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EVALUATION OF MATHEMATICAL MODELS TO DESCRIBE THIN-LAYER DRYING AND TO DETERMINE DRYING RATE OF POTATO PEELS USING TRAY DRYING

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ABSTRACT

Potato peel, a by-product of potato processing industry, is a rich source of fibre and anti-oxidants. This massive amount of waste offers significant economic potential for creative uses other than animal feeds or fertilizers. Hence appropriate handling is needed to avoid any environmental violence. In the present study, efforts have been directed to possible utilization of the potato peel, not only from the point of preservation and waste management, but as a profitable adjunct to the food processing industry. In this connection, an experimental study was performed to determine the drying characteristics of potato peel in a laboratory scale tray dryer at a constant air velocity of 0.5m/s and temperature of 70°C. Potato peels were dried for 7 hrs. Drying curve was prepared and results indicated that maximum drying took place in falling rate period. Six different thin layer-drying models were compared with respect to their coefficient of determination (R^2), reduced chi-square (x^2) and root mean square error (RMSE) was selected to better estimate the drying curves. The entire models were showed a good fit to the drying data. However, the Exponential two terms drying model showed the best fit to the experiment data among other models.

Keywords: *Potato peel, tray drying, drying curve*

1.INTRODUCTION

One of the most important industries worldwide is Food processing. Significant amounts of food wastes such as peels, outer leaves, and pulps are generated as a result of manufacturing food products from vegetables and fruits [1]. Such food wastes are generally rich in bioactive compounds and phenols [1]. Moreover, sanitation and disposal problem of food processing by-products is necessary. Therefore numerous ways have been adopted for recycling of such ingredients and utilizing them in several food and / or non-food applications [2]. Hence, by-products of food processing is a promising, inexpensive, affordable, and valuable starting material for the extraction of value added products such as dietary fiber, natural antioxidants, biopolymers, and natural food additives [3-5]. However, the most significant aspect lies in the stability, and economic feasibility of such processing development [6,7].

After corn, wheat and rice, potatoes (*Solanum tuberosum L.*) being fourth in terms of crop size, it is also one of the most popular vegetables [8]. An amount exceeding 325 million tons of potatoes were produced worldwide in 2007. Of these two-thirds potatoes were consumed by consumers and rest were used for non-food applications including animal feeds and pharmaceutical, textile, wood and paper industries [9]. According to Food and Agriculture Organization (FAO), the world annual production of potatoes in 2009 was reported to around 180 million tones [10]. Thus, it is a major source of food waste.

Since potato vegetation came into place long back around 500 B.C in South America [11], for over centuries it has become an important part of human nutrition in terms of its nutritional quality. Converting these potatoes to peels, a major potato chip company utilizes almost 3 billion pounds of potatoes per year [12].

According to USDA crop service statistics of 2006, around 28,004,400,000 pounds potatoes were used to make popular products such as potato chips, French fries, potato flour etc. [8,13]. Of an annual production of over 30 MT, tenth goes to industry to produce such variable products while the remaining is consumed in fresh form itself [10]. Potato peels accounts for about 0.5% of the potato weight. However, its thickness and hence total peel waste varies with the variety of the potato, but on an average it never exceed more than 1% of the potato weight. Therefore, this company alone should generate approximately 15 million pounds of potato peels each year. Thus, worldwide, industrial processing generates between 70 and 140 thousand tons of peels annually [12].

Moreover, total potato production as well as consumption is increasing, especially in developing countries, contributing to more than half of the worldwide harvest [8]. Processed potato products are becoming popular in India [14]. At present India is the biggest potato producer with an output of 20,280,000 tons [15]. Expanding consumption implies parallel increasing volumes of potato peel waste generated during processing [12]. At present, its disposal by the processing plants is a problem. Hence utilization of potato peel obtained during processing of potato is important to the industry [14]. Like any other food processing industry, the by-products from potato processing are principally organic materials, thus its proper management and disposal are significant toward a clean industry.

Toma *et al.* (1979) reported the constituents of potato peel [16]. Potato peels are high total dietary fibre (76.40 %) and is a good source of protein (14.04%) [14]. Furthermore Potato skins are rich source of ascorbic acid (vitamin C), vitamin E, and other phenolic compounds [8,17]. Almost 50% of the total phenolic compounds of potatoes are located in its peels and the adjacent tissues [17]. De Sotillo *et al.* [18,19] reported in his studies that potato peels are composed of 50.3 % chlorogenic acid, 41.7% caffeic acid, 7.8% gallic acid and 0.21% protocatechuic acid, all of which have been found to show significant antioxidant activity in vitro assays [20]. Moreover, potato peel has been studied as feed for pigs [21]. However, it is not suitable, without further treatments, as feed for humans because it is too fibrous to be digested [22]. On the other hand, potato peel

has been successfully used in feeding of multi-gastric animals. Milk fat from cows fed with potato peels shown to be 3.3 g/kg higher than that of control [23].
Number of approaches have been made for potato peels utilization in food and nonfood applications including the extraction and verification of bioactive ingredients and nutritional quality of potato peels and their applications [24]. Another approach was its utilization as a source for natural antimicrobial compounds [25].

Drying is a process to remove water or other liquid from the solid material till an acceptable low value of moisture is achieved [26]. According to several authors the word ‘‘drying’’ is used to describe the process of water removal naturally on exposure to the sun [27] whereas ‘‘dehydration’’ as the artificial drying carried out in controlled conditions [28]. Drying is probably the oldest method of food preservation. Earlier foods such as meat, fish, fruits and vegetables were preserved using sun-drying techniques [27]. Nowadays, drying is regarded not only as a preservation process, but also as a method for increasing added value of foods. Variety of products can be obtained which can be incorporated in breakfast cereals, bakery, confectionery and dairy products, soups, purees and others [29]. Hence drying is an essential, most widely used and a primary method for preservation of agricultural products. Potato peels are organic wastes that are water activity 0.99 at 25°C that support microbial growth, hence its storage is difficult. The material easily spoils when exposed to the air and emits a very foul odour. It also provides a breeding place for a variety of pests, which are hosts of many disease-causing organisms. Increasing landfill costs and societal concerns about solid waste have generated interest in finding an economical outlet for such by-products. Such a great amount of potato waste could become a serious environmental problem and a waste of resources. This was significant for the reason that the potato peels can be best dried without much quality degradation and the dried product can be used as a good source of fibre and other nutrients and hence find great scope in incorporating the dried potato peels in various food products such as biscuits, muffins and cakes, soup mixes, etc, thereby increasing the nutritional value of the foods and at the same time utilizing the waste in a best possible way [30]. Therefore, mathematical models are used that can describe suitable drying mechanisms and predict water removal rates [31]. Lot of literature is available on drying behavior of agricultural products including sweet potato slices, garlic slices, pistachio, grape, rough rice, black tea, banana and prickly pear peel [32]. However there is a lack of information available concerning. This paper aims at studying the drying characteristics of potato peels and its nutritional composition during tray drying.

2. Material and Methods

2.1 **Sample Collection**: Potatoes purchased from local farm market [30].

2.2 **Experimental set up**: The laboratory scale batch type Tray dryer is used [30].

Fig. 1 TRAY DRYER

2.3. **Sample Preparation** [30]:

The seeds were separated from the Potato Peels. The Potato Peels were then cleaned and weighed with the help of a digital electronic balance having an accuracy of 0.01 g. In 2 kg potatoes, potato peels weighed 10 grams. To determine the initial moisture content of the sample, the Potato Peels were subjected to oven drying at 130˚C for one hour. Also the water activity was determined at 25˚C Aqua Lab water activity meter. The weighed sample was spread on to tray subjecting to drying in a tray dryer at temperature of 70°C for two hours, at a constant air velocity of 0.5m/s. The sample was weighed after every 10 minutes until the drying rate became constant. Finally the sample was allowed to cool in a desiccator, and then weighed. Water activity was now calculated for the dried sample.

Theory/ Calculation

2.4. **Drying analysis:**

2.4.1. Moisture content:

$$Mc = \frac{(M_i - M_d)}{(M_i)} x100$$

Mi is the mass of sample before drying and M_d is the mass of sample after drying.

2.4.2. **Drying rate** (Rd):

$$Rd = \frac{(M_i - M_d)}{t}$$

2.4.3. **Moisture ratio is given by**,

$$MR = \frac{(M - M_e)}{(M_o - M_e)}$$

where MR is the dimensionless moisture ratio, M, M_e and M_o are the moisture content at any time, the equilibrium moisture content and the initial moisture content in kg respectively. The equilibrium moisture content (M_e) was assumed to be zero for this experiment because it is very small as compared to M_o [30].

2.5. **Theory of Mathematical modeling**:

A mathematical model is a mathematical analog of the physical reality, describing the properties of a real system in terms of mathematical variables and operations. Development of model is necessary to investigate the drying characteristics of potato peels. Due to the super growth and availability of the computing power, mathematical models have become more realistic and this have in turn fueled rapid rise in the use of such models in product, process, and equipment design and research [33]. There are two types of thin-layer models in use: diffusion models and empirical models. The accuracy of diffusion models to predict moisture content depends on having good assumptions concerning the geometry, moisture diffusivity and temperature profile of a piece of food. The diffusion models need more computation time and computer memory than the simpler empirical models. According to Bruce [34], for simulations of deep-bed drying, simpler models are considered to be useful than the diffusion models where economy of computation is concerned, while the later being more accurate and allow internal moisture movement to be modeled.

However empirical models are more applicable for control technology to drying, as computation requires lesser time. Therefore, it was decided to look at widely used simpler models [35]. In this study, the experimental drying data of potato peels at temperature of 70˚C were fitted into 3 commonly used thin-layer drying models, listed in Table 1. Page's model has been widely used to describe drying behavior of a variety of biological materials [30].

Table 1: Mathematical thin-layer models fitted to experimental data

MODEL NAME	MODEL EXPRESSION	REFERENCE
Page	MR=exp(-kt^n)	Page (1949) in Bruce (1985)
Wang and Singh	$MR=1+at+bt^2$	Wang & Singh (1978)
Exponential two terms model	MR a.exp(-k.t) -a)exp(1(- k.a.t)	Togrul & Pehlivan (2003)
Logarithmic	$MR = a\exp(-kt) + c$	Doymaz.(2010)
Henderson & Pabis	$MR = a \exp(-kt)$	Henderson & Pabis (1961)
Lewis	$MR = exp(-kt)$	Lewis. (1921)

Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalize drying curves. For modeling thin layer drying for agricultural products, the material is first subjected to a constant relative humidity and temperature conditions and the moisture content of the material at any time is measured and is then correlated to the drying parameters [36]. To select the best model for describing the drying curve during drying process the thin layer drying equations in Table 2 were tested. The reduced chi-square (χ^2) and the root mean square error (RMSE) were calculated using following expressions [37]:

$$R^2 = \frac{\sum_{i=1}^{n}(\mathrm{MR}_i \quad \mathrm{MR}_{\mathrm{pre};i}) \cdot \sum_{i=1}^{n}(\mathrm{MR}_i \quad \mathrm{MR}_{\mathrm{exp};i})}{\sqrt{\left[\sum_{i=1}^{n}(\mathrm{MR}_i \quad \mathrm{MR}_{\mathrm{pre};i})^2\right] \cdot \left[\sum_{i=1}^{n}(\mathrm{MR}_i \quad \mathrm{MR}_{\mathrm{exp};i})^2\right]}}$$

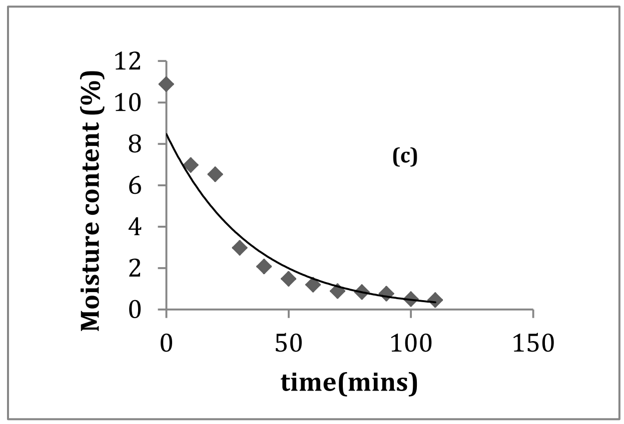
$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{Exp,i} - MR_{\mathrm{Pr}e,i}\right)^2}{(N - Z)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{\mathrm{Pr}e,i} - MR_{Exp,i})^2}$$

Where MR_{Exp},i is the ith experimental moisture ratio, MR_{Pre}, i is the i[th] predicted moisture ratio, N is the number of observations and n is the number of constants. In this study, the nonlinear regression analysis was performed with statistical software, OriginPro 8.5.1 (Origin Lab, Massachusetts). The higher values of R^2 and lower values of the x^2 and RMSE indicates the goodness of the fit [38-40].

2.6. Determination of water activity

The water activity of potato peels was determined at 25˚C (±0.2˚C) using an electronic dew point water activity meter, equipped with a temperature-controlled system which have a temperature stable sensing device. The equipment was first calibrated with saturated salt solutions in the interest range of a_w. For each determination, duplicates readings were obtained, and the average value was reported [30]. An accuracy of about ± 0.003a_w can be obtained by meter under above-mentioned conditions [41].



3. RESULTS AND DISCUSSION

3.1. Drying curves

A rapid drying was observed in dimensionless moisture content. The instantaneous moisture content rapidly decreases as the drying time increases [30]. The variations of drying rate during drying time obtained in this experiment are shown in Fig 2.

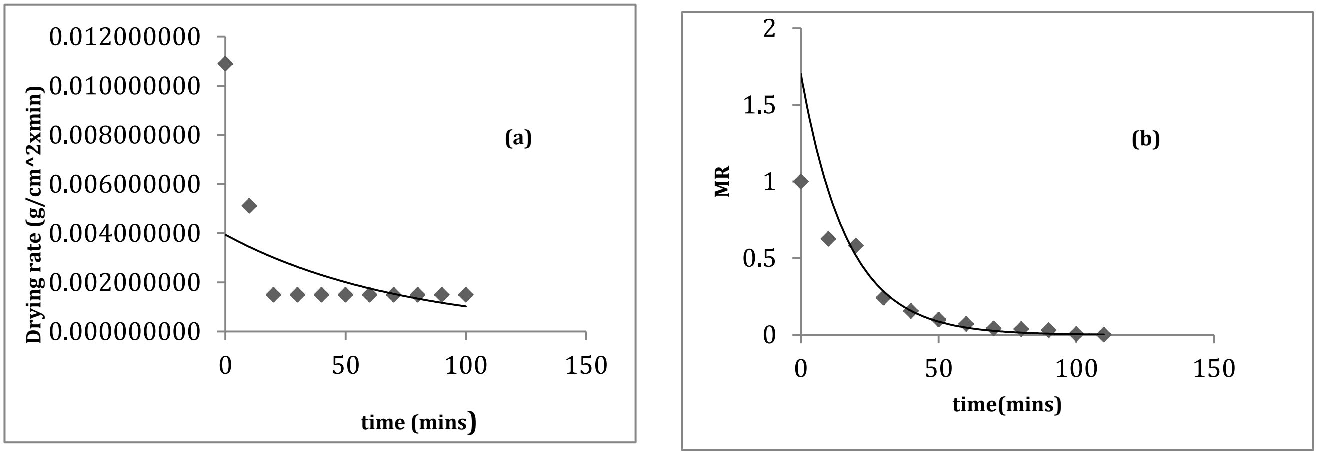


Fig. 2 Drying curves (a) Variation of drying rate with drying time, (b) Variation of Moisture ratio with drying time, and (c) Variation of Moisture content with drying time

It is apparent that the drying rate decreased continuously throughout the drying time. Also the moisture ratio decreased incessantly (Fig. 2). At the beginning of the drying process, the drying rate was very high, but decreased with moisture ratio reduction. However, during the drying process the surface does not remain in a saturated condition, as the movement of water to the surface is not sufficient to maintain saturation [30]. Subsequently, the surface is not in a condition of equilibrium, which results in lowering of the drying rate [42]. Earlier studies on aromatic plants also showed similar results [43,44]. As indicated in these curves, there was no constant rate period in drying and almost all the drying process took place in falling rate period and was started from the initial moisture content (88.91 %, dry basis) to final moisture content (3.846 % dry basis). Similar results were obtained from the earlier studies on different vegetables [30,44-47].

3.2. Evaluation of the mathematical models

During drying, the moisture content data at the different time intervals were converted to a dimensionless parameter called as moisture ratio and then the variations of moisture ratio with drying time at drying temperatures of 70° C were fitted to the selected thin-layer drying models i.e. Page, Wang and Singh, and Exponential two terms, Logarithmic, Henderson & Pabis, Lewis as listed in Table 1. Also the criteria used to estimate goodness of the fits (R^2, RMSE and x^2) and the constants in models (a, b, n and k) are presented in these Table 2. Based on these criteria, the highest R^2 and the lowest RMSE and x^2, the best model was selected. From the Table 2, R^2, RMSE and x^2 values were varied between 0.9780–0.9938, 0.00001 – 0.1282 and 0.000835–0.0029, respectively. However, among the three mathematical drying models, the Page model resulted in the highest values of R^2 (0.9938) and the lowest values of x^2 ($8.35614*10^{-4}$) and RMSE (0.0000138).

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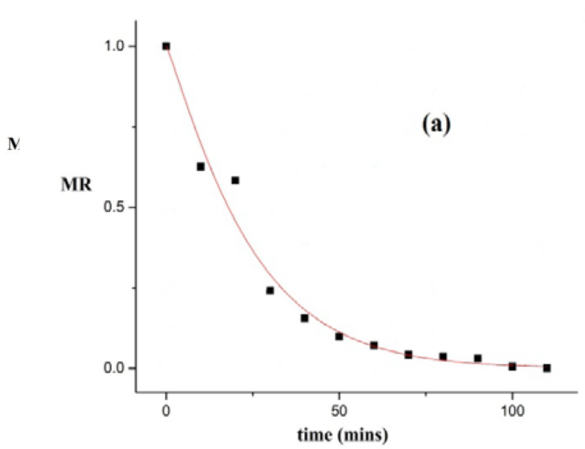
This indicated that the good fit of Page model compared to other models, as shown in Table 2. Page model is found to be good for fitting the drying curves, and as functions of the drying conditions, various model parameters were correlated [48]. Statistical analysis of experimental data showed that temperature was the main factor affecting drying rate.

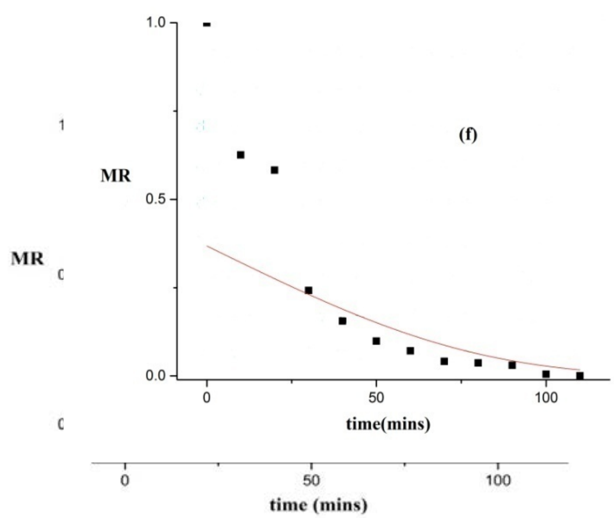
Table 2: Modeling of moisture ratio according to drying time for potato peels.

Model	Coefficients	R^2	x^2	RMSE
Page	k=0.0272 n=1.12159	0.97619	0.00246	0.01187 0.12783
Wang and Singh	a= -0.02578 b= 1.59318E-4	0.93768	0.00644	0.00143 1.61343E-5
Exponential two terms	a= 1.61659 k= 0.05182	0.97665	0.00241	0.23442 0.00736

Logarithmic	a= 1.02288 k=0.03933 c=-0.0191	0.97207	0.00289	0.05215 0.00506 0.0327
Henderson & Pabis	a=1.00985 k=0.04161	0.97381	0.00271	0.04689 0.00334
Lewis	k=1.01283	0.47534	0.05423	0.00788

To validate the developed model, the experimental data were plotted against the predicted values. The results showed smooth and good scatter of the data points around the fitted line. This confirms the goodness of the developed model to estimate the moisture content of potato peels in a tray drying. Figure 3 shows the observed





moisture ratio versus predicted moisture ratio.

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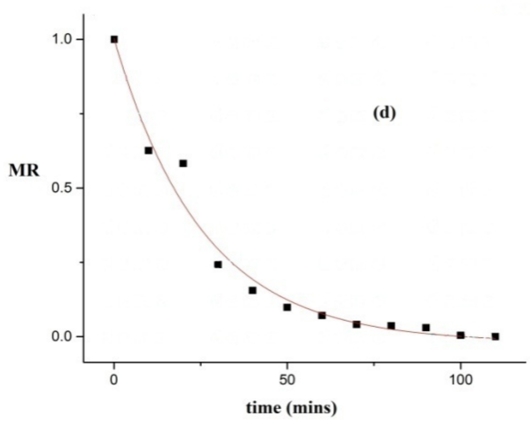
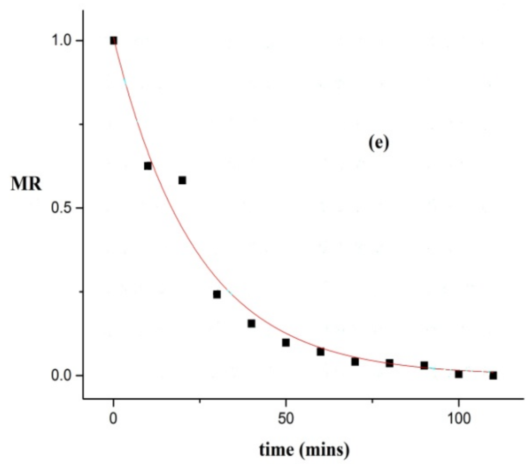


Fig.3. Comparison of experimental and calculated dimensionless moisture content of potato peels (a) Page model, (b) Wang & Singh Model, (c) Exponential two terms model, (d) Logarithmic model, (e) Henderson & Pabis model, (f) Lewis model



3.3 Variation of the water activity with drying

The use of water activity help in predicting the storage behavior of potato peels, which is beneficial to determine apart from moisture content, just to be more assure about the chances of the potato peels to gain or loss any moisture on exposure to ambient relative humidities [30,49].

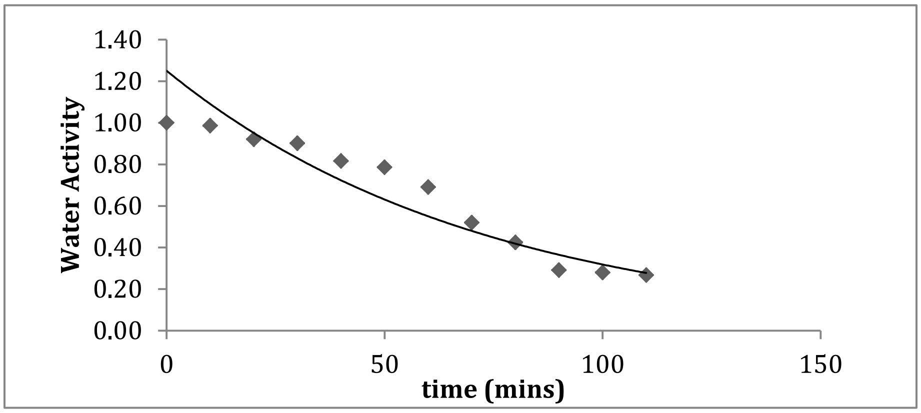


Fig.4 Water activity of potato peel

Drying considerably reduces the water activity of the material [47]. The graph was plotted between water activity v/s time and water activity v/s moisture content. The time was in minute and the water activity was determined at 25˚C (Figures 4).

4. CONCLUSIONS

In the present study, drying behavior of the potato peels was investigated under tray drying. Out of the six models fitted, Exponential two terms model shown the best outcomes as this resulted in a high correlation coefficient (R^2), and values of low chi-square (x^2) and root mean square error (RMSE), which was found to be adequate in describing the thin layer drying characteristics of potato peels in a tray drying.

Also, drying of potato peels offers numerous advantages. Not only it is a promising solution for food waste management but also the abundantly available inexpensive potato peels can serve as a pool house of nutrients and can be used in the developing countries to combat micronutrient deficiencies by incorporating potato peels powder to prepare various value added food products. However, preparation of such value added products and to ascertain their acceptability needs investigation [30].

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