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Optimization of temperature and power density in microwave-assisted hot air oven drying and storage stability of dried apple sticks

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Abstract

Apple (*Malus Demestica* cv. Cortland) is a perishable fruit due to its high moisture content. In this study, apple sticks were dried to increase their shelf life. Osmotic dehydration was used as pretreatment followed by microwave-assisted hot air drying (MAHD) at different temperatures (45 ºC, 55 ºC, 65 ºC) and microwave power densities (0, 0.5, 1 W/g). Optimum process parameters were estimated by the central composite design of response surface methodology (RSM). The results showed that the temperature and power density had a significant effect on response variables. Optimum conditions of moisture content (9.54%), time (100 minutes) and change in color (7.54) were found at 65 ºC and 1 W/g microwave power density (MWPD). Then the samples dried at optimum conditions were stored at ambient temperature and analyzed for color, moisture content, texture and total fungal count at regular intervals for 75 days. The results showed a non-significant change in color and fungal counts from 10.45 to 10.73 and from 0.45 to 0.69 log cfu/g respectively, and a significant decrease in moisture content from 10.11% to 5.69% was observed from 0 to 75 days. While increasing firmness resulted in increased force and energy to the breaking point and micrographs of electron microscope showed shrinkage in cell structure along with storage. The brittleness of apple sticks increased significantly during storage but remained acceptable till the end of 75 storage days.

Keywords: Shelf life; Moisture contents; Time; Texture; Color; Fungal count.

Highlights

- Quality of microwave-assisted hot air-dried apple sticks remained acceptable at ambient storage for 75 days

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1 Introduction

Apple belongs to family Rosaceae and there are around 7500 different types of apples known in the globe, with the main differences being color, shape, and herbal nourishing component (Karaaslan & Ekinci, 2022). Fruit grown can be found in massive quantities all around the world. Apple's genetic diversity has allowed it to adapt to different environments in both warmer and colder places. After bananas and watermelons, it is the third most important fruit crop (Ghinea et al., 2022). Apples can be consumed fresh or in products produced such as cakes, pies, and fresh juice or filtered, fermented into alcoholic beverages such as cider, wine, and brandy, or further processed into vinegar (Ullah et al., 2021).

Dehydration is also another popular method of fruit preservation; seeing that dried products can be used as ready-to-eat healthy snacks or as raw ingredients in other processed products such as jam, jelly, cakes, and cookies, and have several other advantages such as the convenience of handling and cost-effective transportation, packaging, and storage (Kowalska et al., 2018; Sullivan et al., 2021). Convective drying is the food industry's most commonly used drying method (Kahraman et al., 2021). Hot air dryers account for more than 85% of industrial dryers due to their ease of operation. However, the longer drying time and higher energy usage result in flavoring and nutritional ingredient degradation, structural breakdown as well as color change (Md Salim et al., 2019; Zielinska et al., 2018). It requires more latent heat of vaporization to diffuse from the material surface, resulting in shrinkage and case hardening throughout the drying process. As hot air drying effectively removes water from the product's surface or adjacent to the product's surface (Andrés et al., 2004). Whereas the microwave has the distinct property of heating the material from within the product and creating a pressure gradient that aids in moving the water to the exterior surface. Because microwave heating is faster than traditional heating, it can save more energy than traditional heating (Martins et al., 2022; Md Salim et al., 2017).

However, there are several disadvantages to using microwave drying, such as uneven heating, which results in non-uniform drying due to a lack of sample geometric uniformity and unequal irradiation exposure. The combination of hot air drying and microwave drying procedures can improve final product quality and drying rate (Shahriar et al., 2022). As a result, it is suggested that adopting a combination of microwave hot air drying could improve the drying rate and product quality (Souza et al., 2022).

Agricultural products are generally exposed to various pretreatments prior to drying in order to improve quality and reduce drying time (Deng et al., 2019). The moisture content of the sample and the microwave power used influenced energy consumption during microwave drying; however, energy consumption can be modified by adjusting the moisture content of the sample (Jindarat et al., 2015). The moisture content of fresh food products can be reduced by using osmotic dehydration as a pretreatment of the food drying process (Çağlayan and Barutçu Mazı, 2018). It can be performed at room temperature and normal pressure, and water is removed from the product without phase change due to an increase in the drying rate, which saves energy, and a reduction in the final water activity at the completion of the process (Assis et al., 2017). As a result, osmotic dehydration paired with convective drying is a low-cost, energy-saving approach for fruit preservation (Kaur Dhillon et al., 2022).

The purpose of this study was to examine the effects of drying temperature (45 ºC, 55 ºC, 65 ºC) and microwave power density (0, 0.5, 1W/g) on drying time, moisture content, and color change during microwave-assisted hot air drying (MAHD) and keeping quality of apple sticks during storage.

2 Material and methods

The apples of the Cortland variety were purchased at a local market in Montreal, Quebec, Canada. After 5 to 6 days of storage at 4 ºC, rinsed and sliced into uniform size (about 6 mm thickness, 20 mm length) sticks with a manual fruit slicer.

2.1 Pre-treatment

Fresh apple sticks were blanched for 30 seconds in hot water (100ºC) to prevent browning. The samples were then osmotically dehydrated in a continuous flow osmotic dehydrator at 45ºC for 180 minutes with a sugar content of 65% as a drying pretreatment. After osmotic dehydration, apple sticks were gently blotted with paper towels to remove the excess surface solution.

2.2 Microwave-assisted hot air drying

A experimental setup was used as described by Md Salim et al. (2017). In each experiment, approximately 65 grams of apple sticks were placed onto the sample holder and subsequently held within the microwave cavity (Figure 1a-1b). The superficial air velocity was set at approximately 1.4 m/s, and the power density (0, 0.5, and 1 MW power density w/g) and temperature (45, 55, and 65 ºC) were adjusted as required. Sample mass was recorded via data acquisition system (Hewlett-Packard, USA) by the computer at different time intervals and sample temperature was monitored by the optic fiber sensor. All the samples were dried until reached the constant mass.

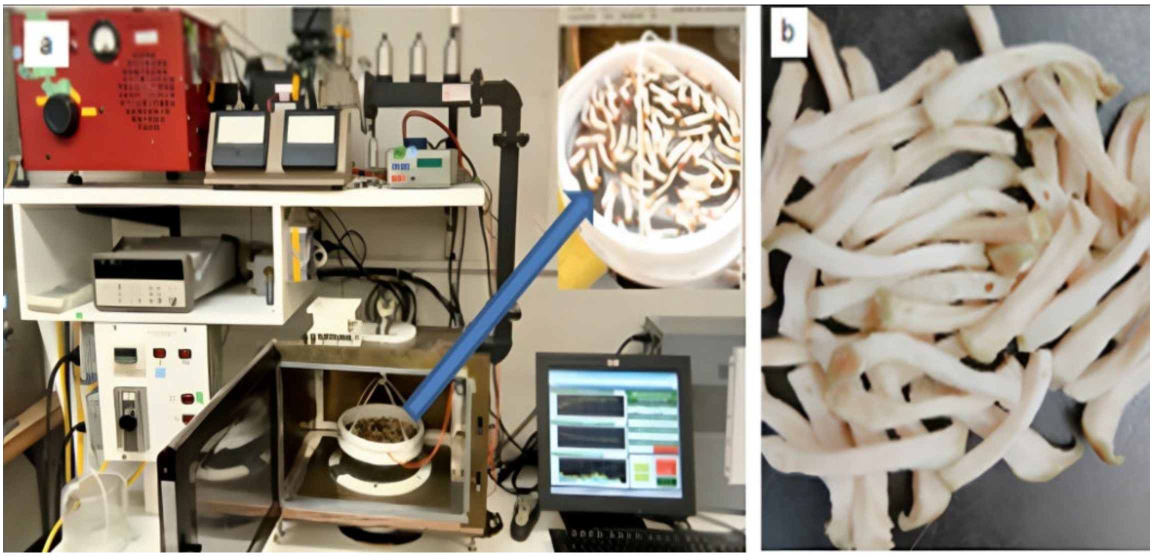

Figure 1. Photographs of microwave-assisted hot air drying (a), dried apple sticks (b).

2.3 Moisture contents

Moisture content of apple sticks were measured by the oven drying method as described by in method AOAC (Association of Official Analytical Chemists, 2000) No. 981.25.

2.4 Change in color (ΔE)

For the measurement of variation in color of dried apple sticks, tristimulus colorimeter (Minolta Co. Ltd, Japan) was used. Hunter-Scotfield equation was used for measurement of L*, a* and b* (L* showed degree of lightness, a* represents the degree of redness and b* indicates the yellowness). Equation 1 is given bellow:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

$\Delta L = L^* - L^*_0$, where L* is the degree of lightness of dried samples, L_0^* is the degree of lightness of fresh samples: $\Delta a = a^* - a_0^*$, where a* is degree of redness of dried samples, a_0^* is the degree of redness of fresh samples: $\Delta b = b^* - b_0^*$, where b* is the degree of yellowness of dried samples, b_0^* is the degree of yellowness of fresh samples

2.5 Texture analysis

A puncture test was performed at regular intervals to measure the change in hardness of dried apple sticks. Texture analyzer of Intron 4502, Boston, USA was used with a cylindrical probe diameter of 3.7 mm and a crosshead speed of 25.000mm/min.

2.6 Microbial analysis

Dried apple sticks were examined for *Coliform* and *Salmonella spp.* directly after drying to evaluate the sanitary setting for product development. While the yeast and mold counts were investigated at regular intervals of 15 days using the technique described by Downes & Ito (2001).

2.7 Microstructure analysis

A thin cut cross section area of randomly selected dried apple sticks was fixed on the rotator holder of a scan electron microscope (HITACHI TM3000). Micrographs of dried apple sticks were taken at 100x resolution at 25-day intervals over a 75-day period.

2.8 Packaging and storage

The dehydrated apple sticks (10g) were vacuum packaged in 200g high density polyethylene bags using a vacuum packaging machine (DZ-260S) and stored at 25 ± 2 ºC in a dark place. Over a period of 75 days, samples of sealed dried product were randomly examined at 15-day intervals.

2.9 Design of experiments and statistical analysis

The central composite design (CCD) with two variables and three levels was used to estimate the temperature and power density on time, moisture content, and colour of dried apple sticks. The face centered CCD was used with three levels of temperature and microwave power density (MWPD) as shown in Table 1. The CCD had 4 axels and 13 trial runs (Table 2). The centre point was repeated five times to evaluate procedure repeatability. Response for temperature and MWPD on time, moisture contents, and colour of dried apple sticks is shown in Table 3. Regression analysis on the data obtained from the CCD experiments was performed. The results showed that the effects were significant and highly significant when the p-value was less than 0.05 and 0.0001, respectively, indicating a strong relationship between the variables (Table 4). The "Design Expert 8.0.6" software was used for data analysis, experimental design, and optimization.

Table 1. Levels of independent variables in a central composite experimental design.

Symbols	Variables	Low level	Mid level	High level
A	Temperature (ºC)	45	55	65
B	MWPD (W/g)	0	0.5	1

Table 2. The experimental design used for temperature and Microwave Power Density (MWPD).

Run	Uncoded variables		Coded variables	
	Temperature (ºC)	MWPD (W/g)	A	B
1	65	1	1	1
2	55	0.5	0	0

Table 2. Continued…

Run	Uncoded variables		Coded variables	
	Temperature (°C)	MWPD (W/g)	A	B
3	55	0.5	0	0
4	65	0.5	1	0
5	55	0.5	0	0
6	65	0	1	-1
7	55	0	0	-1
8	45	0.5	-1	0
9	55	0.5	0	0
10	55	1	0	1
11	55	0.5	0	0
12	45	1	-1	1
13	45	0	-1	-1

The experimental data was used to find the predictive mode for MAHD process and optimum conditions. The general form of a quadratic model used is given below (Equation 2):

$$R = A + B + AB + A^2 + B^2 \quad (2)$$

Where, R is the calculative response (moisture content %, time in minutes, color change), A and B are the factors (i.e., temperature and MWPD).

During storage, the change in color (ΔE), microbial analysis, texture and moisture contents were analyzed using factorial Analysis of Variance (ANOVA) at $p < 0.05$ significance with “Statistix 8.1”. The results display the mean values along with the standard deviation. The Tuckey HSD test was used to determine the statistical difference among the treatment means.

3 Results and Discussion

Higher values of moisture content (15.82%) and time (222 min) were observed at 65 ºC hot air temperatures and 0 MWPD (Table 3). Table 4 shows high correlation coefficients, indicating a fit of experimental data to Equations 3, 4, and 5. The ANOVA results also showed that the lack of fit for response variables was not significant at the p = 5% level. The effects of temperature (A), MWPD (B), (AB), and B2 on moisture content and colour change were shown to be significant (Table 4).

Optimum moisture content of 9.54% and time of 100 were observed at 65 ºC, 1W/g MWPD treated samples (Table 5). When apple sticks were dried at 1w/g MWPD, the drying time was reduced by 50% when compared to drying at 0 MWPD. The drying time decreased by increasing microwave power, while it increased by lowering the microwave power (Qin et al., 2022). Using microwave energy during the drying process boosted moisture evaporation. Similar findings have been found for flax straw (Nair et al., 2012), Moringa oleifera (Dev et al., 2011), pumpkin slices (Alibas, 2007), and broccoli slices (Md Salim et al., 2017).

The effects of change in temperature (45 ºC, 55 ºC, 65 ºC) and MWPD (0, 0.5, 1 w/g) on moisture %, time, and color change are given in Figure 2a, b, and c respectively. The drying time decreased by increasing the microwave power, while it increased by lowering the microwave power (Figure 2b). Similar results were found by Musielak & Kieca (2014), they also showed that both increase in temperature and time can damage the product quality when worked with beetroot and carrot slices. Increasing the temperature and MWPD increased the effective moisture diffusivity while decreasing the firmness and drying rate of Black-gram nuggets (Sakre et al., 2022).

Color is the most important quality parameter from a consumer’s acceptance perspective. A decreasing trend in color change was observed at higher temperature 65 ºC and MWPD of 1 w/g,

(Figure 2c). In another study, the drying time of beef chips decreased as microwave power and temperature increased. The sensory quality of samples dried at higher temperatures (70 ºC) and microwave power (180 W) was higher (Aykın-Dinçer et al., 2021). When apple sticks were dried at a higher temperature (65 ºC) and MWPD (1 w/g), the drying time was shorter than at 45 ºC and 55 ºC and 0 and 0.5 MWPD, respectively, resulting in greater color retention. The reason could be microwave drying, in which heating occurs within the material, resulting in a pressure differential that causes rapid water migration to the surface and efficient removal of surface water by hot air. By use of both drying processes resulted in a reduction in drying time and color degradation.

Table 3. Response for temperature and MWPD.

Run	Temperature (ºC)	MWPD (W/g)	Time (min)	Moisture content (%)	Change in color (ΔE)
1	65	1	100	9.54	7.65
2	55	0.5	152	12.83	10.69
3	55	0.5	140	13.18	11.03
4	65	0.5	132	10.97	9.08
5	55	0.5	148	12.91	10.95
6	65	0	222	15.82	14.69
7	55	0	248	16.45	15.87
8	45	0.5	168	13.97	11.93
9	55	0.5	151	12.88	10.73
10	55	1	120	11.53	9.56
11	55	0.5	155	12.69	10.61
12	45	1	150	12.65	11.59
13	45	0	270	17.79	16.67

$$Sqrt\left(Time\right) = +12.21 - 0.88A - 2.31B - 0.18AB + 0.027A^2 + 1.15B^2 \tag{3}$$

$$Sqrt\left(Moisture\right) = +3.55 - 0.30A - 0.18B - 9.097AB + 0.32A^2 - 0.13B^2 \tag{4}$$

$$Sqrt\left(Change\ in\ color\right) = +3.28 - 0.22A - 0.44B - 0.097AB - 0.035A^2 + 0.27B^2 \tag{5}$$

Table 4. Analysis of variance and regression coefficients for response variables.

Source	Time	MC	ΔE
Intercept	12.21	3.58	3.28
A	-0.88**	-0.19**	-0.22**
B	-2.31**	-0.37**	-0.44**
AB	-0.18	-0.057*	-0.097**
A^2	-0.027	-0.042	-0.035*
B^2	1.15**	0.16*	0.27**
P-value	<0.0001	<0.0001	<0.0001
F-value	190.79	150.69	594.72
R^2	0.9927	0.9908	0.9977
R^2adj	0.9875	0.9842	0.99.60
R^2pred	0.9726	0.9308	0.9930
Lack of fit	0.7145	0.0981	0.7188

**Significant at < 0.0001. *Significant at < 0.05.

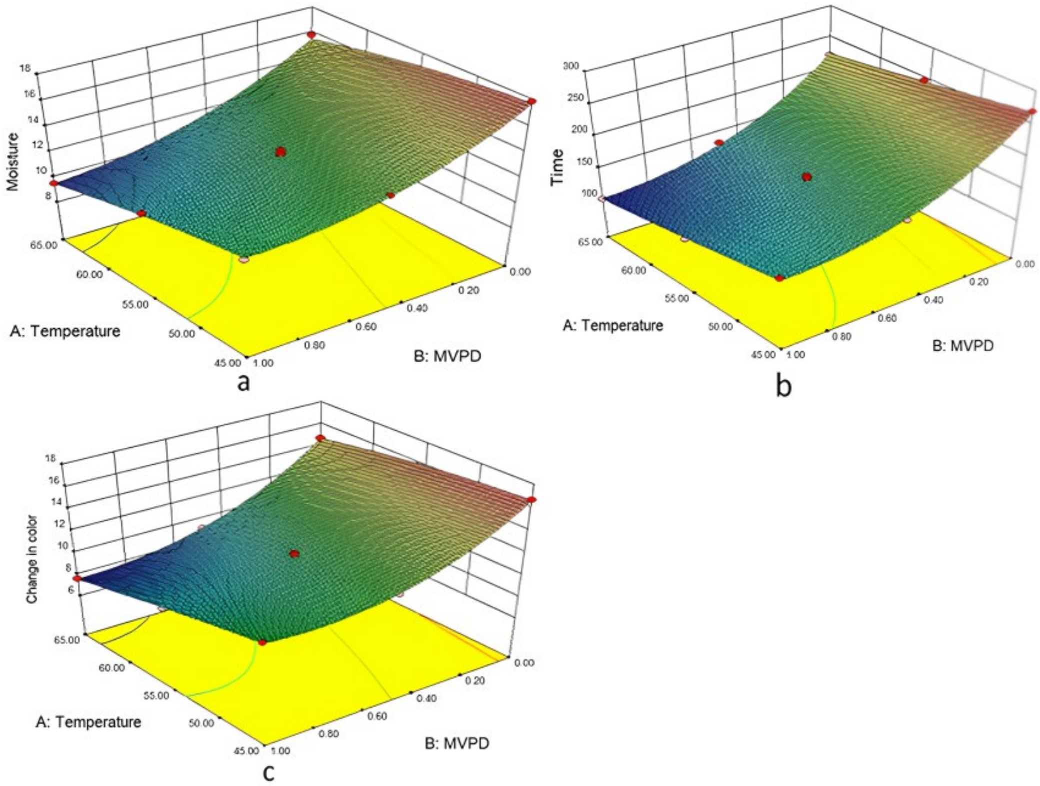

Figure 2. Effect of temperature and MWPD on moisture content (a), time (b) and change in color (c).

Table 5. Optimum condition.

	Temperature (°C)	MWPD (W/g)	Time (min)	MC	Color
Predictive	65	1	100	9.53	7.60
Actual	65	1	100	9.54	7.64

3.1 Storage study

Dehydrated apple sticks were evaluated for colour, texture, moisture content, and microbiological count at 15-day intervals for 75 days.

3.2 Color change (ΔE)

The color of the dried product is an essential factor that influences consumer acceptance. As shown in Table 6, storage (days) has a significant effect on the values of L* a* and b*. The findings demonstrated that increasing storage produces a loss of lightness, an increase in redness, and an increase in the degree of yellowness. The storage days had no effect on the overall ΔE. As a result, the color of dried apple sticks was preserved over time. It was most likely due to a decline in moisture content, which affects enzymatic and non-enzymatic activity.

The change in color (ΔE) of dried fruit during storage is due to enzymatic and non-enzymatic browning (Schulze et al., 2014; Udomkun et al., 2016). Another cause of color change could be the oxidation of ascorbic acid, which requires light and oxygen (Korbel et al., 2013). Color retention in apple sticks may also be attributed to vacuum packaging and storage in a dark place.

3.3 Microbial analysis

Microbes in dried fruits are damaging to customers' health and sensory quality. On the first day, apple sticks were examined for *Salmonella* spp. and *E. coli* to ensure that the sanitization process was successful. Both kinds of microorganisms were not discovered, confirming the efficiency of hygienic practices. There is no fixed limit for yeast and mold count for fruit acceptance, although when the fungal count exceeds 10^6 CFU/g toxic substances are created, this is regarded as an acceptable limit during fruit storage (Lee et al., 2003).

In the current study, storage had no effect on yeast and mold count (Table 7). At zero days, the minimal yeast and mold count was 0.45 Log CFU/g, with a minor but statistically insignificant increase with storage days. The drying technique reduced the moisture content (MC), which was important in retaining the shelf stability of apple sticks at room temperature. Moisture content influences microorganism proliferation, chemical reactions, and fungal growth (Ahmed et al., 2016; Gvozdenović et al., 2007). MC is an important parameter since different microorganisms require varied ranges of MC to flourish. The initial moisture level of apple sticks was about 10%, which decreased by about 4% until the end of the storage period, preventing yeast and mold counts. In another similar study, a moisture content of less than 13% was recommended to prevent fungal growth in dried pepper (Maurya et al., 2018).

3.4 Texture and moisture contents

Texture (hardness or softness) is related to the amount of force and energy needed to break or puncture the sample (Tello-Ireland et al., 2011; Vega-Gálvez et al., 2011). It is the most significant characteristic for customer acceptance of dried fruits. Table 7 shows the textural properties of the apple sticks. A considerable rise in force and energy to break is detected with storage days, and a decreasing trend in MC was observed from 0 day to 45 days (Table 7), followed by a continuing but non-significant drop in MC. The decrease in MC is accompanied by an increase in sample hardness or force and energy to break (Rizzolo et al., 2011). A significant difference of 4.3% was observed between the initial (10.11%) and final moisture contents (5.69%) from 0 to 75 days respectively, with no apparent changes in vacuum packaging. The data suggest that the MC may have evaporated through the pores of the polyethylene sheet into the surrounding atmosphere.

Table 6. Effect of storage on color change of apple sticks during storage.

Storage days	Color change			
	L*	a*	b*	ΔE
0	72.86 ± 1.91^{a}	0.74 ± 0.31^{c}	14.19 ± 1.13^{f}	10.45 ± 0.10^{a}
15	72.95 ± 1.64^{a}	0.89 ± 0.5a^{b}	14.28 ± 0.22^{e}	10.33 ± 0.11^{a}
30	72.89 ± 1.56^{a}	0.84 ± 0.47^{bc}	14.52 ± 0.56^{d}	10.32 ± 0.05^{a}
45	72.60 ± 1.11^{b}	0.90 ± 0.26^{ab}	14.83 ± 1.85^{c}	10.53 ± 0.13^{a}
60	72.41 ± 1.39^{c}	0.94 ± 0.17^{ab}	14.86 ± 1.34^{b}	10.71 ± 0.08^{a}
75	72.37 ± 2.29^{c}	0.98 ± 0.34^{a}	14.95 ± 0.95^{a}	10.73 ± 0.14^{a}

Similar letters displayed column-wise (across storage days) are not statistically different.

Table 7. Effect of storage on moisture content (MC), texture and total fungal count (TFC) of apple sticks during storage.

Storage days	Moisture content (%)	Texture		TFC (Log cfu/g)
		Force (N)	Energy (J)	
0	10.11 ± 0.13^{a}	29.22 ± 1.21^{e}	0.048 ± 0.01^{d}	0.45 ± 0.08^{a}
15	7.96 ± 0.06^{ab}	32.15 ± 1.79^{d}	0.049 ± 0.02^{d}	0.54 ± 0.09^{a}
30	7.41 ± 0.09^{ab}	38.83 ± 1.83^{c}	0.055 ± 0.02^{c}	0.51 ± 0.21^{a}
45	6.49 ± 0.16^{b}	53.67 ± 2.49^{b}	0.062 ± 0.06^{b}	0.60 ± 0.26^{a}
60	5.58 ± 0.15^{b}	85.72 ± 1.91^{a}	0.082 ± 0.02^{a}	0.69 ± 0.32 ^{a}
75	5.69 ± 0.22^{b}	85.70 ± 2.36^{a}	0.084 ± 0.05^{a}	0.69 ± 0.47^{a}

Similar letters displayed column-wise (across storage days) are not statistically different.

3.5 Microstructure

Under a scanning electron microscope (SEM), the effects of storage on the cross-section areas of apple sticks were examined after 75 days of storage at regular intervals of 25 days. The effects of storage on tissue structure can be shown by comparing micrographs of samples taken at 0, 25, 50, and 75 days (Figure 3). The structure of cells changed significantly over time. The tissue structure of the dried sample at 0 day revealed ordered structured cells with some collapsed and burst cells (indicated by green arrow heads). The damaged cells are the result of solid gain during osmo-pretreatment (Figure 3a). Mandala et al. (2005) found a comparable collapse in the cell wall as a result of sugar macromolecule penetration in apple slices after osmo-pretreatment. Cells appear to be mildly contracted after 25 days (Figure 3b), slightly contracted after 50 days (Figure 3c), and substantially constricted, deformed cells with fractured surfaces after 75 days (Figure 3d). The texture of the stored apple sticks became more brittle due to increasing moisture evaporation during storage. The increase in moisture loss was highest at the end of storage, resulting in noticeable alterations to the cells at the end of 75 days (Figure 3d). The findings are consistent with previous research on quince and mango slices (Akbarian et al., 2015; Haneef et al., 2022).

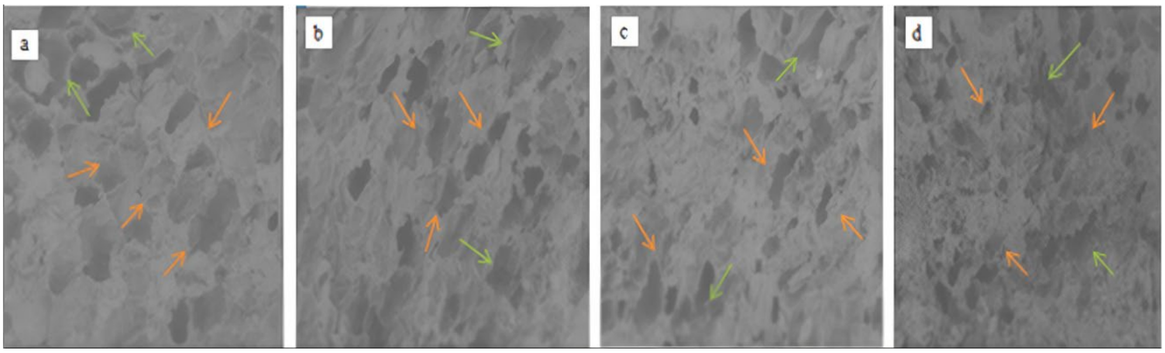

Figure 3. Micrographs of apple sticks stored at room temperature, a,b,c, and d are images of the cross-section areas of apple sticks after 0, 25, 50, and 75 days.

4 Conclusion

It is concluded that increasing the drying temperature and power density reduced drying time and boosted mass reduction. These findings indicated that the high temperature and high power density of MWHA can be employed to remove moisture faster during the drying of apple sticks. Storage study revealed sustained color, a lower fungus count, a drop in moisture content, an increase in stiffness, and greater shrinkage in cell structure. As a result, the dried apple sticks were analyzed for various quality and safety parameters and were found to be safe for consumer health. The only limitation of the storage study was the moisture loss of samples, which increased the texture firmness and change in microstructure; the undesirable effect of moisture loss could be avoided by improved packaging procedures. It would be the most valuable value addition in dried snacks if dried on a commercial scale with improved packaging techniques.

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