctuations in temperature
- Could be recharged passively

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Selection of heat storage

- Chemical
- Thermal
  - Sensible
  - Latent - Suitable fo continuously heating material at 50 - 60 ^{0}C[a]

[a] Karunesh Kant et al. (2016). "Thermal energy storage based solar drying systems: A review". In: *Innovative food science & emerging technologies* 34, pp. 86–99.

Timeline for the project

DDP first stage

- Selection of dryer
- Selection of heat storage materials
- Development of models for drying with PCM

DDP second stage

- Test and adjustment against existing experimental data
- Design of a PCM based solar dryer
- Socio-economic analysis of the dryer

Thank you
Questions?