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Mathematical modeling of seasoned onion slices by different drying methods

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Abstract
The main aim of the project is to study the Mathematical modeling of seasoned onion slices by different drying methods on moisture content, drying rate, and sensory attributes of seasoned onion slices. Seasoned onion (*Allium Cepa*) slices of uniform thickness were dried at three different temperatures (50 °C 60 °C and 70 °C) at constant air velocities in a dehydrator and two other dryers (microwave oven and hot air oven). Dried samples were evaluated for sensory attributes (*viz.* color, taste, and flavor) and quality attributes (*viz.* moisture content, drying rate). The samples were sealed in low-density polyethylene (LDPE) bags and stored and room temperature. The experimental drying kinetics data for seasoned onion slices were used to fit five thin layer drying models Henderson and Pabis, Page, Geometric model, Logarithmic model, and Modified Page model considering R^2, SSE, MSE, RMSE as statistical criteria in selecting the best model. The logarithmic model provided the best fit for the drying. It had the highest R^2 and lowest RMSE values. The maximum value of R^2 evaluated was 0.999. This indicates that the Logarithmic model is appropriate to describe the dehydration behavior for the seasoned onion slices.

Keywords: Onion, moisture loss, mathematical modeling, and dryers

1. Introduction
Onion (*Allium cepa* L.) is an important vegetable crop grown and consumed widely across the world. As a culinary ingredient, it adds to the taste and flavor in a wide range of food preparations and it is also used as a salad. Thus, there is a steady increase in the demand for onion across the world. China is the leading producer of onion constituting about 27% of the world's total production. India (22.03%) is the second-largest producer in the world with an area of 12.64 Lakh hectares and production of 206.01 Lakh tones (2014-15). The top ten countries including China and India, (mostly Asian countries) constitute more than 60% of the total world production. Yields of onion were higher in the case of Turkey (30.3 MT/ha) followed by Brazil (23.1 MT/ha) and China (22 MT/ha). Due to lower yields, though India has the highest area under onion, it stands second in the production of onion in the world. Hence, there is a lot of potential for increasing the production of the onion by improving the yields. Indians eat 15 million tons of onions a year (www.agritech2016.com).
The onion (*Allium cepa* L.) has widely been used even in ancient times as a food seasoning and also as natural medicine. In current times, the onion is an important vegetable that is served as an ingredient in dishes, as toppings on burgers, in seasonings, and as chip coatings.
Onions are a cool-season crop. The germination of onions is slow at 6 to 7 ºC, the optimum germination temperature range is 10 to 35 ºC, and the maximum temperature is 40 ºC. The onion crop is adapted to a growing season with air temperatures at 13 to 24 ºC. Low temperatures early in the season are desirable with higher temperatures after bulb formation. The onion is tolerant of frost but seedlings are generally only tolerant down to -1ºC. Some bunching onion cultivars overwinter in the milder areas of Atlantic Canada. Adequate soil moisture is required due to the relatively small root system.
Seasoning is about improving the flavor of your food mostly via the addition of salt and pepper. Although herbs, spices, sweet things, and acidic things can also be considered seasoning, we'll focus on salt and pepper for today.
Onion (Allium cepa) is an important vegetable crop grown and consumed widely across the

world. Onion is the seasonal crop. Onion storage is a wide problem in India because onion is routing starts when then the humidity is high and the temperature is low in the environment. Drying is the oldest method to the preservation of onion and increases the self-life of dried onion slices. The crisis of onion due to failed Monsoon and production is low then the price of onion is high in the market. Seasoning is about improving the flavor of your food mostly via the addition of salt and pepper. Onion is also used in soups, sauces, and for seasoning of foods.

2. Material and Methods

2.1 Materials

2.1.1 Onion fresh onions (*Allium cepa*)

It was procured in bulk from the local market of Allahabad and was used in the present study. To prepare the onions for the drying experiments. The onions were cut into slices of uniform thickness using a sharp stainless-steel slicer. The direction of the cut was perpendicular to the vertical axis of onion bulbs. A sample of approximately 100 g of onion slices of uniform diameter and uniform thickness were carefully set up as a single layer on the drying tray for use in the drying experiment.

2.1.2. Olive oil

Olive oil is a monounsaturated fat and the cornerstone of the famous Mediterranean diet. Most people choose olive oil because of its many proven benefits to human health. Olive oils offer even more a world of fruity bitter tastes that chefs are capturing to elevates dishes to a level they never thought possible. Olive oil was used for preparing the seasoning of the onion slices.

2.1.3 Salt and pepper

Black pepper is the fruit of the black pepper plant from the *Piperaceae* family and it is used as both a spice and a medicine. Black pepper is one of the most widely traded spices in the world. It is not considered a seasonal plant and is therefore available throughout the year. When dried, this plant-derived spice is referred to as a peppercorn and is then ground into a powder to be put on food to add flavor and spice.

Flow-chart for seasoned onion slices preparation

Selection of raw onion

↓

Cleaning

↓

Grading

↓

Peeling

↓

Washing

↓

Cutting (slicer)

↓

Seasoning (olive oil, salt, peper)

↓

Drying (microwave, tray dryer and hot air oven)

↓

Packaging

↓

Storage

Fig 1: Schematic flow chart of seasoning of onion slices

2.2 Mathematical modeling

The drying data was used to determine the drying ratio of the sample at various temperatures and pre-treatments which were then fitted into five semi-theoretical and empirical thin-layer drying models to determine the best model that would best describe the drying process. The moisture ratio was computed from the relationship below:

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad 2.1$$

Where,
MR = moisture ratio
M_i = initial moisture content
$M_{t\,=}$ moisture content at any time
M_e = equilibrium moisture content

The moisture ratio would be calculated as:

$$MR = \frac{M_t}{M_i} \quad 2.2$$

The drying rate of the samples was calculated according to (Chakraverty, 1981) as:

$$DR = \frac{W}{t \times \left(\frac{M_{bd}}{100}\right)} \quad 2.3$$

Where *DR* is the drying rate (g of water/min/100g b.d material), *W* is the amount of water removed (*g*), M_{bd} is the weight of bone-dry material (*g*) and t is the time (*min*).

The thin-layer drying models to be tested are modified page, Logarithmic, Geometric, Henderson & Pabis, and Page. A graph of moisture ratio will be plotted against the drying time, from which the drying constant (k,) along with the various other parameters of the above models will be determined.

Table 1: Thin layer drying mathematical models

S. No.	Model name	Model	References
1	Geometric	MR = at^n	Chandra and Singh (1995)
2	Logarithmic	MR = a exp (-kt) + C	Midilli & Yaper, (2002)
3	Page	MR = exp (-Kt^n)	Page, (1949)
4	Handerson & Pabis	MR = a exp (-kt)	Handerson & Pabis, (1961)
5	Modified Page	MR = exp (Kt)^n)	White *et al*. (1981)

2.3 Statistical analysis

Three statistical tools were used to examine the fitness of the above models to the drying data. The tools are Chi-square (x^2) or Mean Square Error (MSE), Coefficient of determination (R^2) (Taheri-Garavand, Rafiee, & Keyhani, 2011), Sum of Squares Error (SSE) and Root Mean Square Error (RMSE). The analysis was conducted using XLSTAT (2015 version) statistical software. XLSTAT is Microsoft Excel add-in software.

$$x^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-n} \quad 3.11$$

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(\overline{MR}_{pre} - MR_{esp,i}\right)^2}\right] \quad 3.12$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{N}} \quad 3.13$$

$$SSE = \left[\frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N}\right] \qquad 3.14$$

Where
$MR_{exp,i,}$= ith experimental moisture ratio
$MR_{pre,i,}$= ith predicted moisture ratio
N = number of observations
n = number of constants

3. Results and Discussion
3.1 Drying characteristics
The process temperatures chosen for the study were 50ºC, 60ºC & 70ºC. During the experiment, it was observed that the temperatures affected only the time of dehydration. As the temperature was increased the drying time was decreased. The relationship between moisture content, drying time was shown in fig 2 to fig 7. The moisture content decreased very rapidly during the initial stage of drying, as there was fast removal of moisture from the surface of the Product.

3.1.1 Effect of drying methods on the moisture content of seasoned onion slices during drying process at 50 °C
The initial moisture content of the seasoned onion slice sample was 593.98% (d.b.). The moisture loss was directly proportional to the temperature. The experiment was set up in different dryers *viz.* microwave oven, hot air oven, and dehydrator, the moisture content (10.67, 13.87, and 16.37%) of seasoned onion slices at 50 °C respectively.

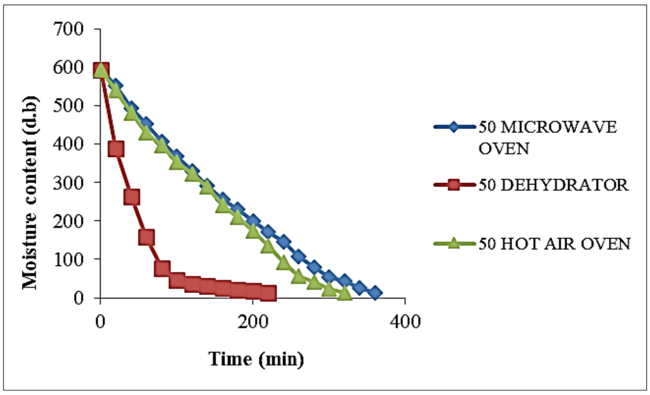

Fig 2: Effect of drying methods on the moisture content of seasoned onion slices during drying process at 50 °C

3.1.2 Effect of drying methods on the moisture content of seasoned onion slices during drying process at 60°C
The initial moisture content of the seasoned onion slice sample was 593.98% (d.b.). The moisture loss was directly proportional to the temperature. The experiment was set up in different dryers *viz.* microwave oven, hot air oven, and dehydrator, the moisture content (11.51, 14.67, and 13.37%) of seasoned onion slices at 60°C respectively.

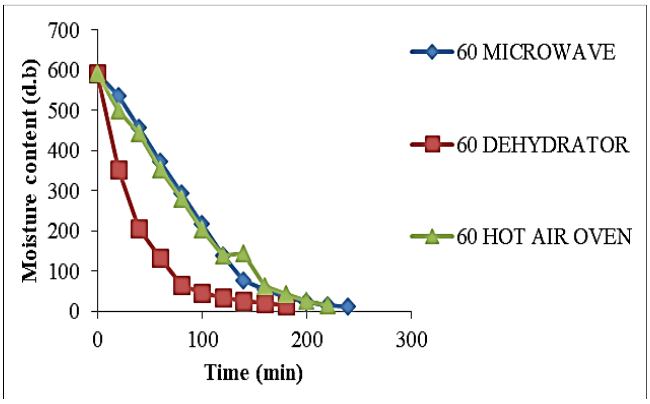

Fig 3: Effect of drying methods on the moisture content of seasoned onion slices during drying process at 60 °C

3.1.3 Effect of drying methods on the moisture content of seasoned onion slices during drying process at 70 °C
During drying at 70 °C air temperature, the initial moisture content of the seasoned onion slices was 593.48% (d.b.). The experiment was set up in different dryers *viz.* microwave oven, hot air oven, and dehydrator, the moisture content (12.55,13.18 and 13.94%) of seasoned onion slices at 70 °C respectively.

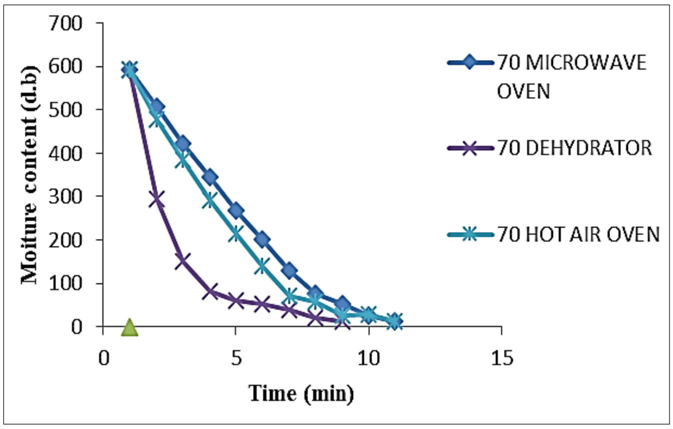

Fig 4: Effect of drying methods on the moisture content of seasoned onion slices during drying process at 50°C

3.2. Drying rate
The moisture content of onion slices was relatively higher during the initial phase of drying resulting in higher absorption of heat and led to increased product temperature and higher drying rate to higher moisture diffusion. As the drying of seasoned onion slices progressed, the loss of moisture in the product decreased the absorption of heat and resulted in a full drying rate during the latter part of the drying.

3.2.1 Effect of drying methods on drying rate of seasoned onion slices at 50 °C
The effect of drying rates of samples under the different dryer (microwave, hot air oven, and dehydrator) are indicating that the drying rate decreased with the increase in drying time and decreased moisture content. I observed 0.021, 0.028, and 0.101 g/min/g at an initial level of drying rate, and the final

level drying rate was found as 0.015,0.017 and 0.026 g/min/g respectively.

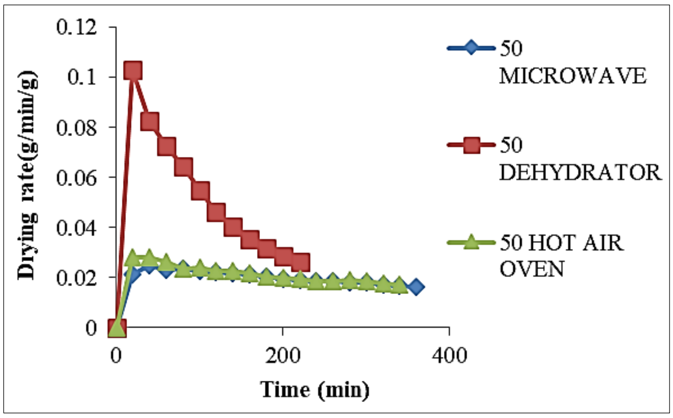

Fig 5: Effect of drying methods on drying rate of seasoned onion slices at 50°C

3.2.2 Effect of drying methods on drying rate of seasoned onion slices at 50°C

At 60°C, the seasoned onion slices were found 593.98% (d.b.), at the initial level moisture content. The effect of drying rates of samples under the different dryer (microwave, hot air oven, and dehydrator) are indicating that the drying rate decreased with the increase in drying time and decreased moisture content. I observed 0.028, 0.047, and 0.121 g/min/g at the initial level of drying rate, and the final level drying rate was found as 0.024, 0.026, and 0.032 g/min/g respectively.

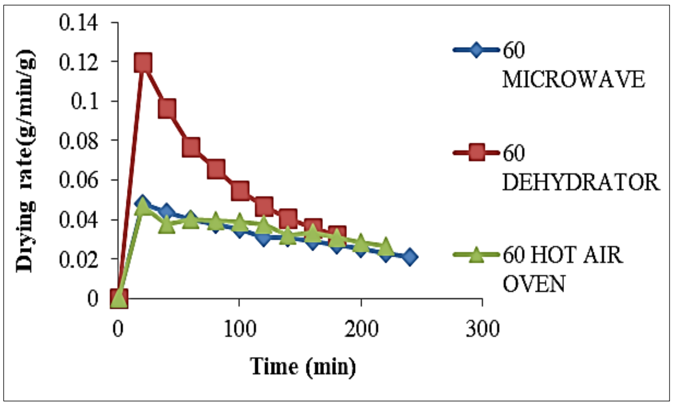

Fig 6: Effect of drying methods on drying rate of seasoned onion slices at 50°C

3.2.3 Effect of drying methods on drying rate of seasoned onion slices at 50 °C

The initial moisture content of the seasoned onion slices was 593.48 (d.b.) at 70°C drying air temperature. The effect of drying rates of samples under the different dryer (microwave, hot air oven, and dehydrator) are indicating that the drying rate decreased with the increase in drying time and decreased moisture content. I observed 0.040, 0.052, and 0.151 g/min/g at the initial level of drying rate, and the final level drying rate was found as 0.028, 0.029, and 0.036 g/min/g respectively.

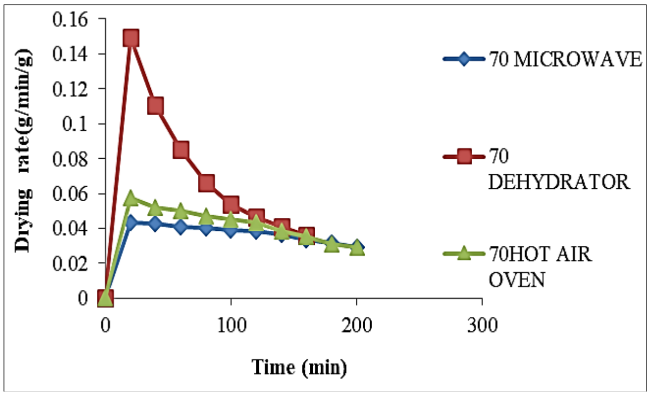

Fig 7: Effect of drying methods on drying rate of seasoned onion slices at 50°C

3.3 Sensory evaluation

Sensory attributes including color, aroma, taste, and overall acceptability are determined by hedonic rating tastes as recommended by Hedonic rating taste is used for evaluation of sensory characteristics. This test is used for acceptability by the consumer for the product. The color of sample B was more attractive than sample A, sample C, and sample D. The taste was almost the same. Flavor and overall acceptability were higher of sample B than others than sample A during the 0 days.

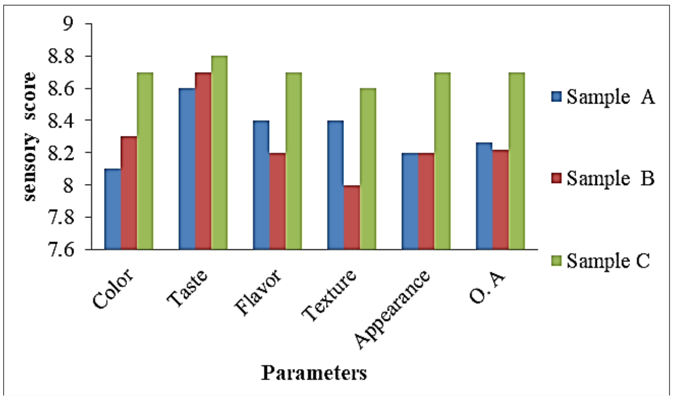

Fig 8: Sensory evaluation of seasoned onion slice

3.4 Fitting of drying models

Five thin layer drying models were selected to evaluate which one was the best fit for the different dehydration methods of seasoned onion slices. Hence, the experimental data obtained were fitted into these models, and correction parameters are presented in Tables 2 to 6.

Table 2: Correlation parameters for Henderson and Pabis model

Dryer	Temp.	Pr1	Pr2	R^2	SSE	MSE	RMSE
Dehydrator	50	0.115	-0.007	0.993	0.000	0.000	0.002
	60	0.139	-0.009	0.991	0.000	0.000	0.003
	70	0.181	-0.001	0.983	0.000	0.000	0.006
Microwave oven	50	0.025	-0.001	0.889	0.000	0.000	0.001
	60	0.065	-0.003	0.980	0.000	0.000	0.002
	70	0.047	-0.002	0.925	0.000	0.000	0.001
Hot air oven	50	0.028	-0.002	0.954	0.000	0.000	0.001
	60	0.047	-0.002	0.862	0.000	0.000	0.002
	70	0.062	-0.003	0.973	0.000	0.000	0.002

Table 3: Correlation parameters for the logarithmic model

Dryer	Temp.	Pr1	Pr2	R^2	SSE	MSE	RMSE
Dehydrator	50	0.115	-0.007	0.993	0.000	0.000	0.002
	60	0.139	-0.009	0.991	0.000	0.000	0.003
	70	0.181	-0.001	0.983	0.000	0.000	0.006
Microwave oven	50	0.025	-0.001	0.889	0.000	0.000	0.001
	60	0.065	-0.003	0.980	0.000	0.000	0.002
	70	0.047	-0.002	0.925	0.000	0.000	0.001
Hot air oven	50	0.028	-0.002	0.954	0.000	0.000	0.001
	60	0.047	-0.002	0.862	0.000	0.000	0.002
	70	0.062	-0.003	0.973	0.000	0.000	0.002

Table 4: Correlation parameters for page model

Dryer	Temp.	Pr1	Pr2	R2	SSE	MSE	RMSE
Dehydrator	50	0.485	-0.495	0.937	0.000	0.000	0.007
	60	0.630	-0.535	0.958	0.000	0.000	0.007
	70	1.025	-0.630	0.976	0.000	0.000	0.001
Microwave oven	50	0.035	-0.113	0.631	0.000	0.000	0.002
	60	0.045	-0.075	0.705	0.000	0.000	0.006
	70	0.070	-0.140	0.728	0.000	0.000	0.003
Hot air oven	50	0.052	-0.180	0.924	0.000	0.000	0.001
	60	0.083	-0.186	0.772	0.000	0.000	0.003
	70	0.126	-0.242	0.835	0.000	0.000	0.001

Table 5: Correlation parameters for geometric model

Dryer	Temp.	Pr1	Pr2	R2	SSE	MSE	RMSE
Dehydrator	50	1.265	-0.187	0.962	0.000	0.000	0.005
	60	1.094	-0.214	0.979	0.000	0.000	0.005
	70	0.839	-0.268	0.992	0.000	0.000	0.004
Microwave oven	50	3.364	-0.030	0.643	0.000	0.000	0.002
	60	2.094	-0.038	0.834	0.000	0.000	0.001
	70	2.692	-0.044	0.739	0.000	0.000	0.003
Hot air oven	50	3.022	-0.048	0.993	0.000	0.000	0.001
	60	2.567	-0.057	0.780	0.000	0.000	0.003
	70	2.195	-0.081	0.851	0.000	0.000	0.004

Table 6: Correlation parameters for modified page model

Dryer	Temp.	Pr1	Pr2	R2	SSE	MSE	RMSE
Dehydrator	50	0.485	-0.495	0.937	0.000	0.000	0.001
	60	0.630	-0.535	0.958	0.000	0.000	0.002
	70	0.839	-0.268	0.992	0.000	0.000	0.004
Microwave oven	50	0.047	-0.002	0.925	0.000	0.000	0.003
	60	3.364	-0.030	0.643	0.000	0.000	0.001
	70	0.135	-0.009	0.959	0.000	0.000	0.002
Hot air oven	50	0.028	-0.002	0.954	0.000	0.000	0.001
	60	0.304	-0.000	0.829	0.000	0.000	0.003
	70	2.195	-0.081	0.851	0.000	0.000	0.002

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