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Experimental investigation of different types of dryers for silkworm pupae drying

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Abstract
Silkworm pupae (*Bombyx Mori*) is not well known among consumers but it is an interesting by-product obtained after the extraction of silk thread from cocoons. It is an immediate by-product of reeling industry obtained after reeling off the silk thread. Dead pupae are highly perishable and value addition to silkworm pupae can be enhanced by finding suitable preservation methods by conversion of pupae into convenient processed products for wider market acceptability. The Present investigation is aimed to study the drying of wet silkworm pupae by using different types of dryers and physical properties of silkworm pupae were studied before and after drying. Dead silkworm pupae were dried by using different dryers and best drying method is selected based on retention of biochemical parameters. The drying time has taken to reduce the moisture content from 80.5 per cent (w.b) to 8.05 per cent (w.b) using different dryers *i.e.,* open sun drying, solar tunnel dryer, tray dryer, vaccum tray dryer and freeze dryer in 23 hours at 30.85 ºC, 8 hours at 64 ºC, 6 hours at 65 ºC, 7.5 hours at 55 ºC and 12 hours at – 46 ºC. Freeze drying is found to be the best method for drying of silkworm pupae compared to the other four drying methods. Because freeze dried pupae retained all nutritional and physical properties similar to raw pupae.

Keywords: Silkworm pupae, drying methods, physical properties

Introduction
India is the second largest producer of silk next to China according to annual report of central silk board 2018, which produces about 60000 MT of silk per year. Silkworm pupae **(***Bombyx Mori***)** is an immediate by-product of reeling industry obtained after reeling off the silk thread. The silkworm pupae were traditionally discarded in an open environment as they contain higher percentage of protein, fat, amino acids and minerals.

In silk industry nothing goes waste, as every waste brings additional revenue as well as additional employment. Surprisingly, this value addition may even go up to 10% to 25% in a various sectors of post cocoon with effective management and utilization of the waste. As far as silk reeling sector is concerned, silk and pupae wastes are the main by-products (Sujatha *et al*., 2016) [10].

Silkworm pupa is rich in vitamins such as D and B_{12}. Large quantity of pupae that accumulate in reeling process could be utilized better to produce value added by-products, by adopting improved technology / process. The oil extracted from dried pupae is used for animal biscuits, cosmetics, soaps while cake is used as feed for fish and poultry (Sujatha *et al*., 2016) [10]. Silkworm pupae have been found to be a rich source of protein. In India, large number of wastes produced from reeling process was used as raw material sources for various industries, including animal nutrition.

Drying is an excellent way to preserve food. The high moisture content in fresh pupae produce is the basic cause for spoilage, Removal of moisture reduces the cost of storage and transportation, by reducing the weight and volume of final product. The optimization of such an operation leads to an improvement in the quality of the output, sometimes the production is much more than the requirement in such cases farmers have to sell the produce at very low rates, there by incurring great loss which can be minimized by drying. The drying is an agricultural technique related to food preservation, but every year, millions of dollars worth of gross national product are lost through spoilage. So, the value addition to silkworm pupae can be achieved by suitable preservation methods and pupae can be processed into various end products for wider market acceptability in different fields.

Hence, it is essential to find out a solution to overcome the problems associated with conventional drying, different drying technologies for development of desired quality dried pupae without changing its nutritional qualities, to reduce the cost of animal feed available in the market and to balance the nutritional requirements of feed so the importance of silkworm pupae in health, food, animal feed, pharmaceutical and cosmetic products. The proposed investigation undergone to select a suitable drying technology for drying of silkworm pupae.

Materials and Methods

Raw material procurement: Raw silkworm pupae were collected from the reeling centre in government cocoon market of Ramanagara (D), Karnataka (state), which were discarded after reeling off the silk thread. The outer skin was removed and spoiled pupae were discarded to prevent contamination from other pupae and those were sorted out to get uniformity of silkworm pupae.

Determination of physical properties of raw silkworm pupae

Size

The average size of silkworm pupae was determined by measuring three linear dimensions namely length (L), width (W) and thickness (T) for 100 randomly picked pupae. The vernier calipers (6-inch, Aerospace, Micro Precision Calibration Inc.) used for measurement was having an accuracy of 0.001 mm (Vilche *et al*., 2003) [16].

Geometric mean diameter

The geometric mean diameter (Dg) of the silkworm pupae was calculated by using the relationships given by Mohsenin, (1970) [12].

$$Dg = (LWT)^{1/3},$$

where, L is the length (m), W is the width (m) and T is the thickness (m)

Sphericity

The sphericity (Φ) of pupae was calculated using the relationship as suggested by Jain and Bal (1997) [9].

$$\Phi = \frac{(LWT)^{(1/3)}}{L}$$

Volume

The volume (V) of pupae was calculated using the relationship as suggested by Jain and Bal (1997) [9].

$$V = \frac{\pi w^2 L^2}{6(2L-W)}$$

Surface area

The surface area (S) was also found by a relation suggested by Jain and Bal (1997) [9].

$$S = \frac{\pi B L^2}{2L-B}$$

Mass of hundred pupae

The mass of one hundred manually counted pupae was measured by using an electronic balance (Citizon, CG-203 model) with an accuracy of 0.001g (Baryeh, 2002) [2].

Bulk density

Silkworm pupae were filled into a container of known dimensions. The excess pupae were stroked off so that top surface was even. The bulk density (BD) was determined by the weight of sample to volume of the container.

Color measurement by using Minolta Chroma meter

The colors of silkworm pupae were determined by using Minolta chroma meter CR-200b. The term *L** indicates lightness or darkness, '*a**' indicating 'Hue' and '*b** indicating 'Chroma'. The color difference of pupae before and after drying was determined to understand the changes in color during drying.

Moisture content determination

The initial and final moisture content of samples were determined by the oven dry method. Sample of about 10 g were taken in a cup and kept in the hot air oven at 105 °C for 24 hours, after that final weight was recorded. The moisture content of the sample was calculated by the following formula

$$\text{(Per cent)} = \frac{Wt - Wf}{Wi} \times 100$$

Where,

MC = Moisture content at time t, Wt=Weight of sample at time t (g), W_f = Weight of oven dry sample (g) and W_i = Initial weight of sample (g)

Drying experiment:

The main purpose of drying of silkworm pupae is to reduce the moisture content (w.b.) of fresh pupae from 75-80 per cent to 8.9 per cent, lower the water activity, increases the shelf life and to reduce the size of product for easy storage, value addition of pupae, handling and transportation. The drying methods have taken for the present investigation were Open Sun Drying, Solar Tunnel Dryer, Tray Dryer, Vaccum Tray Dryer and Freeze Dryer. The drying was practiced by four drying methods, out of five drying methods the best drying method to be selected based on nutritional parameters.

Drying characteristics of silkworm pupae

In order to determine the drying characteristics, the fresh silkworm pupae samples were dried from initial moisture content of 75-80 per cent to 8 -9 per cent (w.b). The results on drying characteristics of silkworm pupae under different dryers were presented.

Biochemical quality parameters

The biochemical quality parameters discussed in this chapter were Protein, Fat, Ash and Starch content. Estimation of crude protein, crude fat, ash and starch content were calculated by using kjeldahl, soxhlet apparatus, muffle furnace and anthrone reagent methods respectively.

Results and Discussion

Physical properties of raw silkworm pupae

The physical properties of raw silkworm pupae such as length, width, thickness, geometric mean diameter, sphericity, surface area, mass of 100 pupae, color values, volume and bulk density as shown in Table 1.

Table 1: Physical Properties of Raw Pupae

Physical properties	
Length (mm)	23.82
Width (mm)	11.64
Thickness (mm)	8.47
Geometric mean dia(mm)	10.26
Sphericity	0.43
Surface area (mm^2)	469.32
Colour (*L**, *a**, *b**)	36.49, 11.96, 21.12
Volume (mm^3)	1118.11
Mass (100 pupae in g)	117.15
Bulk density (kg/m^3)	721.31

It was evident from data that geometric mean diameter of silkworm pupae was higher for fresh pupae because of moisture content, hence the geometric mean diameter increases with increase in moisture content. The reduction of surface area was due to shrinkage of fleshy body of silkworm pupae due to moisture loss from the outer surface upon drying. The reduction in volume was due to moisture loss leading to shrinkage of pupae during the drying process. Dronachari and Shriramulu (2017) [5] conducted a study to determine the physical properties of silkworm pupae of different breed (PM X CSR4 and PM X CSR4) were measured at different breeds, initial moisture content and weight of sample under open sun yard drying and solar tunnel dryer. The different treatment combinations of length, width, thickness, geometric mean diameter, sphericity, thousand pupae mass, surface area, volume and bulk density were linearly decreased with moisture content.

Drying of pupae using different types of dryers

The drying of silkworm pupae using different dryers such as open sun drying, tray dryer, solar tunnel dryer, vacuum tray and freeze dryers.

Open sun drying

Raw silkworm pupae collected (Plate 1) of known quantity with an initial moisture content of 80.1 per cent (w.b.) were dried up to final moisture content of about 8.5 per cent, at an average drying air temperature of 30.85 ºC. The drying time taken to reduce the moisture content for safe storage is about 23 hours. The results pertaining to drying of silkworm pupae in open sun drying is presented in Table 2. Dronachari and Shriramulu (2017) [5] conducted an experiment on the development of solar tunnel dryer for drying of silkworm pupae. The results pertaining to drying of multivoltine breed silkworm pupae in open sun yard drying that the reduction in moisture content of silkworm pupae varied from 257.14 (% d.b.) to 218.57 (% d.b.) in case of 10 kg weight of pupae and from 257.14 (% d.b.) to 243.81 (% d.b.) in case of 15 kg of silkworm pupae respectively in the first hour drying period. It was observed that the reduction of moisture content of silkworm pupae followed an increasing trend in the beginning of the drying in open yard sun drying method. The drying rate of silkworm pupae varied from 1.3 to 0.003 kg/h and 0.7 to 0.010 kg/h for 10 kg and 15 kg weight of silkworm pupae. As the drying proceeded the loss of moisture content decreased with the drying time till the samples reached the safe moisture content of 8.69% (d.b).

Plate 1: Sun dried silkworm pupae

Tray dryer

1000 g raw silkworm pupae sample were spread in trays and placed inside the drying chamber. The results obtained for drying of silkworm pupae in tray dryer presented in Table 3. Samples were dried at the temperature of 65 ˚C with a fixed air velocity of 2 m/s. The drying time taken to reduce the moisture content for safe storage is about 6 hours. The final dried sample (8-10 per cent m.c) were collected from the trays and shown in Plate 2. The heated air was coming from the sides of drying chamber. The gap in between trays permits air ventilation. For carrying out tray dryer experiment, 1000 g sample was spread in trays and placed inside the chamber, dry the sample with a fixed air velocity of 2 m/s. Samples were dried at temperature of 65°C Atul *et al*. (2016) [2].

Plate 2: Tray dried silkworm pupae

Solar tunnel dryer

A known quantity of silkworm pupa sample was spread in trays in thin layer and placed inside the drying chamber of solar tunnel dryer. The Experiment was conducted for the silkworm pupae with an intial moisture content of 80.5 (w.b) per cent to dried up to final moisture content of 8.0% per cent (w.b). The sample of 10 kg was taken for drying silkworm pupae were dried in 8 hours at 50-65 °C. The solar tunnel dried silkworm pupae as shown in the Plate 3**.** The results obtained for drying of silkworm pupae in solar tunnel dryer presented in Table 3. The similar results obtained by Tawon *et al.*, (2010) [15]. Conducted an experiment on thin layer drying of silkworm pupae using a solar tunnel dryer. The dryer consists of transparent glass covered flat plate collector and a drying tunnel connected in series to supply hot air directly into the drying tunnel using a blower. Silkworm pupae were dried to the final moisture content of 0.15 kg water/kg dry matter from 4.37 kg water/kg dry matter in 373 min at air flow rate of 0.32 kg/s.

Plate 3: Solar tunnel dried silkworm pupae

Vacuum dryer

The drying time taken to reduce moisture content was about 7.5 hours in vacuum tray dryer at drying temperature of 55°C with 610 mm Hg of vacuum. The vacuum chamber temperature was maintained at 55°C and hot water in/out is 44°C for drying of silkworm pupae. The final dried silkworm pupae were collected from the vacuum chamber as shown in Plate 4. The results obtained for drying of silkworm pupae in solar tunnel dryer presented in Table 3. The similar results obtained by Siyuchen *et al*., (2015) [13]. conducted an experiment drying of banana slices in vacuum drying in order to find the drying and adsorption characteristics of banana.

Plate 4: Vacuum dried silkworm pupae

Freeze Dryer

Before conducting an experiment, a sample of 1 kg of raw silkworm pupae were placed in a deep freezer. The silkworm pupae are fully exposed to a temperature of - 40ºC until the core temperature reached about -18ºC. The water content in the silkworm pupae was crystallized. The crystallized silkworm pupae were placed in a drying chamber of freeze dryer. The vacuum maintained is 0.077 mbar. The drying time to reduce the moisture content of silkworm pupae to 8 per cent in freeze dryer was 12 hours (Table 3). The temperature of product is -46 to -47 °C. The sublimated moisture is condensed on refrigerated plates in the drying chamber. The dried pupae were removed from plates (Plate 5) and packed in aluminium pouches. Ergun *et al*. (2016) [7] studied the drying kinetics of freeze-dried kiwi slices prior to freeze drying, the slices were frozen at - 40 ºC in an air blast freezer for 2 hours. Then freeze dried in a pilot scale freeze dryer at - 48ºC condenser temperature. Vacuum of 13.33 Pa absolute pressure was maintained. Heating plate temperature was set to 30 ºC.

Plate 5: Freeze Dried silkworm pupae

Drying Rate

The physiological losses in weight of silkworm pupae were recorded. Drying rate was calculated for five different drying methods such as open sun drying, tray drying, solar tunnel drying, vacuum drying and freeze drying by using the following equation (Doymaz, 2004) [5].

$$\text{Drying rate (kg/hr)} = \frac{dM}{dt}$$

where,

dM - difference in moisture content (kg) and dt - difference in drying time (h)

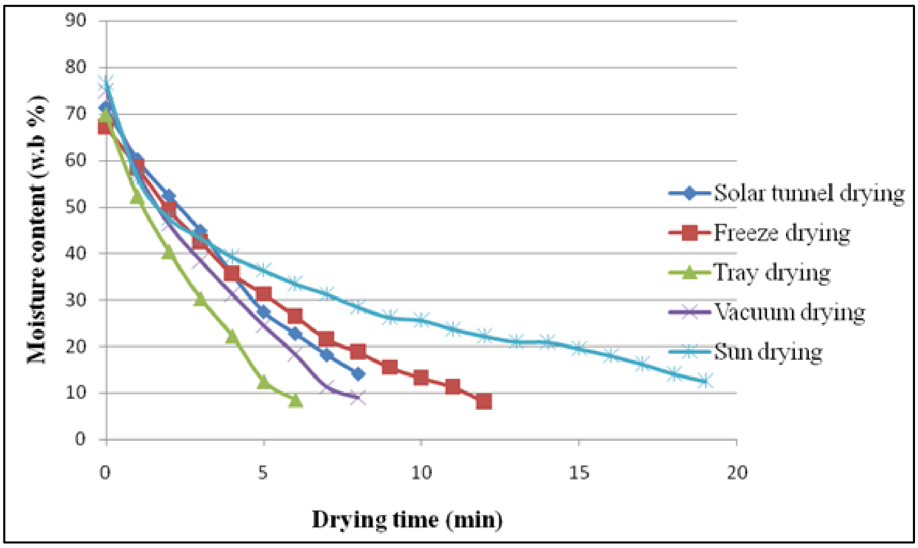

Fig 1: The drying rate for different drying methods

Physical properties of pupae under different drying conditions

Physical properties of pupae such as length, width, thickness, geometric mean diameter, sphericity, surface area, mass of 100 pupae, color values, volume and bulk density under different drying conditions as shown in Table 3.

Table 2: Physical properties of pupae under different drying conditions

Methods	Length (mm)	Width (mm)	Thickness (mm)	Geometric mean diameter (mm)	Sphericity	Surface area (mm^2)
Sun dried pupae	20.45	9.49	6.39	8.47	0.41	308.96
Solar tunnel dried pupae	21.40	9.98	6.33	8.69	0.49	322.84
Tray dried pupae	20.71	10.28	6.32	6.24	0.30	325.53
Vacuum dried pupae	18.05	10.41	6.65	8.49	0.47	306.54
Freeze dried pupae	23.60	11.23	8.49	10.13	0.42	456.36

Table 2: Cont….

Methods	Color			Volume (mm^3)	Mass of 100 pupae (g)	Bulk density (kg/m^3)
	L*	***a****	***b****			
Sun dried pupae	28.05	7.22	10.51	627.84	28.05	343.33
Solar tunnel dried pupae	31.90	8.02	14.99	727.69	37.81	234.78
Tray dried pupae	32.60	8.12	14.80	762.12	36.50	420.00
Vacuum dried pupae	30.66	7.81	12.81	719.59	29.10	299.00
Freeze dried pupae	36.06	8.62	16.21	1022.44	39.00	312.96

Conclusion

Food cooked from silkworm pupae is nutritious and cheap. The problem is that the food made from silkworm pupae can't keep for longer time. The pupae are caused rotten in a short shelf life. Processing productivity of silkworm pupae by drying methods is another way that helps to keep the raw silkworm pupae. It can be stored longer and reduce the weight and volume of product. As a result, the cost of transportation and storage are inexpensive. The protein concentration in dried pupae can be used as feed for poultry, rabbit, cattle and fishes. The pupal cakes were prepared for cattle, pig and fowls. The oil extracted from dried pupae was used for animal biscuits, cosmetics, soaps while cake is feed for fish and poultry Sujatha *et al*. (2016) [10].

Out of five different drying methods freeze drying is the best method for drying of silkworm pupae because it retained all physical and nutritional parameters similar to raw pupae. The freeze-dried pupae retained maximum length, width, thickness, geometric mean diameter, sphericity, surface area, mass of 100 pupae, volume, bulk density and color values of *L**, *a**, *b** were 23.60 mm, 11.23 mm, 8.49 mm, 10.13 mm, 0.42, 456.36 mm^2, 39.00 g, 1022.44 mm^3, 312.96 kg/m^3 and 36.06, 8.62, 16.21 respectively and the biochemical parameters such as protein, fat, ash content and starch content were 52.08, 30.41, 4.7 and 0.81 per cent respectively.

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