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Review Article

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# Investigating the Influence of Drying Temperature and Tray Loads on Kinetics, Moisture Diffusivity, Retention of Bioactive Compounds, and Color Characteristics of Baby Corn

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## Abstract

The drying kinetics of long-graded baby corn was investigated using a tray dryer at 50-70 °C with a tray load of 0.30-0.45 g/cm$^2$. The sample was given pretreatment of microwave blanching to inactivate the peroxidase enzyme. Drying data was fitted in three thin layer drying models viz. Page, Lewis, and Henerson-Pabis. The goodness of models was evaluated based on coefficient of determination ($R^2$), root mean square error (RMSE), and chi-square ($\chi^2$). Page model was found to be the best-fit model. The effective moisture diffusivity for baby corn pieces at different temperatures (50, 60, and 70 °C) with varying tray loads (0.45, 0.40, 0.35, and 0.30 g/cm$^2$) ranged from $2.40\times10^{-11}$ to $7.11\times10^{-12}$ (m$^2$/s); $4.06\times10^{-12}$ to $9.94\times10^{-12}$ (m$^2$/s); $2.94\times10^{-12}$ to $6.80\times10^{-12}$ (m$^2$/s); $3.65\times10^{-12}$ to $8.01\times10^{-12}$ (m$^2$/s), respectively. The activation energy was found in the range of 57416.48 to 36499.29 (J/mol) for tray load 0.45 g/cm$^2$-0.30 g/cm$^2$ respectively. The effect of different temperatures (50 °C - 70 °C) at tray load 0.3 g/cm$^2$ was studied on various heat-labile components of baby corn and color characteristics. A significant reduction in ascorbic acid at $p \leq 0.05$ was found during microwave blanching (21.05 ± 0.15 mg/100 g to 15 ± 0.06 mg/100 g). The effect of drying at different temperatures showed that higher temperatures short time resulted in better retention of ascorbic acid (15.02 ± 0.02 mg/100 g) and total phenolic content (49.02 ± 0.03 mg GAE/100 g). The antioxidant activity in terms of DPPH (% radical scavenging activity) and FRAP was found to be 38.00 ± 0.01% and 124.63 ± 0.01 µg/ml. A significant change in the color values was observed which might be due to the thermal degradation of pigments or nonenzymatic browning reactions.

## Keywords

Microwave blanching, Drying kinetics, Moisture diffusivity, Bioactive compounds, Color value

## Introduction

Baby corn (*Zea mays* L.) is a type of maize with characteristic traits and harvested as young immature unfertilized, tender cobs having 2-3 cm silks on the ear. The cobs 6-11 cm in length and 1-1.5 cm in diameter with regular row arrangement are ideal for consumption in different forms [1]. Baby corn is harvested-1-3 days after silk emergence and when the length of silk is about 0.5-1.0 cm prior to fertilization. A single-day delay in harvesting degrades the quality and taste of the baby corn making harvesting a crucial step [2]. It is the only vegetable considered to be free from pesticide residues and its nutritional value is also comparable to many high-value vegetables. Due to its sweet and succulent taste, it can be consumed raw or cooked in the form of salad, soup, pickles, and other savory and sweet dishes [3]. Baby corn is a perishable crop with a high respiration rate which makes it difficult to store it for a longer duration under ambient conditions and cannot be stored or transported to distant places without special treatments [4].

Drying is one of the economical methods for extending the shelf life of perishable agricultural produce along with other acceptable preservation techniques such as canning and freezing which are more costly and require specific packaging or storage requirements [5]. Baby corn is normally graded into different sizes for application purposes. While short and medium baby corn are meant for direct consumption the long-sized cobs find applications in canning or freezing as whole or cut vegetables [6]. One of the major postharvest problems with baby corn is the development of brown pigment at the tip of the immature ovules, cut surfaces, and silk attached to the young ears [7]. Browning is a common phenomenon in many fruits and vegetables and the underlying mechanisms for the same are either enzymatic or non-enzymatic [8]. Cut surface browning of baby corn is the main factor affecting the acceptability of the consumer. The development of brown color is mainly due to the action of polyphenol oxidase enzyme on the phenolic compounds released from plant tissues [9]. The nutritional and sensory characteristics are also affected by the action of enzymes. Blanching is commonly used as pre-treatment in the drying process for enzyme inactivation with additional benefits like surface cleaning, color, and vitamin retention [10]. Different physical methods of blanching are used to inactivate the indicator enzyme by reducing the activity to 90% [11]. Microwave blanching is gaining popularity over hot water and steam blanching owing to lesser changes in food and overall improvement in sensory attributes [12].

Thin-layer drying is an effective method as it considers drying in a single layer of the sample resulting in rapid drying rates and slow nutrient loss. Different empirical models are being used to describe the process and predict drying behavior. These models consider a direct relation between moisture content and drying time considering the drying fundamentals. These models can help in the automation of processes for economic operations and faster calculations [13]. Several research papers on thin-layer drying and mathematical modelling are available but thin-layer drying of baby corn is not reported so far. Therefore, the study was conducted to perform mathematical modelling of the drying of microwave-blanched baby corn and evaluate the effect of the drying process on various characteristics.

# Materials and Methods

## Blanching

Baby corn of variety Syngenta G5417 was procured from Field Fresh Foods Pvt Ltd., Ladhowal, Ludhiana, India. Before blanching the cobs were dehusked and cleaned manually. As the cobs were harvested at different time intervals so they were categorized as short, medium, and long based on length and diameter. Different grades of cobs were analyzed for physicochemical parameters using standard procedures [6]. Microwave blanching treatment was conducted to inactivate the peroxidase enzyme which is the marker enzyme for blanching. The sample was cut into round pieces with a diameter of 15 ± 0.02 mm and thickness of 0.1-0.2 cm and were microwave blanched (540W for 30 sec) followed by dipping in cold water.

## Drying

The blanched samples 100 ± 1 g per trial were kept on the trays with different tray loads (0.45, 0.40, 0.35 and 0.30 g/cm$^2$) in a tray drier (Labfit India Pvt Ltd., Ahmedabad) and were allowed to dry at different temperatures (50, 60, and 70 °C) till equilibrium was achieved. The sample weight was noted every 15 min for a period of 2 h and later after 30 min till constant weight was achieved. The moisture content on dry basis was determined using the following formula:

$$\%\text{Moisutre Content} = \frac{\text{initial mass of the sample} - \text{mass of dried sample}}{\text{mass of dried sample}} \quad (1)$$

## Mathematical modelling

The convection drying of most of the agricultural produce occurs mainly in the falling rate period. So, already established thin layer drying models can be fitted to moisture ratio (MR) with respect to time. The mathematical models used in the study are given in the table 1.

**Table 1:** Thin layer drying models.

| S. No. | Model name | Model equation |
|---|---|---|
| 1 | Page Model | $MR = \exp(-kt^n)$ |
| 2 | Lewis Model | $MR = \exp(-kt)$ |
| 3 | Henderson and Pabis | $MR = a\exp(-kt)$ |

**Note**: MR: Moisture ratio; k, and n are the model parameters; t: Drying time (min).

## Effective diffusivity

The effective diffusivity was estimated using Fick's second law of diffusion. A plot between the natural logarithmic of MR with time (t) was plotted using the following equation:

$$\ln(MR) = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4L_0^2} \quad (2)$$

Where $D_{eff}$ indicates effective diffusivity (m$^2$/s) and $L_0$ is half of the drying thickness (m)

## Activation energy

Arrhenius equation was used to calculate the activation energy. A plot between the natural logarithm of effective diffusivity ($D_{eff}$) against the reciprocal of absolute temperature (1/T) was used to get the activation energy value as per the following equation.

$$D_{eff} = D_0 \exp\left(-\frac{E_a}{RT}\right) \quad (3)$$

Where $E_a$, $D_0$, R and T represents activation energy (KJ/mol), Arrhenius equation factor (m$^2$/s), gas constant (KJ/mol K), temperature (K), respectively.

## Estimation of physicochemical properties

Random samples (n=10) were taken and the yield (cob, silk, and stalk), length, diameter, and density were determined prior to blanching. Moisture, ash, protein, fat, fiber, carbohydrates, TSS, titratable acidity, and ascorbic acid were analyzed according to the standard methods of analysis [14].

### Determination of color values

The color values were recorded by colorimeter (Accuracy Micro sensors, Inc. Pittsford, New York) for fresh, blanched, and dried samples to observe the effect of drying on the color of treated samples. Changes in color were quantified in the $L^*$, $a^*$, $b^*$ color system, L refers to the lightness and the two chromatic components: The $a^*$ component from green (-a) to red (+a) and the $b^*$ component from blue (-b) to yellow (+b) color. The $L^*$, $a^*$, $b^*$ values were used to determine the total color difference by using equation 4.

$$\textit{Total color difference}, \Delta E = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2} \quad (4)$$

$L_0^*$, $a_0^*$ and $b_0^*$ represent the initial color values of $L^*$, $a^*$ and $b^*$ respectively.

### Determination of total phenol and flavonoid content

Total flavonoid and total phenol content were determined by the method followed by Limmatvapirat et al. [15] with slight modifications.

### Determination of free radical scavenging activity (DPPH)

The antioxidant activity in terms of % inhibition was determined using the method of Kaur et al. [16]. DPPH (2, 2-diphenyl-1-picrylhydrazyl - 90 μmol/L) ethanolic solution was used in the assay. 0.1 ml of extract was pipetted out and put in a test tube followed by the addition of 1.0 ml of DPPH solution, diluted with 2.9 ml of ethanol. The test tube was shaken and left to stand for 60 min in the dark. The absorbance was measured at 517 nm (UV/Vis Spectrophotometer, Shimadzu Corporation, Japan) against the blank.

The following equation was used to determine the antioxidant activity:

$$\% \textit{Antioxidant activity} = \frac{A_0 - A}{A_0} \quad (5)$$

Where, $A_0$= Absorbance of DPPH as blank, A = Absorbance of sample.

### Rehydration analysis

The tray-dried samples were rehydrated at different temperatures with water to baby corn ratio (1:6). After every 5 min interval the weight of the sample was taken till the end of rehydration [17].

### Statistical analysis

All analytical determinations were performed in triplicate. The data obtained for various treatments was recorded and statistically analyzed for one-way or two-way ANOVA by Duncan's multiple range test ($p \leq 0.05$).

## Results and Discussion

### Raw material analysis based on the classification:

The procured raw material was classified based on length as short (4-7 cm), medium (7-11 cm), and long (11-13 cm) and analyzed for physicochemical properties the results of which are depicted in table 2. The results (Table 2) revealed that there was a significant difference at $p \leq 0.05$ in yield (total, silk, cob, and stalk), diameter, length, and density of different grades of baby corn which might be due to the fact that the physical parameters of baby corn get affected by the maturity stage [6]. The increase in true density with maturity might be because of the ongoing changes of the cellular matrix as reported for beans [18].

**Table 2:** Physicochemical parameters of fresh baby corn on the basis of grading.

| Parameters | Short | Medium | Long |
|---|---|---|---|
| Total yield (g) | 35.53 ± 5.00$^a$ | 78.19 ± 5.89$^b$ | 133.43 ± 6.32$^c$ |
| Silk yield (g) | 13.29 ± 2.35$^a$ | 21.07 ± 1.10$^b$ | 23.76 ± 3.24$^b$ |
| Stalk yield (g) | 16.77 ± 2.28$^a$ | 44.19 ± 8.50$^b$ | 80.99 ± 9.17$^c$ |
| Cob yield (g) | 5.35 ± 2.22$^a$ | 12.89 ± 3.26$^b$ | 28.61 ± 7.43$^c$ |
| Length (mm) | 68.61 ± 3.05$^a$ | 102.52 ± 4.24$^b$ | 133.34 ± 7.23$^c$ |
| Diameter (mm) | 11.20 ± 1.67$^a$ | 15.23 ± 1.21$^b$ | 17.63 ± 0.82$^c$ |
| Density (g/cc) | 0.83 ± 0.34$^a$ | 0.96 ± 0.17$^b$ | 1.03 ± 0.23$^c$ |
| Moisture (%) | 87.8 ± 0.35$^a$ | 86.3 ± 0.58$^a$ | 86.2 ± 2.27$^a$ |
| Ash (%) | 0.47 ± 0.31$^a$ | 0.40 ± 0.40$^a$ | 0.40 ± 0.30$^a$ |
| Protein (%) | 2.96 ± 1.57$^a$ | 3.5 ± 1.88$^b$ | 3.54 ± 1.90$^b$ |
| Fat (%) | 0.92 ± 0.50$^a$ | 0.94 ± 0.29$^a$ | 0.94 ± 0.29$^a$ |
| Fiber (%) | 3.58 ± 0.58$^a$ | 3.72 ± 0.51$^a$ | 3.72 ± 0.63$^a$ |
| Carbohydrates (%) | 4.27 ± 0.66$^a$ | 5.13 ± 0.74$^b$ | 5.20 ± 0.78$^b$ |
| pH | 5.35 ± 0.04$^b$ | 5.21 ± 0.01$^a$ | 5.21 ± 0.03$^a$ |
| TSS (°Brix) | 8.5 ± 0.06$^a$ | 11.33 ± 0.58$^b$ | 11.5 ± 0.50$^b$ |
| Titratable acidity (%) | 0.4 ± 0.05$^a$ | 0.4 ± 0.03$^a$ | 0.40 ± 0.04$^a$ |
| Ascorbic acid (mg/100g) | 21 ± 1.20$^a$ | 18 ± 2.05$^a$ | 15 ± 2.25$^a$ |
| Total flavonoid content (mg QE/100 g) | 2.25 ± 0.04$^a$ | 2.26 ± 0.03$^a$ | 2.37 ± 0.01$^b$ |
| Total phenol content (mg GAE/100 g) | 45.40 ± 0.20$^a$ | 47.33 ± 0.49$^b$ | 49.02 ± 0.01$^c$ |
| DPPH (%) | 36.94 ± 0.28$^a$ | 36.99 ± 0.18$^a$ | 37.90 ± 0.12$^b$ |
| FRAP (μg/ml) | 114.18 ± 5.29$^a$ | 116.40 ± 3.27$^a$ | 123.93 ± 1.14$^b$ |

**Note**: Values are expressed as Mean ± SD (n =3) ($p<0.05$); a-c within row with different letters are significantly different at 5% level of significance.

Moreover, it is observed from the analysis based on the grading (short, medium, and long) that with the increase in the length and diameter, there is no significant difference in moisture (87.8-86.2%), ash (0.47-0.40%) pH (5.35-5.21), titratable acidity (0.40-0.40%) and fibre content (3.58-3.72%). However, ascorbic acid content is observed to be decreased with increased maturity ranging from 21-15 mg/100 g. Also, TSS of the short, medium, and long categories changed significantly from 8.5 ± 0.06, 11.33 ± 0.58 and 11.5 ± 0.5°Bx which is probably due to starch hydrolysis to sugar with the advance in maturity [19]. Furthermore, it was clear from the results obtained from the DPPH, FRAP, flavonoids, and total phenol content that long graded have a significant amount of phenolic and flavonoid content and antioxidant activity. However, DPPH of short, medium, and long-graded cobs have weaker activity (36.99, 37.11, and 37.36%, respectively) than other vegetables like carrot (69.04%), cabbage (58.05%), red chilli (78.66%), and green chilli (52.4%) [20].

In addition, a significant difference was observed in FRAP, flavonoid, and total phenol content for short medium, and long-graded corns which were ranging from 114.18 to 123.93 (µg/ml), 2.25 to 2.37 (mg QE/100 g), and 45.4 to 49.02 (mg GAE/100 g), respectively. Several authors have documented that, the polyphenolic content of fruits and vegetables is highly dependent upon their maturing stage. Also, Fuentes et al. [21] estimated the FRAP, DPPH, and total phenolic content of green and red tomatoes. In their study, they observed that the total phenolic content of red tomatoes 33.3 mg GAE/100 g was higher than green tomatoes 27.6 mg GAE/100 g.

## Drying characteristics

Keeping that in view less utilization of long-graded baby corn for edible purposes the present study focused on the value addition of long-graded cobs by blanching pre-treatment followed by drying to attain the maximum benefit of this high-value vegetable. The microwave-blanched (540W for 30 secs) baby corn roundels were tray dried at different temperatures (50, 60 and 70 °C) at different tray loads (0.45, 0.40, 0.35, 0.30 g/cm²) (Table 3). The initial moisture content of microwave-blanched baby corn roundels was found to be 532.91% on dry basis (db). The moisture content was reduced to 4-7% db. From figure 1 plotted against moisture content (%db) and time (h), at different tray loads for different temperatures, it can be observed that the moisture content of the baby corn pieces decreased continuously with the increase in drying time demonstrating that the drying took place in falling rate period in all the treatments. Similar results have been observed for black carrot [22] and watermelon [23] respectively. Also, the drying time decreases with every 10 °C increase in temperature and decrease in tray load. The tray load is directly proportional to the drying time [24]. The dehydration characteristics are greatly influenced by tray load, henceforth, the time taken for drying was found to be more at tray loads 0.45 g/cm² than at 0.30 g/cm².

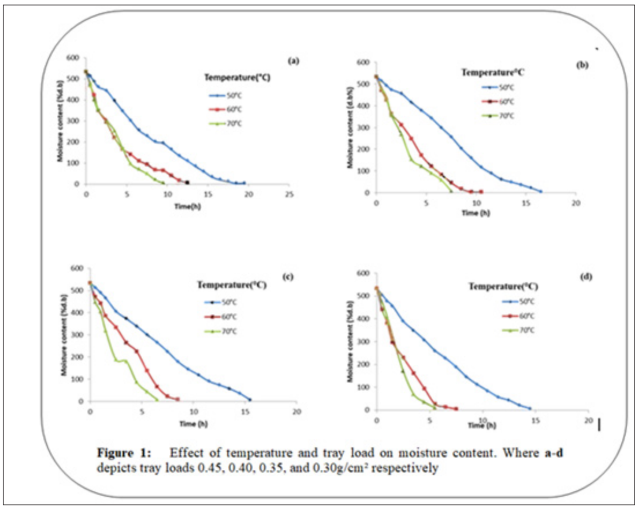

**Figure 1:** Effect of temperature and tray load on moisture content. Where a-d depicts tray loads 0.45, 0.40, 0.35, and 0.30 g/cm² respectively.

The increased drying rate at higher drying temperatures and less tray load led to higher moisture removal at the food and air interface. The increased moisture evaporation rate results in increased moisture diffusion from the internal region of baby corn pieces to the surface, increasing the diffusion coefficients. A similar trend has been reported in various investigations done on different fruits and vegetables as reported by Igbozulike et al. [25] and Jabeen et al. [26]. The values of drying rate constants obtained from different models have been shown in table 3.

## Evaluation of the drying models

The experimental data of moisture content recorded during drying experiments were represented in terms of MR and fitted in the three drying models mentioned in table 1. The higher values of coefficient of determination ($R^2$) and lower values RMSE and chi square ($\chi^2$) were considered as the criteria for the best fitted model. Based on the statistical re-

**Table 3:** Empirical constants of Page, Lewis and Handerson-Pabis models.

| Tray load (g/cm²) | Temperature (°C) | Page model | | | Lewis model | | Henderson-Pabis model | | |
|---|---|---|---|---|---|---|---|---|---|
| | | k | n | $R^2$ | k | $R^2$ | k | a | $R^2$ |
| 0.45 | 50 | 0.068 | 1.376 | 0.91 | 0.314 | 0.531 | 0.314 | 2.7 | 0.53 |
| | 60 | 0.253 | 1.011 | 0.99 | 0.394 | 0.95 | 0.279 | 1.086 | 0.95 |
| | 70 | 0.229 | 1.301 | 0.88 | 0.51 | 0.95 | 0.376 | 1.238 | 0.94 |
| 0.4 | 50 | 0.06 | 1.414 | 0.92 | 0.261 | 0.92 | 0.203 | 1.461 | 0.92 |
| | 60 | 0.218 | 1.31 | 0.88 | 0.506 | 0.92 | 0.38 | 1.298 | 0.92 |
| | 70 | 0.219 | 1.461 | 0.91 | 0.566 | 0.99 | 0.366 | 1.105 | 0.99 |
| 0.35 | 50 | 0.081 | 1.253 | 0.99 | 0.259 | 0.95 | 0.181 | 1.258 | 0.95 |
| | 60 | 0.208 | 1.166 | 0.94 | 0.528 | 0.85 | 0.397 | 1.375 | 0.85 |
| | 70 | 0.326 | 1.381 | 0.87 | 0.69 | 0.96 | 0.46 | 1.132 | 0.95 |
| 0.3 | 50 | 0.103 | 1.232 | 0.98 | 0.305 | 0.91 | 0.229 | 1.35 | 0.92 |
| | 60 | 0.363 | 1.161 | 0.97 | 0.748 | 0.92 | 0.597 | 1.378 | 0.92 |
| | 70 | 0.301 | 1.739 | 0.95 | 0.919 | 0.96 | 0.693 | 1.341 | 0.97 |

**Note**: $R^2$ =regression coefficient, k=drying rate constant, n=drying constant for Page model and a=drying constant for Henderson-Pabis model.

**Table 4:** Statistical results obtained using different models of thin-layer drying of baby corn.

| Tray load (g/cm²) | Temperature (°C) | Page model | | | Lewis model | | | Henderson-Pabis model | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | RMSE | $\chi^2$ | RSS | RMSE | $\chi^2$ | RSS | RMSE | $\chi^2$ | RSS |
| 0.45 | 50 | 0.071 | 0.005 | 0.095 | 0.263 | 0.06 | 1.318 | 0.587 | 0.33 | 6.94 |
| | 60 | 0.019 | 0.0004 | 0.006 | 0.105 | 0.012 | 0.165 | 0.038 | 0.001 | 0.022 |
| | 70 | 0.069 | 0.005 | 0.057 | 0.16 | 0.028 | 0.307 | 0.101 | 0.01 | 0.123 |
| 0.4 | 50 | 0.063 | 0.004 | 0.074 | 0.236 | 0.058 | 0.106 | 0.172 | 0.03 | 0.566 |
| | 60 | 0.068 | 0.005 | 0.114 | 0.175 | 0.032 | 0.114 | 0.119 | 0.015 | 0.144 |
| | 70 | 0.047 | 0.002 | 0.1 | 0.161 | 0.028 | 0.1 | 0.048 | 0.002 | 0.1 |
| 0.35 | 50 | 0.035 | 0.001 | 0.022 | 0.197 | 0.041 | 0.703 | 0.077 | 0.006 | 0.107 |
| | 60 | 0.062 | 0.004 | 0.043 | 0.218 | 0.052 | 0.522 | 0.117 | 0.015 | 0.151 |
| | 70 | 0.067 | 0.005 | 0.041 | 0.16 | 0.029 | 0.232 | 0.048 | 0.002 | 0.02 |
| 0.3 | 50 | 0.037 | 0.001 | 0.023 | 0.194 | 0.04 | 0.64 | 0.129 | 0.017 | 0.286 |
| | 60 | 0.042 | 0.002 | 0.018 | 0.164 | 0.029 | 0.268 | 0.148 | 0.024 | 0.219 |
| | 70 | 0.04 | 0.002 | 0.012 | 0.212 | 0.051 | 0.362 | 0.136 | 0.021 | 0.148 |

**Note:** RMSE=root mean square error, χ2 =reduced chi square, RSS= residual sum of squares.

sults of $\chi^2$, $R^2$, root mean square (RMSE), the Page model was found to be the best-fitted model (Table 4). Similar findings have been reported for black carrot [22] and pitaya peels [27].

The moisture diffusivity and activation energy were estimated by Fick's law diffusion and Arrhenius model (Equation 2 and 3). Linearization of the equation allowed the determination of the effective moisture diffusivity ($D_{eff}$) for different tray load samples. The $D_{eff}$ for baby corn roundels at different temperatures (50, 60, and 70 °C) with varying tray loads (0.45, 0.40, 0.35, and 0.30 g/cm²) ranged from $2.40\times10^{-11}$ to $7.11\times10^{-12}$ (m²/s); $4.06\times10^{-12}$ to $9.94\times10^{-12}$ (m²/s); $2.94\times10^{-12}$ to $6.80\times10^{-12}$ (m²/s); $3.65\times10^{-12}$ to $8.01\times10^{-12}$ (m²/s) respectively. The data showed that with the increase in drying temperature, and reduction in tray load resulted in increased values of $D_{eff}$. This increase results from the increased heating energy which led to the increased diffusion of water molecules [28, 29]. Also, blanching as pre-treatment prior to drying improves the cell membrane permeability which in turn increases the effective diffusivity [30].

**Table 5:** Values of effective moisture diffusivity ($D_{eff}$) and activation energy ($E_a$).

| Tray load (g/cm²) | Temperature (°C) | Diffusivity (m²/sec) | Activation energy (J/mol) |
|---|---|---|---|
| 0.45 | 50 | $2.40\times10^{-11}$ | 57416.48 |
| | 60 | $6.19\times10^{-12}$ | |
| | 70 | $7.00\times10^{-12}$ | |
| 0.4 | 50 | $4.06\times10^{-12}$ | 41333.05 |
| | 60 | $6.9\times10^{-12}$ | |
| | 70 | $9.94\times10^{-12}$ | |
| 0.35 | 50 | $2.94\times10^{-12}$ | 38808.09 |
| | 60 | $5.88\times10^{-12}$ | |
| | 70 | $6.80\times10^{-12}$ | |
| 0.3 | 50 | $3.65\times10^{-12}$ | 36499.29 |
| | 60 | $7.61\times10^{-12}$ | |
| | 70 | $8.01\times10^{-12}$ | |

## Effective moisture diffusivity and activation energy

The activation energy depicts the minimum energy required to initiate the process of moisture transfer from the center of the food to the surface during the drying process. The activation energy for most of fruits and vegetables has been reported in the range of 12.7-110 KJ/mol [31]. In the present study, the activation energy was observed in the range of 57416.48 to 36499.29 (J/mol) for tray load 0.45 g/cm²-0.30 g/cm² respectively as shown in table 5 which agrees with the mentioned range. A decrease in activation energy with increasing temperatures and decreasing tray loads was observed which is due to higher diffusivity.

## Effect of temperatures on bioactive components

The effect of different temperatures (50 °C - 70 °C) at tray load 0.3 g/cm² was studied on various heat-labile components of baby corn and color values. As the heat treatment negatively affects the heat-sensitive nutrients as well as the color of the product the effect of different temperatures becomes important. The results have been shown in table 6. It was observed that both microwave blanching and drying at different temperatures significantly affected nutrient degradation and color values. Ascorbic acid is an important food component present in almost all fruits and vegetables. It is heat labile, pH, metal ion and light sensitive and can be degraded by enzymes also. This vitamin is considered as an indicator to evaluate nutrient loss during blanching and other thermal treatments [30]. The main mechanism of ascorbic acid loss during steam, microwave and infra-red blanching could be action of ascorbic acid oxidase enzyme and thermal degradation while in hot water blanching it is through leaching [30]. In the present study, a significant reduction in ascorbic acid at $p \leq 0.05$ was found during microwave blanching. The value was reduced from 21.05 ± 0.15 mg/100 g to 15 ± 0.06 mg/100 g. The effect of

**Table 6:** Effect of treatments on bioactive components of baby corn.

| Baby corn | Ascorbic Acid (mg/100 g) | TFC (mg QE/100 g) | TPC (mg GAE/100 g) | DPPH (%) | FRAP (µg/ml) |
|---|---|---|---|---|---|
| Fresh | 21.50 ± 0.15$^{c}$ | 2.37 ± 0.01$^{d}$ | 49.02 ± 0.01$^{c}$ | 37.90 ± 0.12$^{b}$ | 123.93 ± 1.14$^{c}$ |
| MWB | 15 ± 0.06$^{b}$ | 3.01 ± 0.02$^{e}$ | 49.68 ± 0.04$^{d}$ | 40.89 ± 0.05c | 124.01 ± 0.06$^{e}$ |
| 50 °C | 14.81 ± 0.01$^{a}$ | 1.98 ± 0.01$^{c}$ | 48.03 ± 0.01$^{a}$ | 34.00 ± 0.02$^{a}$ | 118.63 ± 0.01$^{a}$ |
| 60 °C | 14.98 ± 0.01$^{b}$ | 1.96 ± 0.01$^{b}$ | 48.72 ± 0.02$^{b}$ | 38.00 ± 0.57$^{b}$ | 120.63 ± 0.02$^{b}$ |
| 70 °C | 15.02 ± 0.02$^{b}$ | 1.90 ± 0.03$^{a}$ | 49.02 ± 0.03$^{c}$ | 38.00 ± 0.01$^{b}$ | 124.63 ± 0.01$^{d}$ |

**Note**: Values are expressed as Mean ± SD (n =3) (p<0.05); a-d within column with different letters are significantly different at 5% level of significance. TFC: Total flavonoid content; TPC: Total phenolic content; DPPH: 1,1-diphenyl-2-picrylhydrazyl; FRAP: Ferric reducing antioxidant power.

drying at different temperatures showed that higher temperatures short time resulted in better retention of ascorbic acid as recorded in table 6. Low temperature and longer time facilitate the oxidation of ascorbic acid [32]. The total phenol content and antioxidant activity were found to increase with increasing temperatures [33], whereas the flavonoid content decreases with increasing temperatures; which shows that these are temperature dependent [34]. Among different temperatures, the samples dried at 70 °C were found to retain maximum bioactive components.

## Color values

The L*, a* and b* values for fresh baby corn samples were found to be 75.17 ± 0.37, 4.53 ± 0.21, and 30.27 ± 0.22 respectively which when microwave branched were found to be 71.00 ± 0.32, 5.1 ± 0.21 and 33.3 ± 0.33. The lightness (L*) value decreased whereas a*(redness) and b*(yellowness) values got increased. Higher L* values indicated the lighter color of the sample [35]. The darkness of the color during blanching might be due to non-enzymatic browning [36] which was further intensified significantly at p≤0.05 during drying at 50 °C and 60 °C. The L* value (70.63 ± 0.12) was minimally affected at 70 °C. The a* value significantly increased from 4.53 ± 0.21 for fresh sample to 5.1 ± 0.21 for microwave branched and 5.6 ± 0.01 for drying at 70 °C. The yellowness (b*) value was found to increase due to the presence of the yellow pigments which increases once the samples are blanched [37]. The treated samples after tray drying were observed for color values L* and b* values were found to decrease for different drying temperatures (Table 7).

**Table 7:** Effect of treatments on color characteristics.

| **Baby corn** | **Color values** | | |
|---|---|---|---|
| | **L*** | **a*** | **b*** |
| **Fresh** | 75.17 ± 0.37$^{e}$ | 4.53 ± 0.21$^{a}$ | 30.27 ± 0.22$^{a}$ |
| **MWB** | 71.00 ± 0.32$^{d}$ | 5.1 ± 0.21$^{b}$ | 33.3 ± 0.33$^{b}$ |
| **50 °C** | 57.87 ± 0.33$^{b}$ | 5.3 ± 0.03$^{bc}$ | 33.6 ± 0.12$^{c}$ |
| **60 °C** | 55.67 ± 0.45$^{a}$ | 5.6 ± 0.02$^{d}$ | 38.7 ± 0.11$^{d}$ |
| **70 °C** | 70.63 ± 0.12$^{c}$ | 5.6 ± 0.01$^{c}$ | 39.8 ± 0.31$^{e}$ |

**Note:** Values are expressed as Mean ± SD (n =3) (p<0.05); a-e within column with different letters are significantly different at 5% level of significance.

The L* values of dried samples at temperatures 50 °C, 60 °C and 70 °C were found to be 57.87 ± 0.33, 55.67 ± 0.45, 70.63 ± 0.12 respectively. The lightness value was better in the case of samples dried at 70 °C which is because higher temperatures for a shorter time were found to retain color and carotenoid content than lower temperatures for a long time [36, 38]. After drying, the overall a* and ΔE were found to increase. During the drying of fruits and vegetables browning reactions viz., (enzymatic and non-enzymatic) occurs, leading to an increase in the redness of dried samples [39]. Moreover, with the decrease in the moisture content the value of redness increases. Consequently, the color difference was found to be minimum for the samples dried at 70 °C than that at 50 °C and 60 °C. ΔE was found to be 5.09 ± 0.12 for MWB, 24.44 ± 0.32, 29.02 ± 0.31, and 18.73 ± 0.76 for dried samples at 50, 60, and 70 °C respectively. The ΔE increased with an increase in drying temperature; however, the higher temperature for a shorter time resulted in lower ΔE values as observed. Moreover, the samples dried at 50 and 60 °C have higher values of ΔE since these are exposed for longer time periods hence thermal degradation and oxidation of pigments cause leads to more color difference [36, 40].

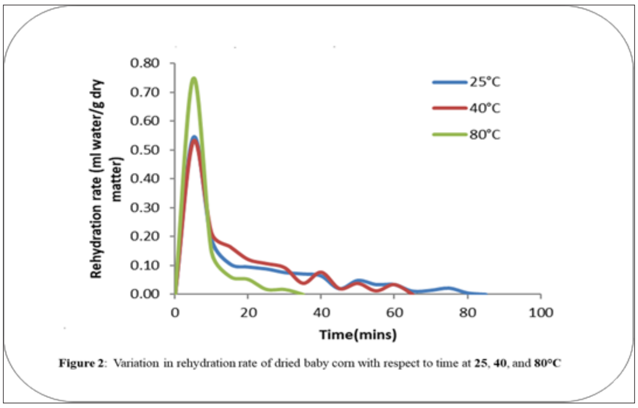

**Figure 2:** Variation in rehydration rate of dried baby corn with respect to time 25, 40 and 80 °C.

## Rehydration kinetics

The dehydrated baby corn roundals (70 °C) were rehydrated at different temperatures (25, 40 and 80 °C). The graph was plotted between the rehydration rate and time; it was observed (Figure 2) that the rehydration rate is higher at higher temperatures. Initially, the rehydration rate increased rapidly which further decreased till it reached equilibrium. This can be attributed to the osmotic pressure that is produced when the material is moistened which leads to the dissolution of soluble components, as solubility changes with temperature, the rate of water absorption rises as the temperature rises due to an increase in the osmotic pressure. Furthermore, the rehydration rate or rehydration capacity depends mainly on the cell wall, composition, capillary structure, porosity, and nature of the sample [41, 42]. The major water-retaining factors include the starchy nature of the material. Also, the swelling of material results due to the imbibition of water [43]. Among the different temperatures under observation, the rehydration rate was more rapid at 80 ˚C than that for the samples rehydrated at 25 and 40 ˚C. Similar behavior has also been reported by several researchers on different matrices including beans [41] and carrot [44].

## Conclusion

The long-graded baby corn cobs were selected for the drying study because of their less utilization in raw form. It was concluded that the drying behavior of baby corn round pieces followed a falling rate pattern and was adequately described by Page's model over the temperature range (50 ˚C- 70 ˚C) and tray loads (0.45 g/cm$^2$- 0.30 g/cm$^2$) used. Out of different temperatures and tray loads employed, the overall drying rate was found to be best for samples dried at 70 ˚C with a tray load of 0.30 g/cm$^2$. The selection was made based on the retention of bioactive compounds and the color values which were found to be maximum at higher temperatures than at lower temperatures. The samples rehydrated at higher temperatures observed higher rehydration rates that can be attributed to the osmotic pressure which is produced when the material is moistened leading to the dissolution of soluble components.

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## Conflict of Interest

None.

## Funding statement

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