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EVALUATION OF TECHNICAL, PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF MOTH BEAN (*Vigna aconitifolia L.) POD COAT POWDER FOR FOOD AND INDUSTRIAL APPLICATIONS*

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Abstract: *Moth bean is an agricultural staple crop that has been used as food, fodder and green manuring along with its by-products like stem, husk and pod coat. These by-products are an excellent source of high nutritional value which can be used to supplement diet. Moth bean pod coat was dried using a Recirculating tray dryer (MRTD), Tray dryer (MTD) and Through flow dryer (MTFD) at 40°C (T_1) and 45°C (T_2) to determine the best drying method and temperature combination for the preparation of dried pod coat powder. The dried pod coats were ground to obtain powdered samples for assessment of engineering, physicochemical and functional properties at 3 ,6 and 9% moisture contents (on dry basis). The pod coat powder samples displayed significant differences in engineering properties and physicochemical properties. The sample with 3% moisture content dried at 40°C(T_1) using MRTD resulted in better engineering properties and phytochemical properties like bulk density (114.6 kg/m^3), tap density (128.2 kg/m^3), polyphenol content (17.21 mg GAE g^{-1}), flavonoid content (6.31 mg CAE g^{-1}) in comparison to other powder samples. The samples of tray drying (MTD)and through flow drying methods showed decreasing trends of nutrient retention and powder properties. The results for proximate composition were found close to each other for all drying methods but differed slightly in case of fibre content. The tray drying sample (MTD) has crude 17.31% fibre content compared to other dried sample. The presence of a good amount of viable minerals in the dried samples is reflected by a high ash content of 3-4% in MRTDT_1 powder at 3% moisture content. Overall, the results obtained indicated that moth bean pod coat powder with a 3% moisture content dried by recirculatory dryer at 40°C showed the best results and has potential to be used as a raw material for food applications.*

Key words: *pod coat, bio-active, engineering properties, powder, minerals.*

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1. Introduction

The agriculture industry produces a large number of by-products that need to be utilized in a proper way to ensure the environmental safety and public health [9]. Pulses play an important role in human diet and contribute to food security. The by-products of pulses (e.g. straw, pod and other plant parts) left after harvesting the seeds are used as ruminant feed [22]. Legume pods, grain husks and stem are examples of by-products from the agriculture industry that have been considered as potential food by-products to satisfy the market of functional products, as they are promising sources of functional compounds. Food industry has also shown a keen interest in these by-products because of their low cost [13].

By-products obtained from agri-food products after harvesting can be revalorized to produce value-added food ingredients. This valorisation has become a major subject of research to improve the cycle of the food chain. It is an opportunity because the possibility of using agri-food by-products for bioactive compound and nutrient extraction has created enormous scope for waste reduction and indirect income generation [17, 31]. The research on identifying the agricultural waste as a source of new potential antioxidants and study their effectiveness in food systems has been an area of interest for food scientists to replace the synthetic antioxidants [5].

So far, there have been very few studies in the literature about the valorization of moth bean pod coat (*Vigna aconitifolia L.*). The literature data available indicates limited exploration of the potential of pulse pods as by-products in the food industry [30]. Pulse pods represent an economical raw material that has been underestimated with its use exclusively as a fuel or fertilizer. A recent study showed that the moth bean pod coat extracts can be used as a replacement for synthetic antioxidant in the edible oil industry because they were found to be effective in preventing lipid peroxidation in soyabean oil samples.

Agro wastes are perishable materials because of their high-water content. Their use is dependent upon preserving their quality as much as possible in the post-harvest phase. So, for the retention of phytochemicals, minerals and other nutrients different drying methods should be used [10].

Drying is a commercially important technique to remove the moisture of the product. Various drying methods are employed to dry different agricultural products, each method having its own advantages and limitations. So, choosing the right drying method is very important in the drying process [23]. For a better exploitation of moth bean pod coat in value added products, it is important to investigate the suitable drying methods for the preparation of powder [3]. The prolonged drying period results in a loss of heat sensitive nutrients, of bioactive compounds and of the sensory quality of the product [27]. Drying treatments inhibit the growth of microorganisms, inactivate certain enzymes and helps in lowering waste volume of by-products [24]. The amount of volatile compounds present in the dried pod coat changes or alters during the drying process, which is dependent on the number of drying parameters, including drying technique, temperature, vacuum level (for processes like flow drying or air-drying), drying duration, and amount of water evaporated during drying. Theses volatile components decrease during drying, but it depends on different drying methods where it can be still retained in a sufficient amount such as through flow dryer and recirculatory dryer as compared to tray dryer. The by-product waste industry has a good impact in the food industry, since plants have long been used as food processing and preservatives [21].

Globally, moth beans are widely processed and consumed, but in today's time we are only focused on the utilization of moth bean seed. The substantial quantity of pod coats that are thrown away as waste hold the potential to be a source of nutritional and bio-active compounds for food industry. This has led to an increased interest in naturally occurring green compounds in the pod coats of moth beans. The use of pod coats in food industry will be also helpful for farmers, as the by-products generated after post-harvest will become an additional source of income for them. Therefore, this research work was undertaken to study the drying behaviour of moth bean pod coats using different dryers, and, the selected engineering, physicochemical and functional properties of the resultant moth bean pod coat powder samples for utilization in food industry.

2. Materials and Methods

2.1. The Variety of Moth Beam

The moth bean seeds of the variety RMO-423 were procured from Swami Keshav Anand Rajasthan Agricultural University, Rajasthan. The moth bean was grown in a sample field located in Meerut (U.P) India. The moth bean pods were plucked from the parental plants which were field dried and deseeded. The field-dried undamaged pods were separated from pods with mechanical or physiological damages for further studies. The initial moisture content of moth bean pod coat was found to be 10.37% (Dry basis). Further the final moisture content was kept as 3, 6 and 9% using different drying techniques as desired in the study.

2.2. Drying Methods Used in the Study

Tray Drying: The moth bean pod coat of different sizes was placed on trays of the re-circulatory tray dryer (M/s Universal Engineering, Baroda). It was operated at 2 m/s constant air flow at 40 and 45˚C temperature. The final moisture content of pod coat was reached to 3-9% (Dry basis) and the drying process was stopped. The dried pod coat was cooled and packed in zip lock packs for further studies.

Through Flow Dryer: Through flow drying was applied to particulate moth bean pod coat in trays and dried at 40 and 45˚C in the through flow dryer. (M/s Hansa Instrument Shahdara, Delhi) Drying was carried out until a moisture content of 3-9% (Dry basis) was achieved.

Recirculatory Tray Dryer: Recirculatory tray dryer (M/s BPTL, Kolkata.), was used for the drying of the pod coat at 40 and 45˚C. This process continued until a moisture content of 3-9% (Dry basis) was achieved.

2.3. Drying Behaviour of the Moth Bean Pod Coat

Drying behaviour at a constant air velocity was studied in laboratory scale dryers i.e. tray dryer (M/s Universal Engineering, Baroda), Recirculatory tray dryer (M/s BPTL, Kolkata.), and Fluidised air flow dryer (M/s Hansa Instrument, Shahdara, Delhi) in the present research work. The samples kept in the dryers were weighed at hourly intervals until constant weight was obtained. The moisture content of the pod coat was studied using the hot air oven AOAC method. The mass balance theory was used for the moisture content analysis at the time of drying. Page's equation (modified) was used to obtain the drying ratios of moth bean pod coat (Eq. (1)). Similar modelling studies were carried by Reyes et al. [20].

$$MoR = \left[\frac{(M_o(t)-M_e)}{M_i-M_e} = exp(-k \cdot t^n)\right] \quad (1)$$

where:

MoR represent the moisture ratio;

Mo(t) – the moisture content at time *t* [d.b. %];

M_i – the initial moisture content [d.b. %];

M_e – the equilibrium moisture content [d.b. %];

t – the drying time [min];

k and n - the equation constants.

2.4. Sample Codes Used for Different Drying Methods

Sample codes for moth bean pod coat powder samples used for the study were presented in Table 1.

2.5. Preparation of Regulated Moisture Content Samples

For an accurate analysis of the engineering properties, the moisture content of all samples needs to be regulated. The moisture content of all samples was redetermined just before the analysis.

Sample codes for moth bean pod coat powder samples used for the study Table 1

Sample Code	Sample Description
$RMTDT_13$	Recirculating tray drying at 40°C with 3% moisture content(d.b.)
$RMTDT_16$	Recirculating tray drying at 40°C with 6% moisture content (d.b.)
$RMTDT_19$	Recirculating tray drying at 40°C with 9% moisture content (d.b.)
$MTDT_13$	Tray drying at 40°C with 3% moisture content (d.b.)
$MTDT_16$	Tray drying at 40°C with 6% moisture content (d.b.)
$MTDT_19$	Tray drying at 40°C with 9% moisture content (d.b.)
$MTFDT_13$	Through flow drying at 40°C with 3% moisture content (d.b.)
$MTFDT_16$	Through flow drying at 40°C with 6% moisture content (d.b.)
$MTFDT_19$	Through flow drying at 40°C with 9% moisture content (d.b.)
$RMTDT_23$	Recirculating tray drying at 45°C with 3% moisture content (d.b.)
$RMTDT_26$	Recirculating tray drying at 45°C with 6% moisture content (d.b.)
$RMTDT_29$	Recirculating tray drying at 45°C with 9% moisture content (d.b.)
$MTDT_23$	Tray drying at 45°C with 3% moisture content (d.b.)
$MTDT_26$	Tray drying at 45°C with 6% moisture content (d.b.)
$MTDT_29$	Tray drying at 45°C with 9% moisture content (d.b.)
$MTFDT_23$	Through flow drying at 45°C with 3% moisture content (d.b.)
$MTFDT_26$	Through flow drying at 45°C with 6% moisture content (d.b.)
$MTFDT_29$	Through flow drying at 45°C with 9% moisture content (d.b.)

Note: d.b. stands for Dry basis.

The equation mentioned by Coşkun et al. [6] was used to calculate the amount of distilled water to be added to generate samples with the required moisture contents (Eq. (2)).

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \tag{2}$$

where:

Q is the quantity of water injected [kg];
W_i – the sample's initial mass [kg];
M_f – the sample's final moisture content in [db %];
M_i – the sample's beginning moisture content in [db %].

2.6. Engineering Properties of Moth Bean Pod Coat Powder

When analysing the quality of moth bean pod powder, one crucial parameter to consider is the disparity in densities. For hoppers and material handling equipment, the coefficient of friction and angle of repose are necessary [14].

Bulk Density: Bulk density of moth bean pod coat powder was determined using the AOAC (2000) method by filling a cylinder of 1000 ml with a height of 45 cm with the pod coat powder [19].

Tap density: The standard procedure for determining tap density involved filling a 100 ml measuring cylinder with pod coat powder, making sure the pod coat powder forms a level surface and tapping the cylinder till the volume continued to decrease. After levelling the surface, the sample was weighed. It was computed as the weight of the pod coat powder divided by the container's volume [19].

Compressibility Index: This characteristic relates to the extent to which the pod coat powder is compressible. The property is indirectly related to cohesiveness, particle size, and relative flow rate, but it does not directly correlate with any of them. The Hausner Ratio formula (Eq. (3)) yields the compressibility index [19].

$$CI = \frac{TD - BD}{TD} \cdot 100 \tag{3}$$

where:

CI is the compressibility index of the sample [%];
TD – the tap density of the sample [kg/m^3];
BD – the bulk density of the sample [kg/m^3].

Angle of Repose: The angle of repose for moth bean pod coat powder was measured using an iron tapering hopper with a 20 mm by 20 mm hole in the bottom and a top that measured 250 mm by 250 mm x 250 mm, respectively. For the test, a 100 mm circular disc was positioned beneath the hopper bottom to allow pod coat powder to pass through it and fall free on the disc. The heap created by the free fall on the disc was measured as height (*H*) and diameter of the disc (*D*) and was used in the calculation of angle of repose (ϑ) in degrees. The pod coat powder angles of repose were determined using the Equation (4), from Rani et al. [19].

$$\vartheta = tan^{-1}\left(\frac{2H}{D}\right) \tag{4}$$

where:

ϑ is the angle of repose [degree];
H – the cone's height [cm];
D – the disc's diameter [cm].

Coefficient of static friction: A frictionless pulley, a rectangular box with its ends opened, a loading pan, and test surfaces made of mild steel, stainless steel and plywood made up the apparatus used to measure the static coefficient of friction. On one side, weights were added to the pan until the rectangular box was just sliding, and on the other, the rectangular box was placed on the experimental surface that was filled with a known quantity of sample. The ratio of weights added to material mass was used to calculate the coefficient of static friction [19].

2.7. Proximate Analysis of Moth Bean Pod Coat Powder

The proximate composition of pod coat powder was determined according to the AOAC (2000) methods [15]. Ash content was determined in a Muffle furnace (Tempo Instrument pvt. ltd) at 550 ± 25°C by obtaining the grey ash and then calculating it for the result. The total protein and fat content were determined based on the Kjeldahl method (Gerhardt) and on the Soxhlet fat extraction (Borosil pvt. Ltd) method respectively. A 6.25 conversion factor was used for protein content estimation. Fiber was estimated by means of the Acid-Alkali method. Triplicate samples were analysed for each parameter.

2.8. Phytochemical Screening

Moth bean pod coat powder was screened for different phytochemicals by means of the chemical qualitative analysis method (Table 2). The compounds that have been found present in the powder were further determined using a quantitative analysis.

2.9. Quantitative Analysis of Bio-active Compounds

2.9.1. Preparation of the Extract

Petroleum ether at 60 to 80°C was used for the preparation of extract of the powdered samples. The extract for each sample was prepared using the Soxhlet method; by treating 100 g of defatted powdered sample with methanol for eight hours [21]. The quantitative estimation of extracts was done for tocopherols, tannins, flavonoids, total phenols, and DPPH free radical scavenging activity.

2.9.2. Determination of Total Phenolic Content

Gallic acid was used as a standard in the Folin-Ciocalteu method to calculate the total phenolic content (*TPC*). The TPC of pod coat powder extracts were estimated by adding 1.0 ml of Folin-Ciocalteu reagent and 2.0 ml of 20%, w/v Na2CO3 to 1 ml of extract, mixing, and adding water to reach a final volume of 50.0 ml. After 50 minutes of undisturbed time, the mixture was centrifuged for 10 minutes at 6000 rpm. Following the removal of the supernatant, the absorbance at 730 nm was measured, and the total phenolic content was expressed as milligrams of gallic acid equivalent per gram (mg GAE g^{-1}) [18].

2.9.3. Determination of Flavonoids

Flavonoids were estimated using the aluminium chloride colorimetric method. A test tube was filled with 1 ml of the diluted extract. 0.3 ml of 5% $NaNO_2$ were added to the extract. Five minutes later, 0.3 ml of 10% $AlCl_3$ was added. After adding 2 ml of 1M NaOH right away, the contents were combined and diluted with distilled water to reach a final volume of 10 ml. The absorbance was measured at 510 nm, in comparison to a blank [18]. The number of flavonoids in the samples was reported as mg CAE g^{-1}, or mg catechin equivalent per g of extract.

Phytochemical screening of bio-active compounds at T_1 and T_2 Table 2

Phytochemical	Result (T_1)	Result (T_2)
Polyphenol	+	+
Tannin	-	-
Saponin	+	+
Cardiac glycosides	-	-
Quinones	-	-
Tocopherol	+	+
Flavonoid	-	-
Alkaloid	-	-
Coumarins	-	-

Note: (+) represent the positive compound present in the powder (-) stand for the compound that is not present in the powder.

2.9.4. Determination of Tocopherol Content

Using α-tocopherol as a standard, Philip's method was used to estimate total tocopherols. Aliquots of α-tocopherol in ethanol and extract in concentrations of 10, 20, 30, 40, 50, and 60 ppm were taken into a flask, and the volume was adjusted to 8 ml using ethanol. This mixture was treated with 1 ml of 2,2-dipyridyl reagent and then 1 ml of $FeCl_3.6H2O$ reagent. After shaking the mixture for ten seconds, absorbance at 520 nm was measured using ethanol as a blank [18].

2.9.5. Determination of Tannin Content

Using tannic acid as a standard, the Pearson method was slightly modified to determine the tannin content. Separate test tubes were filled with 1 ml of extract or standard tannic acid solution (0.01, 0.02, 0.03, 0.04, 0.05, and 0.06 mg/ml). Each test tube was then filled with 1 ml of Folin-Denis reagent and 2.5 ml of saturated sodium carbonate solution. Distilled water was added to bring the total volume to 10 ml, and the mixture was thoroughly shaken. After 30 minutes of incubation at room temperature (roughly 30°C), the mixtures' absorbance was measured at 760 nm against the reagent blank [18].

2.9.6. 2,2'-Diphenyl-1-picrylhydrazyl (DPPH) Free Radical Scavenging Assay

The *DPPH* free radical scavenging method was used to assess the extracts' antioxidant activity [1]. To put it briefly, 2.5 ml of 2,2'-diphenyl-2-picrylhydrazyl radical (DPPH: 0.025gL^{-1} in methanol) was combined with 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, and 10.0 mg of extract. The final volume was 10 ml with methanol, mixed by vertexing for 5 minutes, and then put right into a spectrophotometer called Spectronic 20 (Milton Roy Company). As the reaction gradually reached a plateau (time at steady state), the absorbance was measured at 517 nm every 10 minutes. The percentage decrease in absorbance after two hours in comparison to the control, which represents the percentage of DPPH scavenged, was used to express the antioxidant activity [18].

2.10. Statistical Analysis

The data obtained was analysed and interpreted by an analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) at a level of 5% of significance, using the Statistical Analysis System (SAS 9.4 TS L1M2, SAS Institute Inc., NC, USA). All the measurements were performed in triplicate and the mean value, standard deviations, coefficient of variation, and Se (±) were calculated.

3. Results and Discussion

3.1. Drying Behaviour of Moth Bean Pod Coat

The graphical representation of the drying characteristic of pod coat has been shown in (Figure 1 and 2) as per the two different temperatures, *viz*., 40 and 45˚C. As the drying process went on, more energy was needed to extract the moisture from the pods. However, initially the moisture absorption process was maximal for all three dryers in the first hour due to the low resistance shown by the pod coat to moisture loss [32].

The moth bean pod coat took 390-460 min to dry when dried at 40 to 45˚C. A drying graph of moth bean pod coat exposed to air at two drying temperatures was drawn by plotting a graph of moisture content against temperature. Defining the rate of drying of biological by-product in falling period is very difficult, therefore for this purpose a modified version of Page's drying equation was fitted to forecast the pace at which pod coat would dry [32]. It was obtained that the temperature has a substantial ($p \leq 0.05$) impact on drying time. The fluctuation of the modified Page's model constants "*K*" and "*n*" with the drying air temperature for the pod coat was found to follow a regular trend. The moisture ratio obtained for pod coat, or drying rate, was determined to be (0.79, 0.55, and 0.33) for 40˚C and (0.81, 0.68, and 0.44) for 45˚C for the recirculatory tray and for through flow dryers, respectively (Figures 1 and 2). From the data, it can be concluded that temperature and time affect drying behaviour.

The optimal drying results for moth bean pod coat were achieved with all three dryers operating at 45˚C with constant air velocity. This was due to the higher initial temperature, which rapidly eliminated surface moisture and accelerated the drying process (Figure 2). The drying air temperature had a considerable impact on drying time; the best results were obtained when drying at 45˚C in a recirculating drier, whereas the worst results were obtained when drying in a tray dryer at 40˚C. It required more time for pod coats with a lower moisture ratio to dry using flow dryer.

3.2. Engineering Properties of Moth Bean Pod Coat Powder

The engineering properties of moth bean pod coat powder were studied as the average values of three replicates. The recorded engineering properties of moth bean pod coat powder samples are depicted in Figure 3 and 4.

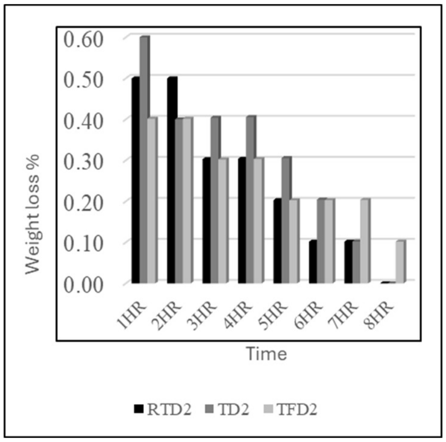

Fig. 1. *Weight loss [%[with time at 40˚C*

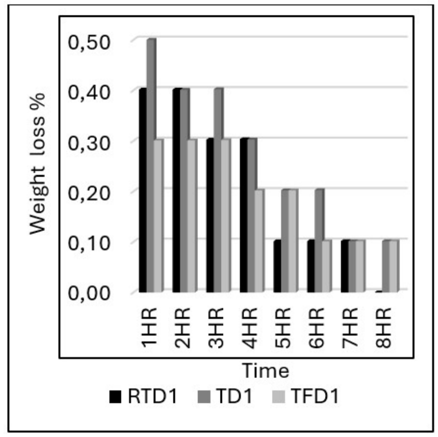

Fig. 2. *Weight loss [%] with time at 45˚C*

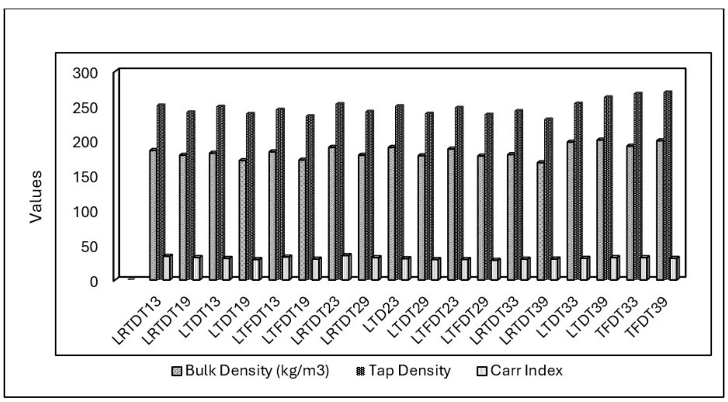

Fig. 3. *Engineering properties of dried samples at different moisture contents (3, 6, 9%)*

Bulk and Tap Density: The bulk and tap density of the pod coat powder depend on the factors like moisture content of the pod coat powder**.** The bulk density was found to be decreasing as moisture content increases in the range of 114.6 kg/m^3 to 111.2 kg/m^3 for 3 to 9% M.C, respectively. According to Pradhan et al. [18] this was caused by a decrease in mass due to moisture gain in the sample compared to the bulk's corresponding volumetric expansion. For pea pods, Yalcin et al. [32] reported a similar declining trend in bulk density.

Tap density is measured as 128.2 to 120.1 kg/m^3 for moth bean pod coat powder for an increased moisture content from 3 to 9% as it also depends on the size and moisture content. The findings were comparable to those of Yalcin et al. [32] for pea pods, and for certain legume pods; however, a distinct trend was noted by Vashisth et al. [29] for faba bean pods. The bulk density and tap density of pod coat powder can be used to finalize the size and capacity of the hopper and of the crushing chamber that provide stability of the machine during operation.

Angle of Repose: The results found for the angle of repose of pod coat powder was in the range of 31.1˚ to 33.3˚. It was discovered that the readings increased within the moisture range of 3-9% (Dry basis). The reason for the increasing tendency of the angle of repose with moisture content is the surface tension from the moisture layer around the particle, which holds the grain aggregate together according to Pradhan et al. [18].

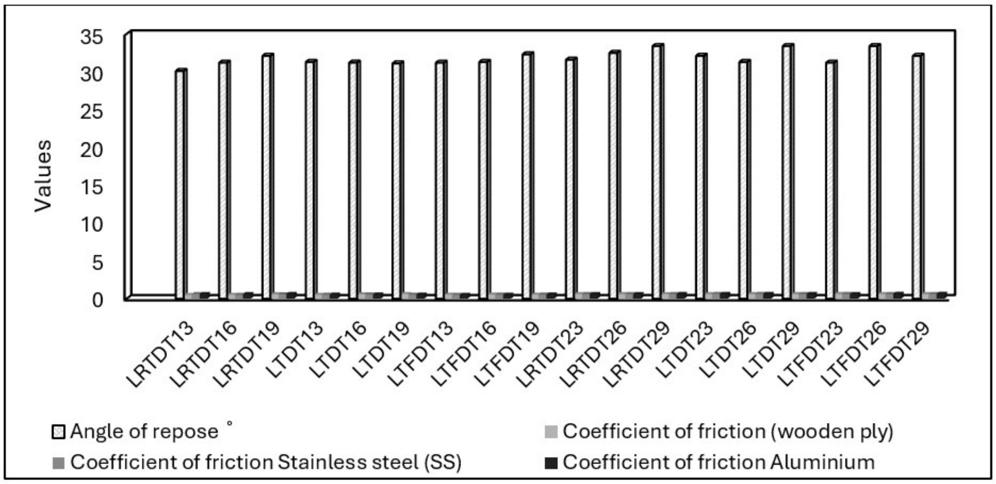

Fig. 4. *Engineering properties of dried samples at different moisture contents (3, 6, 9%)*

Coefficient of friction: The wooden ply surface had the highest coefficient of static friction values for the pod coat powder, followed by the stainless-steel surface. It was found that for all contact surfaces, the static coefficient of friction rise linearly with an increase in moisture content. A higher moisture content may cause the coefficient of friction to rise because the water in the pod coat provides a cohesive force on the surface of contact Pradhan et al. [18]. In the present study, the coefficient of friction increased with an increasing moisture content from 3 to 9% (Dry basis) in the cases of plywood, stainless steel, and aluminium sheet, respectively. Maximum friction was provided by plywood at all moisture contents, followed by aluminium sheet and stainless steel closely behind. The stainless steel is a smoother and more polished surface; this may be the reason for the lowest static coefficient of friction when compared to the other materials.

3.3. Proximate Analysis

The results for proximate composition were found close to each other for different samples but differ slightly in case of fibre content. The tray drying sample ($MTDT_1$3- $MTDT_1$9) found the crude fibre content in the range of 17.31-19.41%, whereas $MTDT_2$3-$MTDT_2$9 found a slightly lower value in the range of 16.44-18.41% for a moisture content of 3 to 9 %, whitin the samples (Table 3).

For through flow drying which shows a trend of increase on increasing the moisture content from 3 to 9 %, this could be due to the water absorption of the fibrous tissue of pod coat. However, some results highlight the importance of the broad bean pod (*Vicia faba L.*) and pea (*Pisum sativum* L.) as sources of fibres and whose flour's exhibited functionality in the preparation of baking and confectionery products, like good water holding capacity, positively impacts bread texture [13].

The recirculatory drying sample shows the highest ash content value of 4.12% (Table 3) that also shows the presence of viable minerals in the dried samples. For all the dried samples the impact of the moisture content on the ash content was not statistically significant. The findings are consistent with a related study which reported that increasing the amount of cassava flour in bread production led to an increased of the ash content [13]. Similar results were found by Sultana [26] for moringa leaves which show the presence of minerals like calcium and phosphorus.

Table 3

Proximate composition of moth bean pod coat powder dried by different drying methods at 40 and 45°C to 3, 6, 9% moisture contents (d.b.)

Sample number	Sample	MC [d.b. %]	Ash [%]	Protein [%]	Fat [%]	Crude Fiber [%]
1	$MRTDT_13$	3.12±0.12^{a}	4.12±0.31^{a}	6.81±0.12^{a}	0.44±0.02^{a}	16.12±0.31^{a}
2	$MRTDT_16$	5.44±0.17^{b}	4.09±0.22^{a}	6.44±0.16^{b}	0.46±0.01^{a}	17.22±0.39^{b}
3	$MRTDT_19$	8.12±0.14^{a}	4.04±0.34^{b}	6.01±0.14^{c}	0.45±0.03^{b}	18.41±0.41^{a}
4	$MTDT_13$	3.41±0.19^{c}	4.01±0.11^{bc}	5.88±0.16^{bc}	0.39±0.01^{b}	17.31±0.24^{ab}
5	$MTDT_16$	5.14±0.22^{b}	4.03±0.33^{b}	5.24±0.27^{b}	0.33±0.01^{a}	18.29±0.42^{b}
6	$MTDT_19$	8.21±0.21^{a}	4.09±0.41^{b}	5.01±0.14^{c}	0.47±0.02^{b}	19.41±0.33^{a}
7	$MTFDT_13$	3.51±0.13^{ab}	3.88±0.39^{b}	6.33±0.18^{a}	0.41±0.03^{ab}	16.01±0.56^{c}
8	$MTFDT_16$	5.72±0.33^{b}	3.81±0.55^{b}	6.01±0.21^{a}	0.41±0.01^{ab}	17.11±0.11^{c}
9	$MTFDT_19$	8.91±0.21^{a}	3.79±0.29^{b}	5.88±0.11^{a}	0.42±0.03^{ab}	18.01±0.55^{c}
10	$MRTDT_23$	3.01±0.11^{b}	3.99±0.28^{c}	6.23±0.21^{b}	0.38±0.00^{a}	15.99±0.38^{ab}
11	$MRTDT_26$	6.01±0.19^{c}	3.81±0.22^{b}	6.01±0.19^{c}	0.37±0.01^{b}	16.11±0.18^{a}
12	$MRTDT_29$	9.11±0.19^{b}	3.89±0.28^{a}	5.81±0.23^{b}	0.36±0.00^{a}	17.99±0.34^{b}
13	$MTDT_23$	3.09±0.12^{c}	4.06±0.29^{a}	5.41±0.31^{c}	0.41±0.01^{a}	16.44±0.12^{a}
14	$MTDT_26$	6.11±0.24^{ab}	4.01±0.17^{b}	5.01±0.61^{bc}	0.42±0.01^{b}	17.21±0.14^{b}
15	$MTDT_29$	9.13±0.22^{c}	4.05±0.49^{a}	4.99±0.33^{c}	0.39±0.01^{ab}	18.41±0.22^{ab}
16	$MTFDT_23$	3.11±0.19^{d}	4.09±0.33^{b}	6.13±0.23^{d}	0.49±0.05^{b}	15.01±0.08^{b}
17	$MTFDT_26$	6.01±0.14^{b}	4.03±0.21^{ab}	5.89±0.31^{cd}	0.47±0.01^{c}	16.21±0.18^{bc}
18	$MTFDT_29$	9.03±0.29^{ab}	4.11±0.32^{b}	5.01±0.33^{c}	0.45±0.04^{b}	17.01±0.11^{b}

Note: p Value<0.05 using Duncan method, alphabetical superscript homogenous subsets.

Crude fat for moth bean pod coat powder was found to amount to 0.33 to 0.49 %, respectively (Table 3). The proximate composition analysis was performed to observe a compositional change in pod coat powder due to the difference after harvesting. The higher ash content, lower crude fat and higher fibre content in pod coat powder can be attribited to the concentration of minerals, degradation of lipid bonds and to the presence of high fibrous tissues in it. The protein content of pod coat powder was found to be in the range of 4.99 to 6.81%, which declines with increasing the moisture content respectively. It has been reported in cassava flour that the decrease in fat content was likely caused by the accompanying enzymes' high proteolytic and lipolytic activity, which in turn caused a loss of nutrients [25]. The protein and lipid contents of other flour products were similarly shown to have decreased in earlier studies on storage. The protein content has been found to aid in functional properties like water holding capacity [2].

The standard error obtained by dividing the standard deviation by mean predict variation in between drying methods with varied moisture content readings.

3.4. Quantitative Analysis of Bioactive Compounds

3.4.1. Determination of Total Phenolic Content

MRTDT$_1$3 extract with 17.21 mg GAE g^{-1} (Table 4) *TPC* have a high phenolic activity as compared to other dried samples. The lowest phenolic content was found in extracts from moth bean samples that were flow-dried at 40°C. The total phenolic content of the pod coat was significantly affected by all drying techniques. Samples with the same dry weight were dried using drying procedures and the extracted dry weight from the dried samples was equal [16]. The higher percentage of total phenols obtained from MRTDT$_1$3 may be due to more efficient extraction of insoluble phenolic components, such as condensed tannins and phenolic acids attached to cell wall polysaccharides or proteins. Therefore, the total phenol concentrations in the samples were unaffected by residual moisture. The total phenol content of the samples significantly decreased after the field samples were dried [16].

3.4.2. Determination of Flavonoids

Flavones, isoflavones, and flavonol are the three subgroups of flavonoids that are present in moth bean extracts. Flavonoids were detected in MTFDT$_1$3 is 5.13 mg CAE g^{-1}, whereas 4.29 and 3.82 mg CAE g^{-1} for MTFDT$_1$6 and MTFDT$_1$9 respectively (Table 4). Mesophyll cells were left behind under a lot of stress for a while after the pod coat was harvested. Mesophyll cells have endured and can carry out intricate metabolic processes like turning intermediate molecules into flavonoids, which promotes flavonoid accumulation. Nevertheless, mesophyll cell metabolism was slowed due to the low temperature at which the MRTDT$_1$3 technique was applied, and no appreciable material changes were discovered [16].

3.4.3. Determination of Tocopherol Content

MRTDT$_1$3 sample's tocopherol has the highest content of tocopherol in the methanol extract (5.46 mg/g), followed by the MTFDT$_1$3 (4.62 mg/g) and MTDT$_1$3 (5.09 mg/g) extracts compare to MRTDT$_1$6 (4.61 mg/g) MTFDT$_1$6 (3.93 mg/g), and MTDT$_1$6 (4.81 mg/g) (Table 4). This also shows a decreasing trend of tocopherol with increase in moisture. Additionally, analyses showed that the tocopherol breakdown that took place during pod drying was affected by the drying temperature. Tocopherol loss during drying at high temperatures and near ambient conditions averaged about 10% [4].

Quantitative analysis of Bioactive compounds of moth bean pod coat powder dried by different drying methods at 40 and 45°C to 3, 6, 9% moisture contents (d.b.) Table 4

Sample number	Sample	Phenolic content [mg GAEg^{-1}]	Flavonoid content [mg CAEg^{-1}]	Tocopherol content [mg/g]	Tannin content [mg TAEg^{-1}]
1.	$MRTDT_1$ 3	17.21±0.03^b	6.31±0.07^a	5.46±0.06^c	2.21±0.08^b
2.	$MRTDT_1$6	15.71±0.05^a	5.12±0.03^c	4.61±0.02^a	2.32±0.04^b
3.	$MRTDT_1$9	11.44±0.04^b	4.48±0.04^a	4.92±0.01^a	2.39±0.05^c
4.	$MTDT_1$3	14.61±0.06^c	5.61±0.03^b	5.09±0.06^c	2.18±0.07^a
5.	$MTDT_1$6	13.01±0.02^b	4.08±0.02^c	4.81±0.07^a	2.22±0.08^b
6.	$MTDT_1$9	11.51±0.04^a	3.04±0.01^b	4.63±0.04^b	2.31±0.04^c
7.	$MTFDT_1$3	13.41±0.07^b	5.13±0.02^b	4.62±0.03^a	2.02±0.04^c
8.	$MTFDT_1$6	12.61±0.02^b	4.29±0.04^b	3.93±0.05^b	1.95±0.05^a
9.	$MTFDT_1$9	10.32±0.03^c	3.82±0.05^b	3.63±0.03^c	1.65±0.07^b
10.	$MRTDT_2$3	14.34±0.07^a	6.61±0.07^a	5.89±0.02^a	2.28±0.03^c
11.	$MRTDT_2$6	11.98±0.04^c	5.81±0.03^b	4.74±0.04^b	2.14±0.05^a
12.	$MRTDT_2$9	10.71±0.06^b	4.10±0.05^c	4.76±0.03^a	1.98±0.06^b
13.	$MTDT_2$3	14.32±0.06^a	5.46±0.05^b	5.62±0.05^a	2.32±0.04^c
14.	$MTDT_2$6	13.45±0.02^b	4.32±0.02^a	4.84±0.07^b	2.13±0.02^a
15.	$MTDT_2$9	12.32±0.01^c	3.27±0.05^b	4.35±0.03^c	1.98±0.03^b
16.	$MTFDT_2$3	13.85±0.07^a	5.14±0.04^c	4.13±0.05^b	2.09±0.04^b
17.	$MTFDT_2$6	12.54±0.04^c	4.42±0.03^b	3.87±0.02^b	1.87±0.02^a
18.	$MTFDT_2$9	10.86±0.05^b	3.86±0.07^a	3.53±0.01^c	1.43±0.01^a

Note: p Value<0.05 using Duncan method, alphabetical superscript homogenous subsets.

The ambient drying process in a thick bed entails moisture moving from pod to air primarily through a relatively thin layer known as the drying zone. Depending on the atmospheric air's ability to dry crops, the progressive drying method can take anywhere from a few days to twelve days during the postharvest season [7]. The pod layer acts as an air outlet layer and retains moisture during the drying process while it awaits the passing of the drying front. It has the same amount of moisture as the grain did at first [8].

3.4.4. Determination of Tannin Content

$MRTDT_1$9 (2.39 mg TAE g^{-}1), $MTDT_1$9 (2.31mg TAE g^{-}1) and $MTFT_1$9 (1.65 mg TAEg-1) (Table 4) extracts show a good amount of tannin content compared to other dried samples. The amount of tannin extracted from the pod was constrained by drying. These findings suggest that pod moisture content has a major impact on tannin inactivation.

As evidenced by the absence of oxygen (heating under vacuum) and the addition of EDTA-disodium, which had little protective effect on tannin inactivation in pod coat, oxygen and metal ions only play a limited role in the tannin inactivation process [11].

3.5. 2,2'-Diphenyl-1-picrylhydrazyl (DPPH) Free Radical Scavenging Assay

To quantify antioxidant activity (Figure 5), the 2,2' diphenyl-1-picrylhydrazyl radical (*DPPH*) method was employed using BHA as a reference [11]. The MRTDT$_1$3 extract showed the best activity among all the powder samples (Figures 6 to 8). The higher phenolic and flavonoid content of methanolic extracts along with their enhanced capacity to scavenge free radicals, demonstrates a positive correlation between phenolic composition and antioxidant activity. The difference in the IC$_{50}$ values indicates that the recirculatory dried samples have a weak inhibitory concentration resulting in stronger antioxidant properties followed by the through flow dried sample.

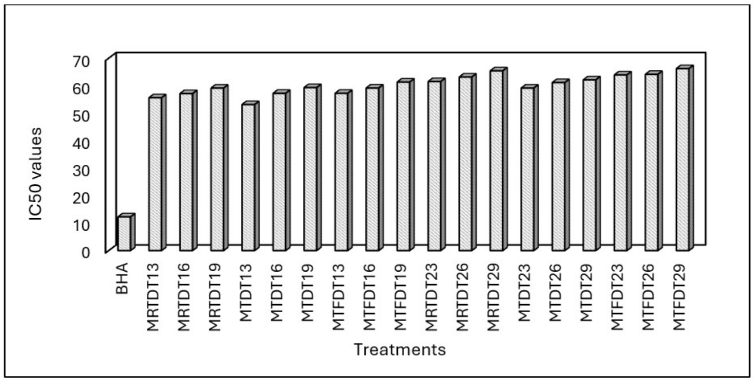

Fig. 5. *IC$_{50}$ values of DPPH assay at 3, 6 and 9% moisture contents*

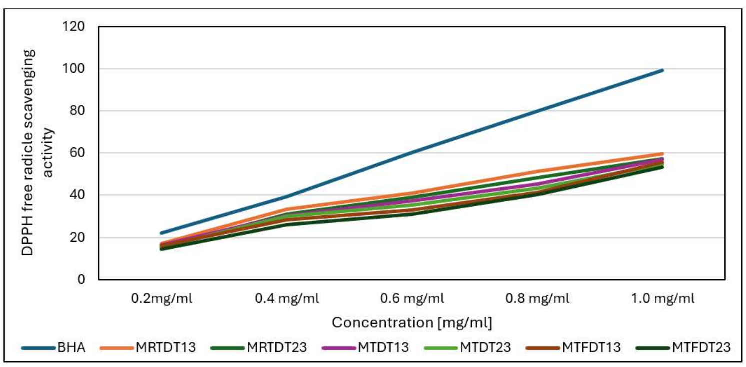

Fig. 6. *Antioxidant activity of moth bean powder of dried samples at a 3% moisture content (Dry basis)*

Tray drying of samples resulted in a higher inhibitory concentration that implies its weaker antioxidant activity. The samples dried at lower temperature showed better antioxidant activity. The reason may be that the heat from the air dryer breaks down cell walls and subcellular compartments, producing antioxidants through thermal chemical reactions, simultaneously suppressing antioxidant oxidation by thermally inactivating oxidative enzymes [28].

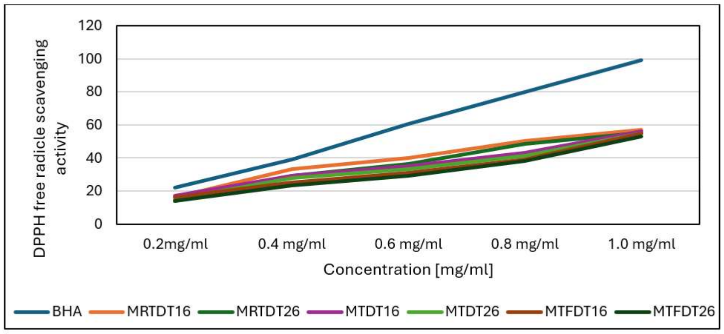

Fig. 7. *Antioxidant activity of moth bean powder of dried samples at a 6% moisture content (Dry basis)*

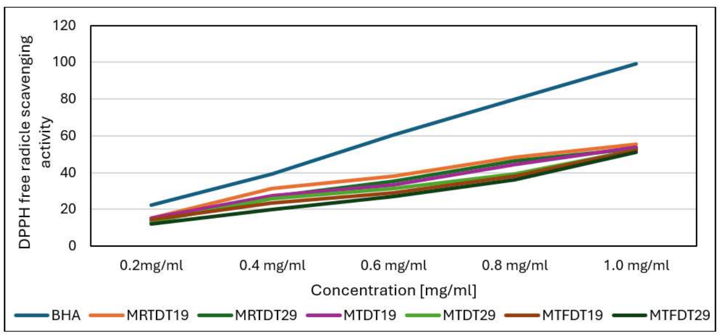

Fig. 8. *Antioxidant activity of moth bean powder of dried samples at a 9% moisture content (Dry basis)*

Heat treatment sometimes may also enhance the release of phytochemicals such as lycopene, resulting in a loss of antioxidant activity. So, the overall effect of temperature on antioxidant activity is dependent upon the combined effect of various factors. Low moisture levels inactivate enzymes and hinder microbial growth. This may explain the trend of higher antioxidant activity values with lower moisture levels of 9 to 3%, as more oxidative enzymes may have been inactivated.

4. Conclusion

The research work focused on the analysis of engineering and functional properties of moth bean pod coats. The engineering properties of moth bean pod coat powder showed a variance according to different moisture content levels of the pod coat powder. The sample subjected to recirculatory drying at a 3% moisture content (Dry basis) showed the best results for powder quality. The proximate analysis showed that moth bean pod coat powder can be used as a source of crude fibre for making value-added products with a low fat and high fibre content. The drying of moth bean pod coats at 40˚C in a tray dryer was found to be best for the retention of nutrients based on a proximate analysis. Also, moth bean pod coat powder showed the presence of bioactive compounds on a phytochemical screening and can be used as a low-cost source for the extraction of bioactive compounds. The presence of antioxidant activity and other bioactive compounds is advantageous for its use in products like bakery products, flours, soups, etc. which usually have high fat content.

The relation between engineering and the phytochemical properties found that if the temperature of drying increased, the phytochemical properties decreased for the same drying methods; for example, $MRTDT_1$ compared to $MRTDT_2$ found better results in case flavonoids and tocopherol at 40 to 45°C respectively. Moth bean pod coat powder has shown potential to open new and diverse prospects across several industries. Specifically, the feed and food sectors may find in pod coat powder a valuable source of nutrients like crude fibre and bioactive substances with low costs. The above study concludes that pod coat powder of moth bean holds economic value and can be further utilized in the food industry.

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