Food Sci. Biotechnol. Vol. 18, No. 4, pp. 985 ~ 990 (2009)

Food Science and Biotechnology

Optimization of Drying Temperature and Time for Pork Jerky Using Response Surface Methodology

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Abstract Response surface methodology (RSM) was applied to determine the optimum drying conditions for pork jerky. The physicochemical properties of pork jerky, such as final moisture content, water activity (Aw), pH, and shear force were investigated. In addition, sensory characteristics of pork jerky were evaluated and were used as a parameter for determining the optimum condition. Pork jerky samples were dried at different temperatures between 40 to 80°C for the time ranged from 0 to 10 hr. The predicted values for moisture content, Aw, and shear force of dried pork samples were in good agreement with the experimental values with correlation coefficients (R^2) of 0.95, 0.96, and 0.97, respectively. Both drying temperature and time significantly (p<0.01) affected moisture content, Aw, pH, and shear force and their interactions were also significant at p<0.01 except for Aw. RSM showed the optimum drying conditions for pork jerky, based on moisture content, shear force, and sensory evaluation to be 65-70°C for 7-8 hr.

Keywords: pork jerky, drying condition, optimization, response surface methodology (RSM), textural property

Introduction

Jerky is one of the oldest meat products that is preserved by curing and drying, but jerky is still in high demand as a snack food because it is nutritious, shelf-stable, and microbiologically safe. A significant amount of these jerky-type products are consumed in the USA (1,2), and they are produced by consumers at home as well as by industrial establishments. Numerous recipes for making jerky are available and many are specific for a particular species, e.g., beef, pork, poultry, and game animals. Jerky products can be made with different marinate techniques that include variations in ingredients, marinate volume, soaking time, and solution temperature, and drying conditions.

Diversity in processing parameters for jerky products may cause ineffective drying resulting in subsequent disease microbial survival or growth. To reduce the incidence pathogenic bacteria and outbreaks involving fermented meats, Leistner (3) recommended the use of a multi-hurdle strategy to food processing industries that prepare dried and semi-dried meat, since a combination of hurdles can lead to a safer product. Important hurdles commonly used in food processing include bacteria static temperatures, lower water activity (Aw), lower pH, and redox potential (E_h). A product reaches a constant Aw of 0.70-0.75 in ready for consumption and normally shelf-stable for 6 months if not left unpacked (4). Chang and Carpenter (5) reported that jerky products are convenient and nutritious and production takes 10-24 hr in temperature controlled rooms. Consumers prefer high quality foods with good flavor, texture, and nutrition, but one of the drawbacks of jerky can be its hardness and chewiness of over dried (6), the resulting jerky is often brittle, dry, difficult to chew, and may have an undesirable color. Incorporation of recovered meat products less than 20% of the formulation has been reported to not cause textural and sensory concerns (7,8). Hence, jerky texture can be altered by the moisture contents, as is done for other intermediate moisture meats, but jerky manufacturing methods also include extrusion and infusion of meats with humectants to lower Aw (9).

Most Korean meat consumers prefer pork belly and boston butt, as a consequence the Korean pork industry has suffered from a lack of consumption of low-preference pork leg, tenderloin, and loin by consumers. In view of the constantly growing popularity of the intermediate moisture food in Korea, there is relatively limited knowledge of this type of snack food by consumers. Compared to beef jerky, production of pork jerky is a rather empirical process and suffers from lack of control of time and temperature. The objectives of this study were to optimize drying temperature and time for processing pork jerky by response surface methodology (RSM) and to investigate the relationship among moisture content, Aw, pH, shear force, and sensory evaluation of the pork jerky.

Materials and Methods

Preparation of dried pork jerky samples A total of 8 pigs (cross-bred Yorkshire×Landrace ♀, ×Duroc ♂, 100 ±5 kg) were randomly selected at a commercial slaughter plant and after slaughter the *Semimembranosus* muscle was dissected from each carcass 48 hr postmortem. All subcutaneous and intermuscular fat and visible connective tissue were removed from the fresh muscles. After dissection, the muscles were frozen and stored at –20°C until used within 2 days. The frozen pork was thawed at 4°C overnight, sliced into 0.5 cm thick pieces with a meat slicer

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Received February 13, 2009; Revised March 18, 2009; Accepted March 23, 2009

(HFS 350G; Hankook Fugee Industries Co., Ltd., Seoul, Korea) and cut into cubes of $10.0\times4.0\times0.5$ cm^3. Sliced pork jerky samples were the cut same direction as the muscle fibers. The curing ingredients including salt, sugar, and sodium nitrite were purchased from a local food additives market. The sliced samples were then cured for 24 hr in a marinade brine containing 70% water, 1.5% salt, 1.0% sugar, 0.007% sodium nitrite, and 0.03% sodium erythobate based on total weight. The cured sliced pork samples were dried at different temperatures from 40 to 80°C over a range of 0 to 10 hr using a dryer (DS80-1; Dasol Scientific Co., Ltd., Hwaseong, Gyeonggi, Korea). After drying and cooling to room temperature, samples were analyzed for moisture content, water activity, pH, shear force, and sensory evaluation.

Moisture content Moisture content was determined according to AOAC Methods (10). The total moisture content of individual samples were determined from their pre-dry and dry weights (dried in an air oven at 102°C for 24 hr) and expressed as the percentage of pre-dry weight and g water/g dry weight.

Water activity (Aw) Three pieces of the dried pork jerky samples from each treatment were selected and cut into small pieces using sharp scissors and were chopped prior to measurement of Aw. The chopped pieces were put into Aw cups, and their Aw were measured with a Aw meter (AQS-2, Nagy Mess System; Siedlerstr., Gaeufelden, Germany), calibrated at ambient temperature (20°C) with distilled water (Aw=1.000) and saturated solutions of NaCl (Aw=0.756) and KCl (Aw=0.853).

pH The pH was measured in triplicate using a digital pH meter (MP230; Mettler, Im Langacher, Greifensee, Switzerland). Approximately 3 g of pork jerky sample were cut into small pieces and 27 mL of distilled water added. Slurry was then made using a homogenizer (T25basic; IKA, Selangor, Malaysia) and the pH measured. The pH meter was calibrated daily with standard buffers of pH 4.0 and 7.0 at 25°C.

Shear force Shear force (kg/cm^2) was determined using the Instron Universal Testing Machine (Model 3343) with plunger knife type. Cross-sections as close as practicable to $0.5\times2.0\times4.0$ cm^3 were cut from each pork jerky treatment and the shear force was measured. The samples cross-sections were placed in the center of the blade and sheared at a crosshead speed of 100 mm/min and a full scale load of 490 N ($kg\cdot m/sec^2$) (23).

Sensory evaluations The sensory panels consisting of students, faculty, and staff of the Gyeongsang National University (in Korea) evaluated sensory characteristics of the pork jerky. Panelists (at least 20 untrained, randomly chosen individuals) were selected based on their frequency of jerky consumption and willingness to participate in the test. Though untrained, most of the panelists were familiar with sensory testing through previous studies conducted at our laboratory. Pork jerky samples ($2.0\times2.0\times0.5$ cm^3) from each treatment were placed in covered glass containers and served warm (30°C) to the each panelist one at time. The samples were transferred into glass containers (Pyrex with plastic cover) about 30 min before the sensory test started. The panelists evaluated the samples for appearance, color, flavor, juiciness, tenderness, and overall acceptability using a 9-point hedonic scale as described by Carr *et al.* (11). The panelists evaluated each characteristic of the sample using a 9-point hedonic scale, where 1 point was 'dislike extremely' and 9 point was 'like extremely'. Samples were presented to judges in individual booths under fluorescent light.

Statistical analysis and curve fitting The effects of temperature and time were analyzed by analysis of variance using the SAS statistical program (12). Each treatment group was prepared in triplicate and for each measurement 3 samples were used. Treatment differences were analyzed using analysis of variance (ANOVA) with the general linear model (GLM) was used to determine the statistical significance at 95% significant level. All data analysis was performed using SAS for Windows, 9.1 version. In addition, response surface curves were fitted using a second order model of the form:

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_{11}x_1^2+\beta_{22}x_2^2+\beta_{12}x_1x_2$$

Where y is the measured response, x_1 is the drying temperature, x_2 is the drying time, and β_i terms are coefficients.

The data analysis for relationship between Aw and moisture content of jerky products at various drying temperature and time was performed by Sigma plot 2001 (SPSS Inc, Chicago, IL, USA). The predicted curve was obtained by fitting experimental data to the eqations as follows (24).

$$y=-1.26\times10^6x^6+5.87\times10^6x^5-1.00\times10^6x^4+1.00\times10^6x^3-6.18\times10^6x^2+1.8\times10^6x-2.16\times10^5$$

Where y is the predicted moisture content, x is Aw.

Results and Discussion

Moisture content and Aw One important attribute of jerky is the moisture content in the product both before and after drying. Changes in the moisture content of pork jerky during drying at various temperatures are shown in Fig. 1. The moisture content varied from 71.42 to 5.03% depending upon the time and temperature of processing. The moisture content of pork jerky decreased as drying temperature and time increased ($p<0.05$). The moisture contents of pork jerky at 80 and 60-70°C decreased rapidly for 4 and 6 hr, respectively, while those at 40-50°C decreased continuously during drying for 10 hr. The final moisture contents of pork jerky after 10 hr, dried at 80, 70, 60, 50, and 40°C were 5.03, 6.06, 6.74, 13.54, and 15.68%, respectively. These results indicate that the low drying temperature took a long time for moisture equilibrium of the pork jerky compared to the 3 high drying temperatures and affected the final moisture content of pork jerky. Results of ANOVA showed that both drying temperature and time were significant factors to moisture content ($p<0.01$) and their interactions were significant at $p<0.01$ (Table 1). Response surface analysis indicated with a maximum R^2 of 0.95. These results show that drying

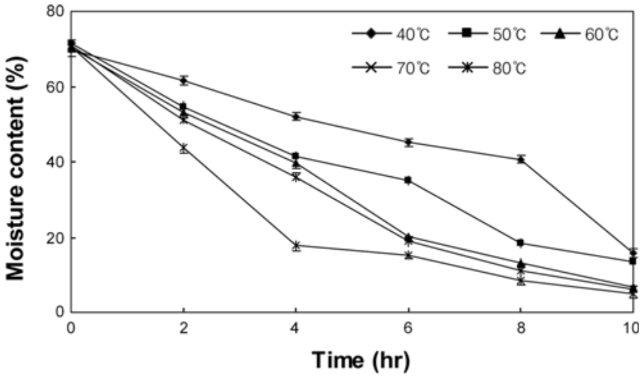

Fig. 1. Effects of drying temperature and time on the moisture content of pork jerky.

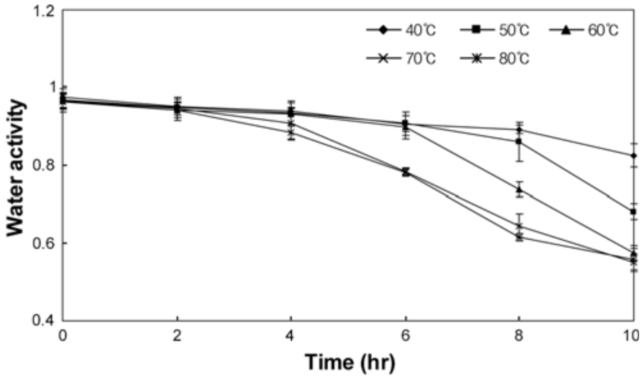

Fig. 2. Effects of drying temperature and time on the water activity of pork jerky.

temperature and time directly affected both drying rate of and total final moisture content of pork jerky during drying.

Jose *et al.* (13) reported that the moisture content of commercial beef jerky ranges from 20 to 40%. Miller *et al.* (14) showed that approximately 35 to 38% was moisture required for adequate sensory properties of jerky from beef heart and tongue. However, in general, the moisture content of pork jerky would be lower than that of beef jerky due to differences in muscle composition and fiber type (i.e., less red muscle fibers and more white muscle fibers in pork muscle). Su and Lin (15) reported that the moisture content of commercial dried sliced pork varied from 19.5 to 20.6% which is lower when compared to beef jerky. Chen *et al.* (16) stated that pork jerky was classified as an intermediate moisture meat (IMM) product with moisture content of about 20 to 25%.

The decreases in Aw of pork jerky in relation to drying temperature and time are shown in Fig. 2. The water activity ranged from 0.97 to 0.55 over the range of dryings time and temperatures. The initial Aw of pork jerky was 0.939 at 40°C, 0.935 at 50°C, 0.931 at 60°C, 0.907 at 70°C, and 0.885 at 80°C, and there were no significant differences in Aw among the samples at different drying temperatures until 4 hr (p>0.05). The Aw of pork jerky dried at 70 and 80°C rapidly decreased after 4 hr and continued to decrease more rapidly until Aw of 0.55 than those at any other temperature. There was significant difference in Aw at 6 hr between 70-80 and 40-60°C samples (p<0.05). The Aw of pork jerky dried at 60 and 50°C decreased below 0.80 after 8 and 10 hr drying, respectively. These results implied that cured pork muscle should be dried over 6 hr at 70-80°C, 8 hr at 60°C, and 10 hr at 50°C to decrease Aw below 0.80 at which microbial growth in jerky-type products was inhibited.

It is essential that IMM products such as jerky should be dried to Aw acceptable for proper shelf-life. The self-life of IMM products decreases with high moisture content and Aw due to inhibition of microbial growth (17). Torres *et al.* (4) reported that final IMM products reached a constant Aw of 0.70-0.75 and was then ready for consumption and normally shelf-stable for 6 months and left open to O_2 the product. Chen *et al.* (16) also stated that Chinese-style pork jerky product that has an Aw of about 0.75 was the most popular traditional Chinese meat item in Taiwan. Table 1 showed that drying time was a significant factor related to Aw (p<0.01), and these was an interaction between the factors (p<0.01). Response surface analysis indicated that the maximum R^2 for the surface was 0.96. Our data suggested that the Aw of pork jerky was indicates with ranged from 0.80 to 0.70 was at 80°C/6 hr, 70°C/6 hr, 60°C/8 hr, and 50°C/9 hr drying to Aw value under 0.75.

On the other hand, the relationship between moisture content and water activity in pork jerky with all data at various temperatures and times is represented in Fig. 3. Moisture content and Aw decreased when drying temperature and time increased. This conclusion was supported by the observation of very high positive correlation between moisture content and Aw (R^2=0.95). This relationship between moisture content and Aw may be very effective for not only quality but also the sensory properties including hardness and eating quality. This would be one of the benefits to control textural property of pork jerky. The concept of Aw has been useful in food preservation and based on the concept many processes could be successfully adapted for designing new products (18). Again, specific changes in flavor, texture, stability, and acceptability of raw and processed meat products have been associated with relatively narrow Aw ranges (19). Yang (20) managed to make semi-dried beef jerky with

Table 1. ANOVA and response surface statistics for pork jerky optimizing at different drying temperature and time

Response	Range	Temp *p*-value	Time *p*-value	Temp-time *p*-value	R^2
Total moisture content (%)	71.42-5.03	0.0077	<0.001	0.0074	0.95
Water activity	0.97-0.55	0.4040	<0.0001	<0.0001	0.96
pH	5.68-5.14	0.0002	<0.0001	<0.0001	0.86
Shear force (N)	186.10-19.11	0.0004	<0.0001	<0.0001	0.97

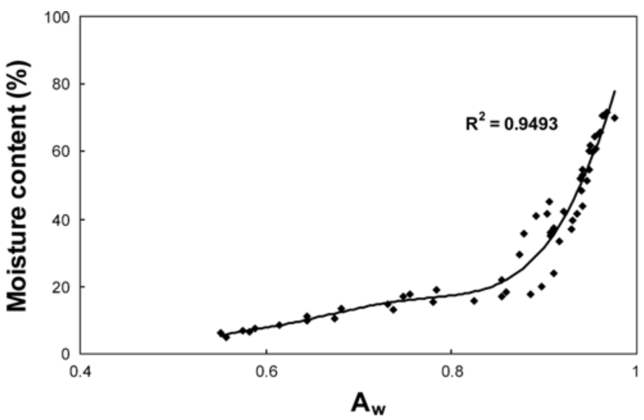

Fig. 3. The relationship between moisture content and water activity in pork jerky.

higher moisture content (Aw 0.85) and improved textural property. Thus, it was suggested that an understanding of the relationship between moisture content and Aw, especially range of Aw 0.75 to 0.85, might be useful to produce the better texture pork jerky.

pH, shear force, and sensory property Changes in pH of pork jerky are shown in Table 2. The pH value increased with increasing drying temperature while increasing drying time resulted in a decrease of pH value. There were significant differences in pH values among drying temperatures after 2 hr drying, and the pH values of 40 and 50°C samples were significantly lower than those of other temperature samples (p<0.05). This shows that the pH of pork jerky can be affected by both drying temperature and time. ANOVA showed that both drying temperature and time were significant factors affecting pH (p<0.01), and response surface analysis indicated that the R^2 for the surface was 0.86 (Table 1).

One of the most important attributes of jerky is the hardness that can be measured as shear force. Shear force values can be used to characterize the IMM products and define differences in total cutting force. In this study, shear force was defined as the maximum force attained as a blade sheared through pork jerky samples, and the results are shown in Table 3. Shear force values varied from 186.10 to 19.11 N (kg·m/sec^2) ours the processing combinations. As expected, shear force value was increased dramatically with increasing drying temperature and time (p<0.05). It was obvious that the increasing of shear force with drying temperature and time was due to decreasing of moisture content. Both drying temperature and time were significant factors affecting shear force (p<0.01), as were the interaction between the 2 factors (Table 1). Consumer's preferences for pork jerky texture various from different areas. According to the results of sensory evaluation, a shear force about 70-80 N (kg·m/sec^2) seems to be the maximum level of acceptable hardness for pork jerky. Therefore it was determined that the shear force of pork jerky was satisfactory if it did not exceed 70-80 N (kg·m/sec^2). Drying times that enabled this maximum limit were 80°C/6 hr, 70°C/8 hr, and 60°C/8 hr drying.

The sensory panels were convened to assess the effect of the different temperature on the color, flavor, tenderness, and overall acceptability of pork jerky for 7 hr drying (Table 4). Sensory evaluation was preformed at different temperatures after 7 hr, since less than 7 hr would not be possible to complete drying. Color and flavor scores were improved by increasing drying temperature, especially at 70 and 80°C drying temperature. Tenderness of pork jerky

Table 2. Effects of drying temperature and time on pH of pork jerky

Temperature (°C)	Drying time (hr)					
	0	2	4	6	8	10
			pH			
40	5.43±0.01^{a}	5.34±0.01$^{zb1)}$	5.29±0.01^{yzc}	5.18±0.01^{ye}	5.14±0.02^{zf}	5.23±0.01^{yd}
50	5.43±0.04^{a}	5.36±0.03^{zb}	5.25±0.05^{zc}	5.15±0.03^{yd}	5.16±0.04^{zd}	5.19±0.05^{zcd}
60	5.43±0.01^{a}	5.43±0.02^{ya}	5.30±0.01^{yc}	5.24±0.12^{yc}	5.32±0.01^{ybc}	5.40±0.00^{xab}
70	5.45±0.01^{b}	5.52±0.01^{xa}	5.44±0.01^{xb}	5.40±0.01^{xd}	5.410.00^{xd}	5.43±0.01^{xc}
80	5.46±0.03^{d}	5.63±0.01^{wb}	5.69±0.01^{wa}	5.52±0.01^{wc}	5.54±0.01^{wc}	5.680.00^{wb}

$^{1)}$Results are expressed as means± SD; Means with different superscript letters in a column ($^{w-z}$) and a row ($^{a-f}$) within each drying temperature and time, respectively, differ significantly (p<0.05).

Table 3. Effects of drying temperature and time on shear force of pork jerky

Temperature (°C)	Drying time (hr)					
	0	2	4	6	8	10
			Shear force (N)			
40	19.40±1.27^{d}	22.93±5.55^{zcd}	27.34±3.72$^{zc1)}$	32.83±4.21^{zb}	49.00±0.20^{zb}	58.31±6.96^{ya}
50	19.40±4.70^{e}	26.95±2.45^{yde}	33.22±2.74^{yd}	43.81±1.67^{yc}	54.88±7.35^{yb}	122.79±10.98^{xa}
60	20.29±5.88^{f}	35.18±1.67^{xe}	49.49±4.02^{xd}	61.05±2.55^{xc}	71.93±10.29^{xb}	128.58±13.72^{xa}
70	20.38±2.25^{f}	45.86±3.72^{we}	54.29±3.43^{xd}	64.39±6.17^{xc}	78.69±2.55^{xb}	131.32±7.94^{xa}
80	19.11±5.49^{f}	42.43±2.25^{we}	60.07±5.68^{wd}	74.87±8.62^{wc}	116.62±5.39^{wb}	186.10±8.33^{wa}

$^{1)}$Results are expressed as means±SD; Means with different superscript letters in a column ($^{w-z}$) and a row ($^{a-f}$) within each drying temperature and time, respectively, differ significantly (p<0.05).

Table 4. Sensory evaluation of pork jerky dried at different temperatures for 7 hr

Temperature (°C)	Color	Flavor	Juiciness	Tenderness	Overall acceptability
40	3.43±0.45$^{x1)}$	2.37±0.35^{x}	4.77±0.41^{x}	0.97±0.52^{z}	2.07±0.68^{x}
50	4.37±0.24^{x}	2.67±0.26^{x}	4.57±0.55^{x}	2.70±0.50^{y}	2.53±0.87^{x}
60	4.43±2.05^{x}	3.47±1.74^{x}	3.57±0.58^{xw}	6.07±0.49^{x}	4.97±0.54^{w}
70	8.17±0.29^{w}	6.10±0.53^{w}	2.80±0.55^{w}	7.37±1.21^{xw}	6.47±0.18^{w}
80	8.13±0.19^{w}	7.57±0.44^{w}	2.57±1.04^{w}	7.93±0.17^{w}	5.73±0.87^{w}

1)Results are expressed as means±SD; w-zMeans with different superscript letters in a column within each drying temperature differ significantly (p<0.05).

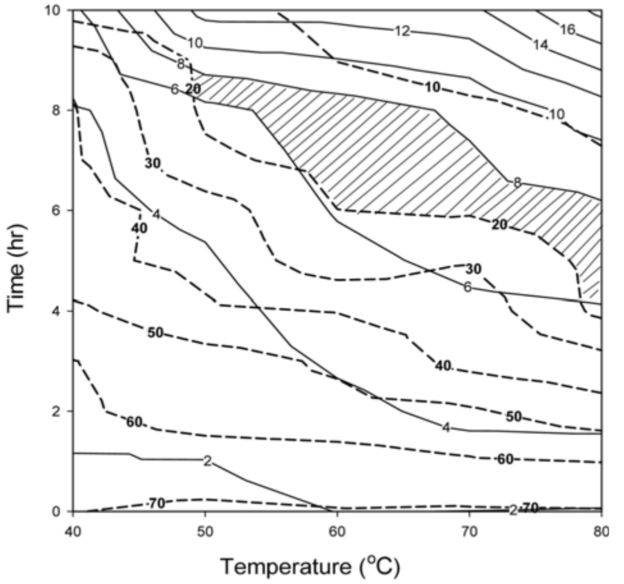

Fig. 4. Superimposing contour map of optimization for the moisture content (----) and shear force (—) on pork jerky for different drying temperature and time.

was improved by increasing drying temperature. The overall acceptability scores ranged from 2.07 to 6.47. The 60, 70, and 80°C drying temperatures had higher likeability scores higher than the 40 and 50°C treatments because of better color, flavor, and tenderness characteristics, with the highest scores at 70°C drying temperature. Our results demonstrated that pork jerky could be made by optimizing the drying condition where pork was dried at 70-80°C drying temperature for 7 hr.

Optimization for processing of pork jerky In order to optimize drying conditions of pork jerky, a contour map of response variables for different drying time and temperature was superimposed to show the range of drying conditions satisfying all the characteristics of the conditions. According to the superimposed map produced by the contour map for the changes in the characteristics of the drying conditions, the predicted range of optimal conditions was seen as areas of slant lines in Fig. 4. Predicted values on final moisture content, Aw, and shear force of dried pork sample in experimented ranges were good agreement with experimented values with correlation coefficient (R^2) of 0.95, 0.96, and 0.97, respectively. Again, Fig. 3 showed a high positive correlation (R^2=0.95) between moisture content and Aw. It was also found from sensory evaluation that drying at 70°C for 7 hr achieved a higher overall acceptability score as compared to other drying temperatures. Response surface analysis showed that the optimum drying condition for the pork jerky, based on moisture content, shear force, and sensory evaluation were obtained with a temperature range of 65-70°C and drying time ranges for 7-8 hr.

Acknowledgments

Han-Sul Yang, Sung-Won Kang, and Jin-Yeon Jeong were supported by the 2nd stage of Brain Korea 21 project (BK 21) in Korea. Authors are grateful for the financial supports.

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