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Effect of Different Brine Injection Levels on the Drying Characteristics and Physicochemical Properties of Beef Jerky

Abstract

Meat jerky is a type of meat snack with a long shelf life, light weight, and unique sensory properties. However, meat jerky requires a long manufacturing time, resulting in high energy consumption. In this study, beef jerky is prepared by injecting different concentrations of brine at different hot-air drying times (0–800 min). When the brine injection levels are increased to 30%, the drying characteristics of beef jerky, such as drying time and effective moisture diffusivity, are significantly improved owing to the relatively high water content and the formation of porous structures. The physicochemical properties (e.g., meat color, porosity, shear force, and volatile basic nitrogen) of the beef jerky injected with 30% brine are improved owing to the shortened drying time. Scanning electron microscopy images show that the beef jerky structure becomes porous and irregular during the brine injection process. Our novel processing technique for manufacturing beef jerky leads to improved quality characteristics and shortened drying times.

Keywords: Beef jerky, Hot-air drying, Brine injection, Drying characteristics, Physicochemical properties

Introduction

Jerky is a lightweight meat snack with a long shelf-life at room temperature; additionally, it possesses intermediate moisture content (MC) and unique sensory characteristics (Choi et al., 2008). Jerky is prepared from raw materials by marinating, cutting, and drying, and these processes contribute to the quality of the jerky (Kim et al., 2021b). However, the low thermal conductivity of dried meat increases drying times and energy consumption in jerky manufacturing (Ando et al., 2016; Li et al., 2018). Additionally, the long drying time causes shrinkage, hardening, discoloration, off-flavor, and destruction of nutrients in the meat muscle (Shi et al., 2021a). Thus, efforts have been made toward developing new processing techniques that can produce soft-textured jerky using less energy and processing time.

Hot-air drying, a commercial-scale drying method, is a water removal process that uses convective hot air. During the drying process, heat is transferred from the air to a medium, and moisture migrates from the internal medium to the surface, where it evaporates into the air (Shi et al., 2021b). As dehydration progresses, the low MC in food decreases the drying rate (DR) owing to water–macromolecule interactions and the partial loss of water–water interactions (Wang and Liapis, 2012). A deformation state with relatively high densities inhibits water migration (Thiagarajan et al., 2006). As the multi-physics problem of food material has been associated with drying characteristics, many previous studies have investigated advanced drying methods, such as vacuum, blanching, freeze-thaw, super-heated steam, and infrared radiation, for drying porous materials (Ando et al., 2019; Feng et al., 2020; Kim et al., 2021a; Kim et al., 2021b; Li et al., 2018).

The needle-based injection process is widely employed in meat processing, in which brine is injected into the muscle using needles under pressure (Andersen et al., 2019). Additionally, the injection of brine can improve the flavor and juiciness of meat products (Xiong, 2005). Previous studies have shown that the brine injection process provides a relatively light color, reduced shear force, and porous structure in the meat owing to the increased MC inside the meat medium (McDonald et al., 2001; McDonald and Sun, 2001). Additionally, the MC in foodstuffs plays a functional role owing to the effect of its specific properties on the thermal conductivity, porosity, and density of meat during the dehydration process (Phomkong et al., 2006). A recent study reported that a high initial MC increased the DR owing to the internal pores made by the noodles

(Deng et al., 2018). During air drying, the increase in water content causes a reduction in density and shrinkage and the generation of a porous structure, which increases heat and mass transfer (Rahman et al., 1996). These increases in water content and heat and mass transfer The increase in heat and mass transfer due to the formation of porous structures and the water content in the meat could lead to reduced energy consumption and drying time (Ando et al., 2019; Chen, 2007). Beef jerky is processed via marinating, tumbling, drying, and packing (Kim et al., 2021a), where marinating and tumbling are the most typical methods used in its manufacturing (Sindelar et al., 2010). Although brine injection can improve the drying characteristics of meat products, it has not been actively adopted for manufacturing beef jerky. In addition, the changes in the drying characteristics in relation to the brine injection level have not been studied.

Therefore, we hypothesize that varying the brine injection level could change the porosity and initial water content in beef jerky, which may result in different DRs and physicochemical properties. Thus, we employed a needle injection technique with different brine injection levels (10%, 20%, and 30%) to produce beef jerky.

Materials and Methods

Preparation of beef jerky

Frozen beef was purchased from a local market (Incheon, Korea) and thawed in a refrigerator at 4 ℃ for 12 h. The visible connective tissues of the beef were trimmed. The beef jerky samples were prepared using different ratios of beef/water: 100%/0%, 90%/10%, 80%/20%, and 70%/30% (w/w) with 1% salt based on the beef weight (w/w). Four kilograms of meat were prepared for each sample, which were marinated with salt water (brine solution) using a needle injection technique. Different levels of brine solution (10%, 20%, and 30% of the total sample weight, w/w) were injected into the beef samples using a meat injector (Ideal-VA, Vakona GmbH, Lienen, Germany); afterward, the beef samples were tumbled in a meat tumbler (Model

MM-80, D-4500, Osnarbruck/W-Germany) at 30 rpm for 1 h. After tumbling, the samples were sliced into pieces of 25 mm × 25 mm × 7 mm and then dried in a convection dry oven (HSC-150, Hanam, Korea) until the total water content was below 50% (dry basis).

Analysis of drying characteristics

The dry oven was operated at an air velocity of 0.5 ± 0.1 m/s on average throughout the continuous measurements collected over 3 min. All samples were dried at 85 ℃ for different drying periods (10, 20, 30, 40, 50, 60, 80, 100, 120, 150, 180, 240, 300, 360, 580, and 800 min). The MC of each sample was determined using the AOAC official method for each period (AOAC, 2000). There were six duplicates in all treatment groups, approximately 4 kg each; the drying kinetics of the beef jerky were plotted using the moisture ratio (MR, g/g), DR (*g/(g*h)*), and effective moisture diffusivity (D_{eff}, m^2/s) with MC on a dry basis (Xie et al., 2020).

MC

The MC of the beef jerky at any time was calculated according to Eq. (1).

$$M_t = \frac{W_t - W_{ds}}{W_{ds}} \tag{1}$$

where W_t is the weight at time *t* of drying (g water/g dry basis), and W_{ds} is the final weight (g) after dry, which can be easily calculated from the initial weight and MC.

MR

The MR during the drying can be expressed using Eq. (2).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{2}$$

where M_0 is the initial MC (g water/g dry solid), M_t is the MC (g water/g dry solid) at time *t*, and M_e is the equilibrium MC during the drying process. Eq. (2) can be simplified as Eq.

(3):

$$MR = \frac{M_t}{M_0} \tag{3}$$

The value of M_e was considered to be zero compared to M_t or M_0 for long drying times (Aykın-Dinçer and Erbaş, 2018).

DR

The DR refers to the mass of water removed per unit time per unit mass of dry material, which can be expressed using Eq. (4):

$$DR = \frac{M_{t1} - M_{t2}}{t_2 - t_1} \tag{4}$$

where t_1 and t_2 are the drying times (min), and M_{t1} and M_{t2} are MCs on the dry basis (g/g) at times t_1 and t_2, respectively. The DR was calculated using Eq. (4).

D_{eff}

The moisture migration during the drying process was controlled by diffusion. Fick's second law, which considers the D_{eff} (m^2/s, Eq. (5)), was calculated when the MC of the beef jerky was reduced below 0.5 g/g (dry basis).

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{5}$$

where Eq. (5) can be solved using Eq. (6) for an infinite slab geometry and uniform initial moisture distribution (Aykın-Dinçer and Erbaş, 2018).

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} exp\left(-\frac{(2n+1)^2 \pi^2}{4L^2} D_{eff} t\right) \tag{6}$$

where n is the number of series terms, t is the drying time (s), and L is the half-thickness of the beef jerky (m). Eq. (6) takes the natural logarithms, which can be expressed as Eq. (7):

$$\ln MR = \ln \frac{8}{\pi^2} - \frac{\pi^2}{4L^2} D_{eff} t \quad (7)$$

The D_{eff} was calculated from the slope of the graph of $\ln(MR)$ plotted against drying time, as shown in Eq. (8):

$$D_{eff} = slope \times \frac{4L^2}{\pi^2} \quad (8)$$

Physicochemical properties

The beef jerky without and with brine injection (10%, 20%, and 30% brine) was dried at 85 ℃ for 280, 240, 210, and 180 min in a convection dry oven (HSC-150, Hanam, Korea). Four kilograms of meat samples were prepared for each treatment group. The MC of each sample was removed to below 0.5 g/g (dry basis) and determined using the AOAC Official method (AOAC, 2000). The physicochemical properties of the beef jerky, including the water activity, pH, color, porosity, volatile basic nitrogen (VBN), and shear force, were measured.

Determination of water activity

The water activity of the beef jerky was determined using a water activity meter (Humimeter RH2, Schaller). The ground sample (3 g) was used to determine the water activity in triplicate at 25 ± 1 ℃.

pH

The pH of the beef jerky was measured using a model LAQUA pH meter (Horiba, Ltd., Kyoto, Japan). Briefly, 5 g of the sample and 20 mL of distilled water were homogenized at 10,000 rpm for 2 min using a homogenizer (DAIHAN Scientific Co., Ltd., Gangwon, Korea). The homogenate was used to determine the pH of the beef jerky.

Color evaluation

A colorimeter (CR-210, Minolta Camera Co., Ltd., Osaka, Japan) was used to measure CIE (International Commission on Illumination) L*a*b* color values. The CIE L*a*b* color values of the calibrated white plate were 97.27, 5.21, and −3.40, respectively.

Porosity

The porosity (ε, %) was calculated from the real density (ρ_r, g/cm) and apparent density (ρ_a, g/cm) (Silva-Espinoza et al., 2020). ρ_r is defined as the weight per volume of only the sample without considering the pores in the material, and ρ_a is defined as the weight per volume of the material, including the pores and water (Pavlov, 2011). ρ_a was calculated using the weight (m, g) and corresponding volume (V, cm^3) as the weight per unit volume (Eq. (9)).

$$\rho_a = \frac{m}{V} \tag{9}$$

ρ_r was calculated based on the sample composition according to Eq. (10), using the densities of the particles.

$$\rho_r = \frac{1}{\frac{X_W}{\rho_W} + \frac{X_{CH}}{\rho_{CH}}} \tag{10}$$

where X_W and X_{CH} are the mass fractions of the water and carbohydrates of beef jerky, respectively, and ρ_W and ρ_{CH} are the densities (ρ_W= 1.4246 g/cm^3, ρ_{CH}= 0.9976 g/cm^3). The porosity was calculated using Eq. (11):

$$\varepsilon = \left(\frac{\rho_r - \rho_a}{\rho_r}\right) \times 100 \tag{11}$$

Analysis of shear force

The shear force (kg) of the beef jerky was measured using a texture analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK) fitted with a Warner–Bratzler blade with a V slot at room temperature. The conditions of the texture analysis were as follows; pre-test speed of 2.0 mm/s, test speed of 2.0 mm/s, and post-test speed of 1.0 mm/s (Kim et al., 2021b).

Volatile basic nitrogen (VBN)

The VBN (mg%) was measured as previously described (Kim et al., 2019). Briefly, 5 g of the beef jerky samples were homogenized at 12,000 rpm for 1 min using 20 mL of distilled water. After filtering through filter paper (Whatman No.1), 30 mL of distilled water was added. A total of 100 μL of indicator (1:1 = 0.066% methyl red in ethanol:0.066% bromocresol green in ethanol) and 1 mL of 0.01N H_3BO_3 were added to the inner section of the Conway microdiffusion cell, and 1 mL of the filtered sample and 1 mL of 50% K_2CO_3 solution were added to the outer section. After incubating for 90 min at 37 ℃, the solution in the inner section was titrated with NH_2SO_4.

Field-emission scanning electron microscopy (FE-SEM)

The beef jerky was cut into three pieces (5 mm × 5 mm × 2 mm) in order to observe the structure. The samples were frozen at −78 °C for 12 h; thereafter, they were sputter-coated with gold in a vacuum evaporator (MC1000, Hitachi, Japan). The FE-SEM instrument (SU8010, Hitachi, Japan) was operated at an accelerating voltage of 5 kV to observe the microstructures at different magnifications. The magnification of all images was 300×.

Statistical analysis

All experimental data were analyzed using SPSS statistics 24 software (SPSS Inc., Chicago, IL, USA). Data were collected from at least three replicates per group and are presented as mean ± standard deviation (SD). A two-way analysis of variance with Duncan’s multiple range test was performed ($p < 0.05$).

Results and Discussion

Drying time of beef jerky decreased with increasing brine injection level

The curves representing MR vs. drying time (min) and DR vs. drying time (min) are shown in Fig. 1. The MR gradually decreased during the drying period (Fig. 1A). Compared to that of the beef jerky sample without brine, the MR of the beef samples injected with 10%, 20%, and 30% brine were lower. The DR increased with increasing MC at an initial drying time of 10 min (Fig. 1B). The beef jerky injected with 30% brine exhibited the highest DR at 10 min. This indicates that the increased DR was due to a relatively high initial MC (Deng et al., 2018). It has been reported that the drying time of the injected samples was shorter than that of the non-injected samples in food materials (Tatemoto et al., 2015). The drying time required to reduce the MC to 50% (dry basis) was decreased by increasing the brine injection levels. When compared to the beef jerky without brine, the drying times for the beef jerky injected with 10%, 20%, and 30% brine were shortened by 14.3%, 25.0%, and 35.7%, respectively (Table 1). The drying time of the beef jerky containing 30% brine (3 h) was significantly shorter than that of the beef jerky without brine (4.67 h) ($p < 0.05$) (Table 1). This indicates that the brine injection process significantly increased the drying process of the beef jerky, and the increased water content of the brine had a positive influence on the drying time. Our data showed similar results to a previous report, in which a high initial MC could be attributed to the accelerated DR and increased number and size of pores (Wang et al., 2019). Additionally, this result corresponds with that of a previous study, which reported that porosity increased with increased water content in extruded cylinders (Jerwanska et al., 1995). This phenomenon may be ascribed to the strong moisture dependence of thermophysical properties (Phomkong et al., 2006). Collectively, our data and previous reports suggest that the drying time of beef jerky could be shortened by injecting more water into meat samples.

Effective moisture diffusivity of beef jerky increased with increasing brine injection level

D_{eff} is the estimated time required to reach 50% MC (dry basis) of the sample. D_{eff} represents the conductive term of the overall moisture transfer mechanisms as the key drying parameter (Chen et al., 2012). The D_{eff} values calculated for all samples at 85 ℃ are shown in Table 1. The D_{eff} of the beef jerky samples was calculated at different times ranging from 3 h to 4.67 h at different brine injection levels. The D_{eff} of the beef jerky injected with 30% brine was the highest ($p < 0.05$). The physical properties, such as volumetric heating, large evaporation, and structure, have a significant influence on the efficiency, energy consumption, and some quality parameters of the final product (Elmas et al., 2020). The MC plays an important role in changing the pore network and D_{eff} (Chen, 2007). Additionally, the increased formation of porous structures by super-heated steam could lead to accelerated moisture diffusivity in semi-dried, restricted jerky (Kim et al., 2021b). Increasing the water content in food samples reduced the water retention capacity and increased the porosity of the structure (Wang and Liapis, 2012). A high initial MC increased the number and size of pores, which increased D_{eff} (Wang et al., 2019). This may be because the MC can affect the thermal conductivity of foodstuffs (Phomkong et al., 2006). Furthermore, the injection process can be attributed to the increased effective moisture diffusivities in wet materials (Tatemoto et al., 2015). Our data showed that the brine injection process can play a major role in determining the thermophysical properties, leading to increases of the DR and D_{eff} of beef jerky.

pH and color of beef jerky were affected by brine injection level

The pH value of the beef jerky was significantly affected by the brine injection level, where the beef jerky injected with 30% brine had the highest pH value ($p < 0.05$; Table 2). This result can be explained by the short drying time caused by injecting brine into the beef jerky, which decreased protein denaturation during the drying process. Indeed, it has been previously reported that a relatively long drying time could decrease the pH value of the jerky by the Maillard reaction and proton exchange within the protein (Kim et al., 2021b; Yang et al., 2009).

The L*, a*, and b* values of beef jerky with different brine injection levels are shown in Table 2. It can be seen that the brine injection process and drying time significantly affected the L*, a*, and b* values of the jerky ($p < 0.05$). The beef jerky injected with 30% brine showed the highest L* and b* values ($p < 0.05$), while the highest a* value was observed in the jerky without brine ($p < 0.05$). The increase in L* values may be due to an increase in the brine injection levels in beef products (McDonald et al., 2001). The degradation of carotenoid pigments and formation of brown compounds were linked to the Maillard reaction, which increased with extended drying time (Ando et al., 2019). A previous study showed that the slow dehydration of chicken jerky induced a relatively dark appearance owing to an increased rate of the Maillard reaction and metmyoglobin formation (Luckose et al., 2017). Collectively, our studies suggest that the reduced drying times facilitated by the brine injection process induced resistance against discoloration.

Effect of brine injection level in water activity, porosity, and shear force of beef jerky

The water activity, porosity, and shear force of the beef jerky with different brine injection levels are listed in Table 3. The water in the beef jerky is in thermodynamic equilibrium, which decreased with a decrease in the amount of free water and the MC (Barbosa-Cánovas et al., 2020). As shown in Table 3, the water activity of the beef jerky was not significantly affected by the brine injection process, drying time, and water content; this is probably because the level of salt was 1% of the beef weight in all the groups. For all samples, a water activity of <0.81 was obtained, indicating that they can be classified as semi-dried foods, which have water activities in the range of 0.60–0.90 and are considered safe from microorganisms (Kim et al., 2021b).

The porosity of the beef jerky increased with increased brine injection level and shortened drying time ($p < 0.05$) (Table 3). The jerky injected with 30% brine had the highest porosity ($p < 0.05$), indicating that the injection process may affect the degree of porosity in raw beef (McDonald and Sun, 2001). Indeed, water molecules can generate porous structures in food materials as dehydration proceeds (Wang and Liapis, 2012). The porosity can increase with an increase in MC owing to reduced particle–particle attraction (Jerwanska et al., 1995). Additionally, the physiochemical properties, such as MC and structure porosity, can accelerate heat and mass transfer, as well as shorten the drying time (Aykın-Dinçer and Erbaş, 2018; Feng et al., 2020). Our data suggest that the beef jerky injected with 30% brine had the highest porosity among all the samples, which was attributed to its accelerated DR; the increased water content through the brine injection process led to this result.

The shear force values of the beef jerky were significantly affected by the different injected brine level ($p < 0.05$; Table 3). The product was hardened owing to the moisture loss during the drying process (Barbosa-Cánovas et al., 2020). The beef jerky injected with 30% brine had the lowest shear force compared with that of the other groups ($p < 0.05$), while the beef jerky without brine showed the highest shear force ($p < 0.05$). A previous study reported that high brine-injection levels afford more tender beef products (McDonald et al., 2001). Additionally, the injection process can limit the formation of a hard layer (Tatemoto et al., 2015), and the formation of a porous structure could prevent shrinkage and toughening of the texture in semi-dried restructured jerky during the hot-air drying process (Kim et al., 2021b). Therefore, our data suggest that the water content, increased by the brine injection process, can lead to a porous structure, resulting in a reduced shear force value of the beef jerky.

VBN of beef jerky decreased with increasing brine injection level

The VBN values of the beef jerky processed with different brine injection levels are shown in Fig. 2. VBN is used as a freshness parameter for meat products. As more brine was injected into the beef jerky, the VBN values of the beef jerky injected with 10%, 20%, and 30% brine were significantly lower than those of the beef jerky without brine injection ($p < 0.05$). The lowest VBN values were obtained for the beef jerky injected with 20% and 30% brine. The VBN values can be increased as the drying process progresses owing to the generation of volatile nitrogen compounds (Chen et al., 2004). When the drying time increases, the protein becomes more degraded, which leads to an increased VBN value (Yang et al., 2017). VBN is produced by protein oxidation, which causes protein degradation and deterioration of meat products (Kim et al., 2021a). Additionally, the formation of volatile components during the drying process is strongly associated with sensory value (Feng et al., 2020). This indicates that a shortened drying time by the brine injection process can improve the quality of the beef jerky by reducing the VBN value.

Observation of the porosity of beef jerky using FE-SEM

FE-SEM images of the beef jerky with different brine injection levels are shown in Fig. 3. The images showed more cracks and pores formed by the brine injection process. The cross-sectional view of the beef jerky without brine showed that it is a typical beef jerky, while the brine injection process caused the matrix to become more porous and irregular. The cross-sections of the beef jerky with 10% brine showed that the myofibrillar structure started changing; jerky injected with 20% and 30% brine contained more cracks and pores than that injected with only 10%. Indeed, the injection process can damage myofibril fragmentation (Christensen et al., 2009). With an increase in water content, the wet mass became more porous, which increased the effective diffusivity (Jerwanska et al., 1995). Additionally, it was reported that rapid moisture loss increases the number of pores and size of cracks during the drying process (Kim et al., 2021b). Microstructural characterization has been associated with moisture diffusivity in food materials (Chen, 2007). Our results suggest that the relatively high brine-injection level led to a porous structure, which induced a rapid DR and D_{eff}.

Conclusion

Our study demonstrated that the application of the brine injection process significantly affected the drying characteristics and physicochemical properties of the beef jerky. In our study, a 30% brine injection level most effectively decreased the drying time and increased the D_{eff} among all groups. The accelerated drying process was attributed to the formation of a porous structure induced by the brine injection process. This process also improved the quality of the dried product in terms of water activity, color, porosity, shear force, and VBN. The FE-SEM images indicated an irregular arrangement and porous structure of myofibril fragmentation in the beef jerky following brine injection. Our results offer valuable information about the influence of brine injection in manufacturing beef jerky, and this technique can be used to optimize the processing of beef jerky. Further studies on the chemical composition and nutritional value of beef jerky with different injection ratios are needed.

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Conflict of interest

No potential conflict of interest relevant to this article was reported.

IRB/IACUC approval

This article does not require IRB/IACUC approval because there are no human or animal participants.

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Tables and Figures

Figure legends

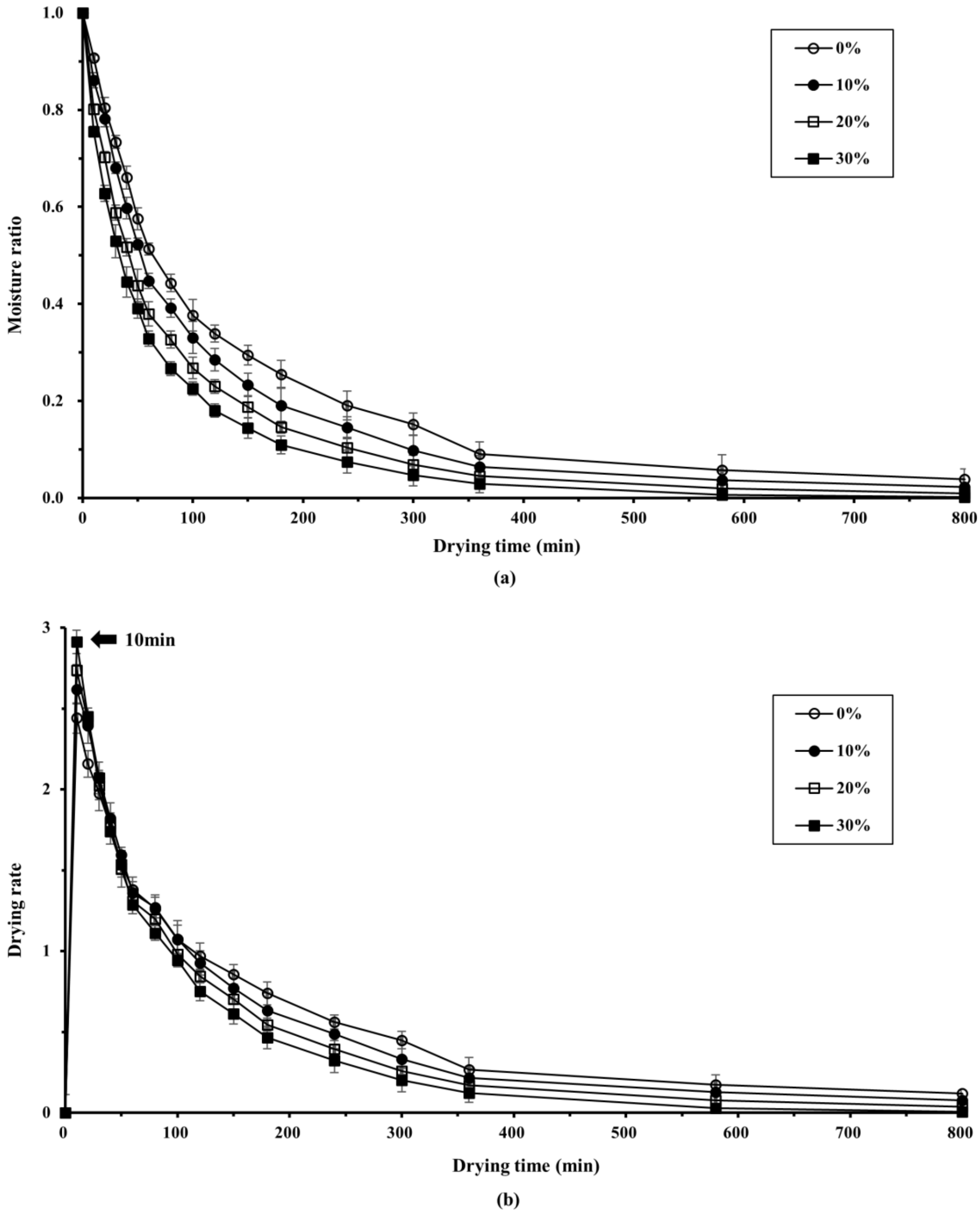

Figure 1. Moisture ratio (a) and drying rate curve (b) of beef jerky processed with different brine injection levels.

0%, 100% beef, drying time: 4.67 h at 85 ℃; 10%, 90% beef/10% water, drying time: 4.00 h at 85 ℃; 20%, 80% beef/20% water, drying time: 3.50 h at 85 ℃; and 30%, 70% beef/30% water, drying time: 3.00 h at 85 ℃. The error bars indicate SD.

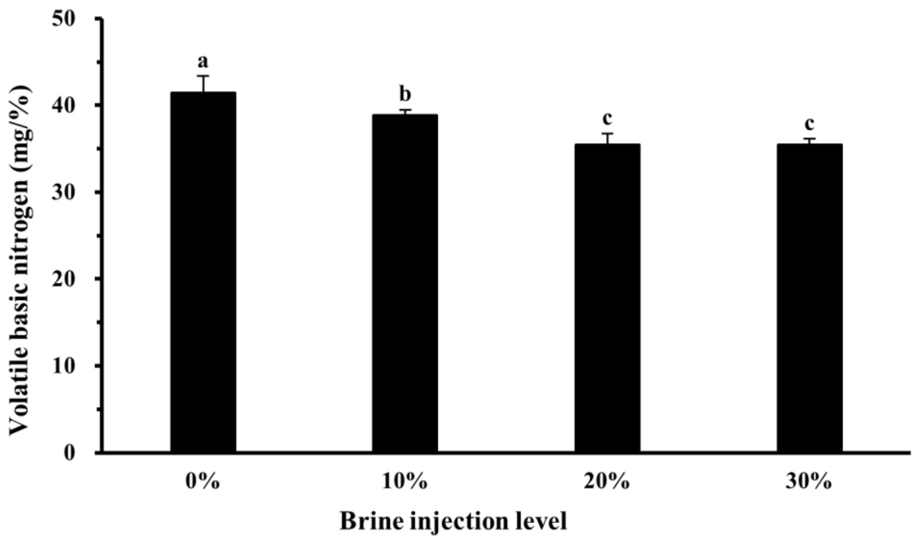

Figure 2. Volatile basic nitrogen (VBN) values of beef jerky processed with different brine injection levels.

0%, 100% beef, drying time: 4.67 h at 85 ℃; 10%, 90% beef/10% water, drying time: 4.00 h at 85 ℃; 20%, 80% beef/20% water, drying time: 3.50 h at 85 ℃; and 30%, 70% beef/30% water, drying time: 3.00 h at 85 ℃. The error bars indicate SD.

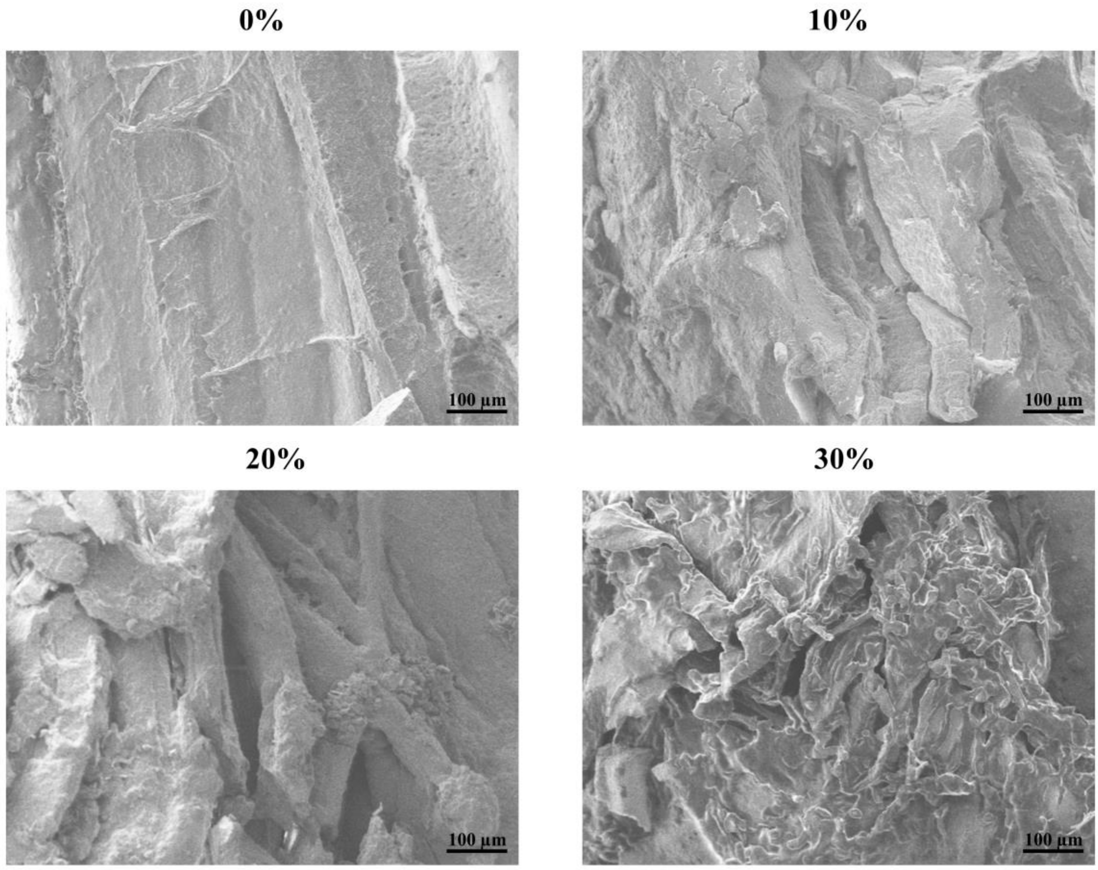

Figure 3. FE-SEM images of the beef jerky processed with different brine injection levels. 0%, 100% beef, drying time: 4.67 h at 85 ℃; 10%, 90% beef/10% water, drying time: 4.00 h at 85 ℃; 20%, 80% beef/20% water, drying time: 3.50 h at 85 ℃; and 30%, 70% beef/30% water, drying time: 3.00 h at 85 ℃.

Tables

Table 1. Effective diffusion coefficient of moisture during hot-air-drying of beef jerky.

Drying conditions			R^2	D_{eff} ($\times 10^{-9}$ m^2/s)
Brine injection level [1)]	**Moisture content (dry basis)**	**Drying time (h)**		
0%	0.50	4.67	0.9656	1.06 ± 0.10 [d]
10%	0.50	4.00	0.9722	1.33 ± 0.16 [c]
20%	0.47	3.50	0.9743	1.57 ± 0.11 [b]
30%	0.49	3.00	0.9790	1.88 ± 0.16 [a]

[1)]0% Brine, 100% beef; 10%, 90% beef/10% water; 20%, 80% beef/20% water; and 30%, 70% beef/30% water.

[a–d)]Data are shown as the mean ± SD. Different letters in superscript within the same line indicate significant differences, ($p < 0.05$).

Table 2. pH and color of beef jerky processed with different brine injection levels.

Brine injection level [1)]	pH	CIE L*	CIE a*	CIE b*
0%	5.66 ± 0.01 ^{c}	35.28 ± 4.54 ^{b}	6.25 ± 1.59 ^{a}	18.29 ± 1.70 ^{b}
10%	5.66 ± 0.01 ^{c}	36.24 ± 4.10 ^{b}	3.14 ± 0.61 ^{b}	18.26 ± 1.51 ^{b}
20%	5.68 ± 0.01 ^{b}	38.46 ± 4.13 ^{b}	3.09 ± 0.91 ^{b}	18.29 ± 1.28 ^{b}
30%	5.73 ± 0.01 ^{a}	43.79 ± 3.95 ^{a}	3.10 ± 0.32 ^{b}	20.52 ± 0.87 ^{a}

[1)]0% Brine, 100% beef; 10%, 90% beef/10% water; 20%, 80% beef/20% water; and 30%, 70% beef/30% water.

[a–c)]Data are shown as the mean ± SD. Different letters in superscript within the same line indicate significant differences, (p < 0.05).

Table 3. Water activity, porosity, and shear force of beef jerky with different brine injection levels.

Brine injection level [1)]	Water activity	Porosity (%)	Shear force (kg)
0%	0.79 ± 0.02	7.69 ± 2.02 [c]	22.83 ± 1.71 [a]
10%	0.78 ± 0.01	9.32 ± 2.43 [c]	19.59 ± 1.60 [b]
20%	0.79 ± 0.02	12.61 ± 2.24 [b]	18.95 ± 1.25 [b]
30%	0.81 ± 0.03	17.34 ± 0.77 [a]	15.83 ± 0.89 [c]

[1)] 0% Brine, 100% beef; 10%, 90% beef/10% water; 20%, 80% beef/20% water; and 30%, 70% beef/30% water.

[a–c)]Data are shown as the mean ± SD. Different letters in superscript within the same line indicate significant differences, ($p < 0.05$).