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# Mathematical modelling and drying kinetics of kinnow and sweet lime peels

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**Abstract**
Peel is one of the prominent by-product of citrus fruit industry. Peel, in general, is discarded as waste which can act as a potential source of phenolic compounds and nutraceutical. In this study, drying characteristics of kinnow and sweet lime peels as a function of drying method and temperature were investigated. The drying experiments were performed using polyhouse drying and cabinet drying (50 and 60 °C. Different drying models such as Page, Modified Page, Henderson and Pabis, Logarithmic were fitted to the drying data. The fitting of the models was compared using various statistical parameters such as correlation coefficient ($R^2$), chi square ($\chi^2$), mean bias error (MBE) and root mean square error (RMSE) to the suitability of the model. According to the regression analysis, Page model was found to be best fitted which satisfactorily describing the drying curves with a correlation coefficient ($R^2 \geq 0.99$) for all drying conditions.

**Keywords:** Kinnow peel, drying models, drying kinetics

## Introduction

India is the 5th largest producer of citrus fruits as a whole which includes the production of fruits such as grapefruit, lime, lemons, oranges, tangerines, etc. Kinnow comes in *'Mandarin'* group of citrus fruits and is grown extensively in Pakistan and India. The aggregate post-harvest loss from orchards to consumers associated with Kinnow ranged from 14.87 (in Delhi market) to 21.91% (in Bengaluru market) (Gangwar *et al*. 2007) [4]. Kinnow peel and pomace are the major by-products of the kinnow juice processing industry and account for about 55-60% of the fresh fruit weight (Kalra *et al*. 1989) [7], the peel recovery in particular is about 27% (Pruthi *et al*. 1984) [16]. Kinnow peel has been extensively used in many food processing operations as a potential source of antioxidants (Babbar *et al*. 2011) [2], pectin (Sharma *et al*. 2013) [19], preparation of ice cream (Mann *et al*. 2013) [14], candy (Aggarwal *et al*. 2014) [1], and extraction of phenolic compounds (Safdar *et al*. (2017) [17].

Sweet lime (*Citrus limettarisso*) is commonly known as "*Mosambi*" in Indian subcontinent. It is native to Asia and best cultivated in India, China, southern Japan, Vietnam, Malaysia, Indonesia, and Thailand. This fruit is eaten fresh or squeezed to make juice, a rich source of vitamin C and replenish energy (Mahendra and Shah 2014) [13]. Globally, a large amount of wet solid waste in the form of peels is produced due to its inadequate utilization. The peel if treated and utilized properly can be directed towards oil extraction (Virot *et al*. 2008, Sikdar *et al*. 2016) [20]. The incorporation of sweet lime powder for making apple jam is also reported (Singh and Verma 2016) [21]. Sweet lime peel is also a potential source of flavonoids, pectin and essential oil (Manthey and Grohmann 1996) [15]. Drying, an appropriate unit operation, is a pre-requisite for the above mentioned extraction process for both the fruit peels, i.e., kinnow and sweet lime.

The drying kinetics of food is a complex phenomenon and requires a suitable to predict drying behavior (Sharma *et al*. 2003) [18]. Scientist from divergent fields have reported the influence of different temperatures on the drying kinetics of many fruit peels, such as kachkal banana peel (Khawas *et al*. 2014) [9], banana peel (Kumar and Saxena 2016) [11], passion fruit peel (Do Nascimento *et al*. 2016) [3]. However, the published literature on the drying kinetics of kinnow and sweet lime peels is limited. Hence, an effort was made to investigate the drying behaviour of kinnow and sweet lime peels as well as to establish a suitable thin layer drying model.

## Materials and Methods

### Abbreviations

| | | | |
|---|---|---|---|
| M | Moisture content | $R^2$ | Correlation coefficient |
| $M_o$ | Initial moisture content | T | Drying time |
| $M_e$ | Equilibrium moisture content | w.b. | wet basis |
| $M_t$ | Moisture content at any time 't' | N | Number of observations |
| MR | Moisture ratio | AVG | Average |
| Z | Number of model constants | k, a, n | Drying model constants |
| h | Hour | rpm | Revolution per minute |
| m/s | Meter per second | °C | Degree Celsius |
| LDPE | Low density poly ethylene | μ | Micron |

### Raw material and sample preparation

Kinnow and sweet lime fruits were brought from the local market of Abohar (Punjab), India. The fruits were cleaned first by washing them with the tap water. The peel fraction from the fruit was removed using a sharp edge knife.

### Moisture content

Moisture content (initial and final) of both the peel samples was determined by drying them in hot air oven at 105 °C (±0.1 °C) to constant weights.

### Drying experiments

The peel samples were dried using two drying systems/methods i.e. Polyhouse drying (Polyhouse fabricated with 100 μm LDPE sheet, maximum attained temperature 63±4 °C) and cabinet drying (50 ºC and 60 ºC) in order to evaluate the drying characteristics. The drying conditions of cabinet drying are 50 °C with air flow rate of 975 rpm (2.0 m/s) and 60 °C with air flow rate of 1003 rpm (2.3 m/s). The range of drying temperature (50-60 °C) was selected as it was reported best with respect to higher retention of antioxidants from orange peels (Garau *et al*. 2007) [5].

### Moisture ratio determination

Moisture ratio (MR) for the samples was calculated using Eq (1) which involves the data of the moisture content at different intervals.

$$MR = \frac{(Mt - Me)}{(Mo - Me)} \quad (1)$$

### Mathematical modelling and statistical analysis

The thin layer drying models such as Page, Modified Page, Henderson and Pabis, Logarithmic (Table 1) were tested to select the most appropriate model for drying of the samples. Correlation coefficient ($R^2$) was one of the primary criteria for selection of the best model. Other statistical parameters such as chi square ($\chi^2$), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit. The model with higher $R^2$ value and lower $\chi^2$ values was considered to be good (Torghul and Pehlivan, 2002) [22]. The deciding statistical parameters can be calculated using Eqs. (2-4).

$$\chi^2 = \sum_{i=1}^{N} \frac{(\text{MR exp.i} - \text{MR pred.i})^2}{N - z} \quad (2)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MRexp.i - MRpre.i) \quad (3)$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(MRexp.i - MRpre.i)\hat{}2]\hat{}1/2 \quad (4)$$

The mathematical modelling, statistical analysis and the drying curves were drawn using Microsoft excel 2010.

**Table 1:** Mathematical models applied to the moisture ratio values

| Model | Equation | Reference |
|---|---|---|
| Logarithmic | MR = a exp(-kt) + c | Yaldiz and Ertekin (2001) |
| Henderson and Pabis | MR= a exp(-kt) | Henderson and Pabis (1961) [6] |
| Page | MR= exp(-$kt^n$) | Kar and Gupta(2003) [8] |
| Modified page | MR=exp(-$(kt)^n$) | White *et al*.(1981) [23] |

### Drying curves

The curve between the moisture ratio and drying time was drawn for kinnow as well as sweet lime peel drying. The drying curves were plotted for different methods of drying i.e. poly house drying and tray drying.

## Results and Discussion

### Experimental drying kinetics

The kinnow peel samples were used for the experiments had an average initial moisture content of 76.79 ± 1.43% (w.b.), and the final moisture content was observed to be 3.43 ± 0.97% (w.b). Furthermore, the initial and final moisture content of sweet lime peel were 74.20 ± 1.72 and 4.97± 0.28 % (w.b), respectively.

### Effect of temperature and drying method

In the case of poly house drying, the drying time required to dry kinnow peel to desired moisture content was 12 ± 1.5 h; whereas, 14.5 ± 1.0 h was required for the sweet lime sample. However, in tray dryer, the kinnow peel sample took 7.5 ± 0.4 h (50 °C) and 6 ± 0.2 h (60 °C), separately. On the contrary, the drying time for sweet lime peels in tray drying system was higher, i.e., 9± 0.6 h (50 °C) and 7± 0.3 h (60 °C), independently. An increase in drying temperature brought a decrease in drying time for both the fruit peels. This decrease in the drying time may be due to continual increase in water vapour pressure within the peel samples which further increased the migration of moisture (Kingsly *et al*. 2007) [10]. In both the cases, higher drying temperature promoted the shorter drying time; whereas, longer drying period- was required at lower drying temperature (Barajas *et al*. 2012). The drying rate decreased continuously throughout the drying period. The constant rate period was not observed for all the experimental conditions and the overall drying took place in falling rate period. The drying curves for Kinnow and Sweet lime are shown in Figure 1 and Figure 2, respectively. The uncontrolled drying conditions during polyhouse drying resulted in the higher drying time.

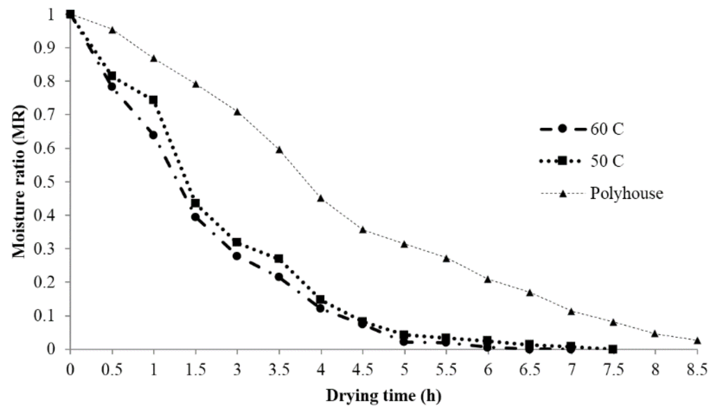


**Fig 1:** Moisture ratio versus drying time of kinnow peel at different drying conditions (50 and 60° C in tray dryer and polyhouse dryer)

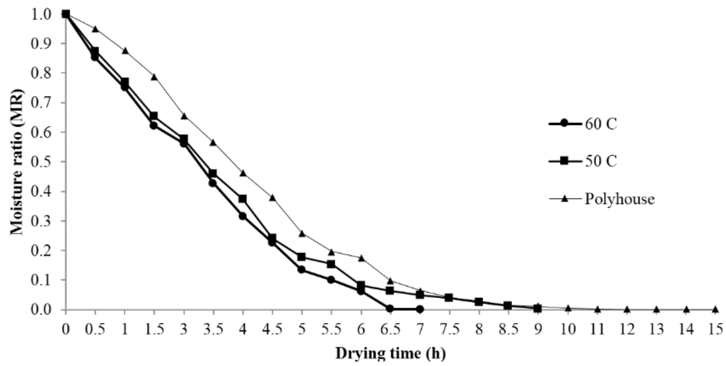


**Fig 2:** Moisture ratio versus drying time of sweet lime peel at different drying conditions (50 and 60 °C in tray dryer and polyhouse dryer)

## Mathematical modelling of drying curves

The intermittent moisture levels were calculated using the difference in weight observed and converted to MR values using Eq. (1). These MR values ofdifferent drying conditions were fitted in all the four models and the respective data is represented in Table 2 (kinnow) and Table 3 (sweet lime). In all the cases, the value of $R^2$ was greater than 0.90 indicating a good fit (Madamba *et al*. 1996) [12] Experimental results showed that the highest $R^2$ value and lowest $\chi^2$ value was obtained in the case of Page drying model for both the peel samples. It can be concluded that Page model accurately represents the drying behaviour of kinnow and sweet lime peel.

**Table 2:** Statistical results showing the fitness of different models at selected drying conditions in kinnow peel

| Drying method | Model | Model constants | $R^2$ | $\chi^2(10^{-4})$ | MBE | RMSE |
|---|---|---|---|---|---|---|
| Poly house | Henderson and Pabis | a=1.11, k=0.28 | 0.989 | 1.61 | 0.0025 | 0.050 |
| | **Page** | **k= 0.112, n=1.605** | **0.998** | **0.05** | **0.0004** | **0.021** |
| | Modified Page | k=0.502, n=0.502 | 0.988 | 3.26 | 0.0035 | 0.060 |
| | Logarithmic | a=1.11, k=0.278, c=-0.007 | 0.989 | 1.66 | 0.0025 | 0.049 |
| Tray (50 ºC) | Henderson and Pabis | a=1.036, k=0.486 | 0.987 | 1.51 | 0.0031 | 0.056 |
| | **Page** | **k=0.400, n=1.157** | **0.988** | **1.10** | **0.0027** | **0.052** |
| | Modified Page | k=0.686, n=0.686 | 0.987 | 1.67 | 0.0033 | 0.058 |
| | Logarithmic | a=1.107, k=0.370, c= -0.103 | 0.989 | 0.86 | 0.0023 | 0.048 |
| Tray (60 ºC) | Henderson and Pabis | a=1.061, k=0.492 | 0.986 | 1.80 | 0.0038 | 0.062 |
| | **Page** | **k=0.257, n=1.703** | **0.998** | **0.17** | **0.0003** | **0.019** |
| | Modified Page | k=0.684, n=0.684 | 0.986 | 2.26 | 0.004 | 0.065 |
| | Logarithmic | a=1.09, k=0.454, c= -0.0307 | 0.986 | 1.61 | 0.003 | 0.058 |

**Table 3:** Statistical results showing the fitness of different models at selected drying conditions in sweet lime peel

| Drying method | Model | Model constants | $R^2$ | $\chi^2(10^{-4})$ | MBE | RMSE |
|---|---|---|---|---|---|---|
| Poly house | Henderson and Pabis | a=1.109, k=0.331 | 0.988 | 2.03 | 0.0030 | 0.0549 |
| | **Page** | **k=0.1430, n=1.6123** | **0.997** | **0.14** | **0.0008** | **0.0284** |
| | Modified Page | k=0.5018, n=0.5018 | 0.986 | 3.95 | 0.0042 | 0.0649 |
| | Logarithmic | a= 1.1088, k=0.3309, c= 0 | 0.987 | 2.15 | 0.0030 | 0.0549 |
| Tray (50 ºC) | Henderson and Pabis | a=0.9926, k=0.2251 | 0.992 | 0.97 | 0.0026 | 0.1767 |
| | **Page** | **k=0.2898, n=0.7772** | **0.990** | **0.73** | **0.0023** | **0.0474** |
| | Modified Page | k=0.477, n=0.477 | 0.992 | 0.98 | 0.0026 | 0.0511 |
| | Logarithmic | a=0.9602, k=0.2468, c=0.0403 | 0.992 | 0.47 | 0.0017 | 0.0414 |
| Tray (60 ºC) | Henderson and Pabis | a=1.1135, k=0.3174 | 0.979 | 4.52 | 0.0060 | 0.0776 |
| | **Page** | **k=0.1034, n=1.7522** | **0.997** | **0.09** | **0.0009** | **0.0294** |
| | Modified Page | k=0.5369, n=0.5369 | 0.980 | 7.78 | 0.0079 | 0.0889 |
| | Logarithmic | a=1.1529, k=0.2914, c= -0.0384 | 0.980 | 4.30 | 0.0055 | 0.0741 |

**Conclusion**

Effect of drying temperature and drying methods on drying time of kinnow peel were investigated. Drying time in polyhouse drying methods was comparatively higher compared to tray drying system. Further, an increase in temperature resulted in the reduction of drying time. It was also found that overall drying occurred in falling rate period. Overall, the results of model fitting suggested that the page model was best fitted to describe the drying characteristics of kinnow and sweet lime peels in the selected drying conditions.

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