For the measurement of pH, the chicken breast were finely ground under sterile conditions. Then, it was homogenized (6,451×g, 1 min) with deionized water (DIW) at a ratio of 1:4 using an Ultra turrax (HMZ-20DN; Poonglim Tech, Seongnam, Korea). The pH of homogenate was determined using a pH meter, and it was calibrated with the standard buffer solutions.

Water-holding capacity (WHC)

The WHC was determined by partially modifying the compression method described by [11]. The core of chicken breast 3 mg was placed on filter paper and pressed for 3 min using a filter press device. The areas of the inner and outer ring zones on the filter paper were measured using a planimeter. The equation for the WHC calculation is as follows:

$$WHC\ (\%) = \frac{Inner\ ring\ zone\ (mm^2)}{Outer\ ring\ zone\ (mm^2)} \times 100$$

Color

The chicken breast was divided into halves and the center was measured using a colorimeter (CR-10, Minolta, Tokyo, Japan). The colorimeter uses a D_{65} light source with an illuminated area of 8 mm. The measured lightness, redness, and yellowness are expressed as CIE L^*, CIE a^*, and CIE b^*, respectively.

TBARS

TBARS was determined using the distillation method described by [12]. Ten grams of chicken breast and 50 mL of DIW were homogenized for 1 min (5,614×g) using a homogenizer (AM-5, Nihonseiki Kaisha), and 200 μL of 0.3% butylated hydroxytoluene was added to prevent further oxidation. After adding 2.5 mL of 4N HCl and 47.5 mL of DIW were added to the homogenate, which was boiled using a heating machine (MS-E102, Lab Merchant, London, UK). The resulting distillate and 0.02 M 2-thiobarbituric acid in 90% acetate were mixed in a ratio of 1:1. The mixture was heated at 100 ℃ for 35 min and cooled in cool water for 20 min. The absorbance of the mixture was measured at 538 nm using a spectrophotometer (Spectra Max ID3, Molecular Devices). The data were substituted into the standard

curve to calculate the amount of malondialdehyde (MDA), and 1,1,3,3-tetraethoxypropane was used as the standard. TBARS was expressed as mg MDA/kg chicken breast.

VBN

The VBN content was determined by partially modifying the Conway microdiffusion method [13]. Ten grams of chicken breast and 90 mL of DIW were homogenized for 2 min (5,614×g) using a homogenizer (AM-5, Nihonseiki Kaisha). The homogenate was used as a sample after filtering through filter paper. The Conway reagent 100 μL and 1 mL of 0.01N H_3BO_3 were aliquoted into the inner Conway dish. In the outer part of the Conway dish, 1 mL of the filtrate and 1 mL of 50% K_2CO_3 were aliquoted. For the blank sample, 1 mL of DIW was used and 50% K_2CO_3 was not added. Vaseline was applied to the lid of a Conway dish to prevent oxygen permeation. Conway dishes were incubated for 2 h at 37°C. 0.02N H_2SO_4 was aliquoted until the solution in the inner part of the Conway dish changed from green to red. The equation for the VBN calculation is as follows:

$$VBN\ (mg\%) = \frac{A_1\ (\mu L) - A_2\ (\mu L)}{W\ (g)} \times 0.14 \times t \times d$$

where A_1 and A_2 are aliquots of the sample solution and blank, respectively; W is the weight of the sample; t is the titer value of 0.02 N H_2SO_4; and d is the dilution factor.

Aerobic bacteria

Chicken breast tissue (25 g) and buffer peptone water (225 mL) were homogenized for 1 min using a stomacher. Dilution solutions were prepared by mixing 1 mL of homogenate with 9 mL of BPW, and the process was repeated as needed. 0.1 mL of the diluted solution was spread onto tryptic soy agar, then smeared, and incubated at 37°C for 24 h. The number of colonies cultured was measured and expressed as log CFU/g.

Statistical analysis

All data were composed by treatments and aging periods, and presented as the mean values ± standard deviations carried out a statistical analysis. The physicochemical and microbial properties of the chicken breast were analyzed by one-way analysis of variance using the GLM procedure with the SAS program. Statistically significant differences were determined at 5% level using Duncan's multiple range test.

Results and discussion

Aging loss and trimming loss

Table 1 shows the aging loss and trimming loss based on the aging temperature and aging period of dry-aged chicken breast subjected to an EFSS. The aging loss and trimming loss by temperature of dry-aged chicken breast subjected to the EFSS tended to increase as the aging period increased. In dry aging, non-edible parts are created because the surface of the meat comes into contact with air and moisture evaporates [14]. The aging loss of the -2℃ treatment showed a significantly lower value than that of the 0 and -1℃ treatments in all aging periods ($p < 0.05$). Trimming loss showed a significantly lower value in the -2℃ treatment than in the 0 and -1℃ treatments in the 3rd and 5th weeks ($p < 0.05$). It is known that the lower the aging temperature of meat, the slower the muscle contraction rate and the faster the moisture in the meat is discharged to the outside [15]. Therefore, it is suggested that the aging loss and trimming loss are low as moisture is discharged the slowest in the -2℃ treatment where the aging temperature is the lowest.

pH

Table 2 shows the pH based on the aging temperature and aging period of the dry-aged chicken breast subjected to EFSS. During the aging process of meat, endogenous proteases such as cathepsin and calpains degrade proteins, and pH increases as metabolites are produced [16]. Therefore, it seems that the pH of dry-aged chicken breast tends to increase as the aging period increases. When electric field stimulation is applied to intramuscular organelles, membrane permeability increases, and when calcium ion inflow from the outside of the cell and intracellular calcium ion concentration increase, proteolytic enzymes that release calcium ions from the cell membrane are secreted [17]. Representative proteolytic

enzymes include cathepsin B and cathepsin L, secreted from lysosomes. The pH increased because the number of metabolites was increased by these proteolytic enzymes. The pH of the -2℃ treatment showed a significantly lower value than the 0 and -1℃ treatments in the 1st week ($p < 0.05$); however, there was no significant difference in the subsequent aging period. In meat, the lower the aging temperature, the lower the activity of the proteolytic enzymes cathepsin B and H [18]. Therefore, since the activity of proteolytic enzymes was lower in the -2℃ treatment with a lower aging temperature than in the 0° and -1℃ treatments, the amount of metabolites produced was small and the pH was low. However, the pH level of chicken breast meat did not show any difference after the 2nd week because the endogenous protease showed a difference in activity depending on the temperature; however, it was exhausted before the 2nd week of aging.

WHC

Table 3 shows the WHC based on the aging temperature and aging period of dry-aged chicken breast subjected to the EFSS. The WHC of dry-aged chicken breasts subjected to EFSS showed a tendency to increase as the aging period increased at all temperatures, and the 0 and -1℃ treatments significantly increased until the 3rd and 4th weeks, respectively ($p < 0.05$). As the pH of meat deviates from its isoelectric point (approximately 5.0–5.4), the water retention capacity increases as the space between protein molecules that can contain water widens [19]. Accordingly, as the pH increases during the dry-aging process, the WHC may be enhanced. After the 2nd week of dry aging, the WHC of the -2℃ treatment was significantly lower than that of the 0 and -1℃ treatments ($p < 0.05$). The drying speed of the -2℃ treatment was slow owing to the relatively low aging temperature, but the 0 and -1℃ treatments were fast-drying to the core, indicating a large increase in WHC. In the 0 and -1℃ treatments, the WHC was not measured at the 4th and 5th weeks, respectively. This is the result of the absence of moisture that can be measured by the compression method, as both free water evaporates from chicken breast due to dry aging, and this meat is suggested to be at an unsuitable level for consumption. Therefore, when dry aging chicken breast by applying the EFSS, it is considered appropriate to age the 0, -1, and -2℃ treatments until weeks 3rd, 4th, and 5th weeks, respectively, when the WHC can be measured.

Color

Table 4 shows the color based on the aging temperatures and aging periods of the dry-aged chicken breast subjected to the EFSS. Zhang et al. [20] reported that the lightness value of meat decreases as the amount of scattered light decreases as moisture evaporates during the dry-aging process. Accordingly, the lightness of all treatments tended to decrease as the aging period elapsed. In addition, the -2℃ treatment showed a relatively higher lightness value than the 0 and -1℃ treatments, which was due to the relatively low loss of moisture during the drying process because the -2℃ treatment had a lower aging temperature. The redness and yellowness of all the treatments tended to increase as the aging period increased. Also, in the 3rd and 4th weeks, the 0℃ treatment showed significantly higher redness and yellowness than the -1 and -2℃ treatments ($p < 0.05$). These results suggest that the protein content in meat increases as the water content decreases significantly, and the myoglobin content increases accordingly [21].

TBARS

Table 2 shows the TBARS levels based on the aging temperatures and aging periods of dry-aged chicken breast subjected to the EFSS. TBARS increases owing to the production of malondialdehyde, a secondary product, as fat in meat is oxidized [22], and the TBARS values of all treatments tended to increase as the aging period increased. However, there was no significant difference between the 0 and -1℃ treatments from the 1st week to the 4th week. This is because Ross 708 broiler breast has a low content of fat that can be oxidized, with a fat content of approximately 0.78–2.53% [23]. de Paula et al. [24] reported that meat with TBARS exceeding 1.0 mg MDA/kg can feel rancid when ingested; however, all treatments showed TBARS values less than 1.0 mg MDA/kg during the aging period, so it is suggested to be an appropriate level for consumption. The -2℃ treatment showed significantly lower TBARS than the 0 and -1℃ treatments at the 1st and 5th week, respectively ($p < 0.05$). Kang et al. [8] reported that the lower the aging temperature of meat, the slower the production rate of MDA could be, and the TBARS value was lower in the -2℃ treatment with a lower aging temperature. Therefore, when the chicken breast

198 was dry-aged by applying the EFSS, the TBARS value showed a slight increase; however, since the final
199 level showed a level suitable for consumption, it is suggested that aging is possible at any temperature.
200
201 **VBN**
202 Table 5 shows the VBN levels based on the aging temperatures and aging periods of dry-aged chicken
203 breast subjected to the EFSS. The VBN values of all treatments showed a tendency to increase as the
204 aging period elapsed, and the 0℃ treatment showed a significant increase based on the aging period ($p <$
205 0.05). The increase in the VBN value is caused by the decomposition of proteins by endogenous enzymes
206 and microbial enzymes during the dry-aging process, and the formation and accumulation of protein-
207 derived basic products such as amines and ammonia [25]. The VBN value of the 0℃ treatment was
208 significantly higher than that of the -1 and -2℃ treatments in the 1st, 2nd, and 4th weeks ($p < 0.05$). This
209 is suggested to be the result that the 0℃ treatment with a high aging temperature is relatively suitable for
210 microbial growth, and the level of protein degradation by microbial enzymes is high. This is a result of
211 the fact that the 0℃ treatment with a high aging temperature is relatively suitable for microbial growth,
212 and the level of protein degradation by microbial enzymes is high. Mentioned by the Ministry of Food
213 and Drug Safety [26], if the VBN value is less than 20 mg% g, it is treated as fresh meat. After dry aging,
214 the final VBN values of the treatments for each temperature were 4.76 mg%, 3.17 mg%, and 2.52 mg%,
215 respectively. Therefore, dry-aging of chicken breasts by applying an EFSS is suggested to be suitable for
216 consumption because the final VBN value corresponds to fresh meat at all temperatures. In addition, since
217 the −2℃ treatment showed the lowest level, it is suggested to be the optimal dry aging temperature.
218
219 **Aerobic bacteria**
220 Table 6 shows the aerobic bacteria levels based on the aging temperatures and aging periods of dry-
221 aged chicken breast subjected to the EFSS. The levels of aerobic bacteria in all treatments tended to
222 increase, and at the 1st, 2nd, 3rd, and 4th weeks, the -1 and -2℃ treatments showed significantly lower
223 values than the 0℃ treatment ($p < 0.05$). This was due to the growth of aerobic bacteria because the meat
224 was exposed to the air during the dry-aging process, and the growth of microorganisms was smooth

owing to the relatively high aging temperature in the 0℃ treatment [27]. A high level of microbial growth in meat can cause an off-odor and discoloration, which can reduce quality; therefore, care is needed [28]. Moller et al. [29] reported that the number of aerobic bacteria in chicken meat starts to decay at a level of 6 log/CFU, and Spyrelli et al. [30] reported that the shelf life of chicken meat ends when the levels of aerobic bacteria exceed 7 log/CFU. Therefore, since the number of aerobic bacteria exceeded 7 log / CFU from the 3rd week of the 0℃ treatment, it was determined that intake was impossible. In addition, since the -1 and -2℃ treatments exceeded 6 log/CFU from the 4th week, aging up to the 3rd week is considered to be microbiologically safe.

Conclusion

This study, an electric field supercooling system to chicken breast and dry-aged it at three temperatures (0℃, -1, and -2℃) to set the optimal aging temperature and period. The aging loss and trimming loss of chicken breast could be minimized when dry-aged at -2℃. Because the WHC of some treatments is not measured due to excessive drying and is inappropriate for intake, it is considered appropriate to age at 0, -1, and -2℃ for up to 3, 4, and 5 weeks, respectively. TBARS and VBN showed safe levels at all temperatures, even at the end of aging, but the -2℃ treatment showed the lowest value. The level of aerobic bacteria in the 0℃ treatment was shown to be contaminated from the 3rd week, and the level of aerobic bacteria in the -1 and -2℃ treatments was showed as less than 7 log/CFU in all aging periods. Therefore, considering the physicochemical and storage properties, it is most appropriate to dry-aged chicken breast at -2℃ for 3 weeks using the electric field supercooling system.

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Tables

Table 1. Aging loss (%) and trimming loss (%) based on the aging temperatures and aging periods of dry-aged chicken breast subjected to the electric field supercooling system

Traits	Temperature (℃)	Dry-aging period (weeks)				
		1	2	3	4	5
Aging loss	0	25.08 ± 3.71^{Ac}	44.93 ± 2.36^{Ab}	56.01 ± 1.49^{Aa}	57.00 ± 2.43^{Aa}	-
	−1	24.09 ± 2.09^{Ac}	38.27 ± 1.46^{Bb}	53.84 ± 3.59^{Aa}	57.47 ± 4.96^{Aa}	67.06 ± 2.68^{Aa}
	−2	12.98 ± 2.09^{Bc}	27.27 ± 2.89^{Cb}	36.42 ± 4.24^{Ba}	47.18 ± 3.76^{Ba}	50.64 ± 3.93^{Ba}
Trimming loss	0	35.18 ± 5.68^{Ac}	43.93 ± 4.20^{Ab}	65.94 ± 4.00^{Aab}	67.04 ± 8.35^{Aa}	-
	−1	30.69 ± 5.03^{Ac}	44.49 ± 1.14^{Ab}	69.35 ± 3.47^{Aa}	69.20 ± 2.64^{Aa}	72.85 ± 1.97^{Aa}
	−2	33.57 ± 4.68^{Ac}	43.66 ± 1.39^{Ab}	62.33 ± 4.73^{Ba}	66.15 ± 3.24^{Aa}	66.16 ± 4.02^{Ba}

All values are mean ± SD.

[a-c] Means in the same row with different numbers are significantly different ($p < 0.05$).

[A-C] Means in the same column with different numbers are significantly different ($p < 0.05$).

342 Table 2. pH based on the aging temperatures and aging period of dry-aged chicken breast subjected to the electric field supercooling system

Trait	Temperature (℃)	Dry-aging period (weeks)					
		0	1	2	3	4	5
pH	0	5.87 ± 0.02^{b}	5.96 ± 0.02^{Aab}	6.01 ± 0.17^{ab}	6.07 ± 0.02^{a}	6.10 ± 0.17^{a}	-
	−1	5.87 ± 0.02^{d}	5.96 ± 0.03^{Ac}	6.04 ± 0.04^{b}	6.06 ± 0.04^{b}	6.20 ± 0.09^{a}	6.28 ± 0.07^{a}
	−2	5.87 ± 0.02^{d}	5.85 ± 0.03^{Bd}	5.93 ± 0.03^{cd}	6.02 ± 0.04^{bc}	6.07 ± 0.14^{b}	6.30 ± 0.06^{a}

343 All values are mean ± standard deviation.

344 $^{a-d}$ Means in the same row with different numbers are significantly different ($p < 0.05$).

345 ^{A,B} Means in the same column with different numbers are significantly different ($p < 0.05$).

346

Table 3. Water holding capacity (WHC, %) based on the aging temperatures and aging period of dry-aged chicken breast subjected to the electric field supercooling system

Trait	Temperature (℃)	Dry-aging period (weeks)					
		0	1	2	3	4	5
WHC	0	54.02 ± 2.34^{c}	65.10 ± 4.58^{b}	93.42 ± 2.52^{Aa}	98.14 ± 0.78^{Aa}	-	-
	−1	54.02 ± 2.34^{e}	62.19 ± 4.10^{d}	75.50 ± 4.98^{Bc}	89.26 ± 2.34^{Bb}	96.71 ± 2.94^{Aa}	-
	−2	54.02 ± 2.34^{e}	60.02 ± 4.10^{de}	64.32 ± 4.60^{Cbc}	67.00 ± 4.31^{Cbc}	69.48 ± 7.10^{Bab}	76.00 ± 9.35^{a}

All values are mean ± standard deviation.

$^{a-e}$ Means in the same row with different numbers are significantly different ($p < 0.05$).

$^{A-C}$ Means in the same column with different numbers are significantly different ($p < 0.05$).

Table 4. Color based on the aging temperatures and aging period of dry-aged chicken breast subjected to the electric field supercooling system

Trait	Temperature (℃)	Dry-aging period (weeks)					
		0	1	2	3	4	5
L^*	0	52.88 ± 0.94^{a}	46.04 ± 1.90^{Bb}	43.85 ± 2.07^{Bc}	42.88 ± 0.84^{Cc}	42.10 ± 0.81^{Cc}	-
	−1	52.88 ± 0.94^{a}	47.80 ± 2.30^{ABb}	46.13 ± 1.69^{ABbc}	44.78 ± 0.40^{Bcd}	43.62 ± 0.61^{Bde}	42.04 ± 2.45^{e}
	−2	52.88 ± 0.94^{a}	48.84 ± 1.09^{Ab}	47.22 ± 1.70^{Ac}	46.43 ± 0.70^{Ac}	46.93 ± 0.29^{Ac}	44.00 ± 0.96^{d}
a^*	0	1.12 ± 0.28^{d}	2.08 ± 0.36^{c}	3.53 ± 0.98^{Ab}	5.07 ± 0.74^{Aa}	5.67 ± 1.18^{Aa}	-
	−1	1.12 ± 0.28^{d}	1.53 ± 0.28^{cd}	1.93 ± 0.71^{Bcd}	2.50 ± 0.62^{Bc}	3.95 ± 1.55^{Bb}	5.84 ± 1.14^{Aa}
	−2	1.12 ± 0.28^{c}	1.43 ± 0.95^{c}	1.62 ± 0.51^{Bc}	1.72 ± 0.43^{Bbc}	2.43 ± 0.48^{Cb}	3.68 ± 0.62^{Ba}
b^*	0	5.08 ± 0.96^{d}	6.83 ± 1.36^{c}	10.68 ± 2.17^{Ab}	11.66 ± 0.92^{Ab}	13.09 ± 0.79^{Aa}	-
	−1	5.08 ± 0.96^{d}	7.32 ± 0.85^{c}	8.35 ± 0.39^{ABb}	8.70 ± 0.42^{Bab}	8.82 ± 0.45^{Bab}	9.57 ± 0.85^{a}
	−2	5.08 ± 0.96^{d}	6.61 ± 0.96^{c}	7.69 ± 1.57^{Bbc}	8.32 ± 0.67^{Bab}	8.57 ± 0.66^{Bab}	9.33 ± 1.09^{a}

All values are mean ± standard deviation.

[a-d] Means in the same row with different numbers are significantly different ($p < 0.05$).

[A-C] Means in the same column with different numbers are significantly different ($p < 0.05$).

Table 5. Thiobarbituric acid reactive substances (TBARS, mg malondialdehyde/kg meat) and volatile basic nitrogen (VBN, mg%) based on the aging temperatures and aging period of dry-aged chicken breast subjected to the electric field supercooling system

Trait	Temperature (℃)	Dry-aging period (weeks)					
		0	1	2	3	4	5
TBARS	0	0.26 ± 0.04^{b}	0.34 ± 0.04^{Aa}	0.37 ± 0.01^{a}	0.35 ± 0.02^{a}	0.34 ± 0.02^{a}	-
	−1	0.26 ± 0.04^{c}	0.33 ± 0.01^{ABb}	0.37 ± 0.04^{b}	0.34 ± 0.01^{b}	0.33 ± 0.02^{b}	0.50 ± 0.06^{Aa}
	−2	0.26 ± 0.04^{d}	0.30 ± 0.02^{Bcd}	0.34 ± 0.02^{bc}	0.33 ± 0.02^{bc}	0.35 ± 0.01^{ab}	0.39 ± 0.01^{Ba}
VBN	0	1.26 ± 0.28^{e}	1.96 ± 0.32^{Ad}	2.52 ± 0.32^{Ac}	3.50 ± 0.28^{Ab}	4.76 ± 0.32^{Aa}	-
	−1	1.26 ± 0.28^{b}	1.31 ± 0.32^{Bb}	1.40 ± 0.32^{Bb}	2.99 ± 0.32^{Aa}	2.99 ± 0.32^{Ba}	3.17 ± 0.32^{Aa}
	−2	1.26 ± 0.28^{c}	1.26 ± 0.28^{Bc}	1.40 ± 0.32^{Bc}	1.96 ± 0.32^{Bb}	2.52 ± 0.32^{Ba}	2.52 ± 0.32^{Ba}

All values are mean ± standard deviation.

[a-e] Means in the same row with different numbers are significantly different ($p < 0.05$).

[A,B] Means in the same column with different numbers are significantly different ($p < 0.05$).

Table 6. Aerobic bacteria (log colony form unit/g) levels based on the aging temperatures and aging period of dry-aged chicken breast subjected to the electric field supercooling system

Trait	Temperature (℃)	Dry-aging period (weeks)					
		0	1	2	3	4	5
Aerobic bacteria	0	3.13 ± 0.19^{c}	5.65 ± 0.29^{Ab}	5.75 ± 0.18^{Ab}	7.49 ± 0.68^{Aa}	7.62 ± 0.70^{Aa}	-
	−1	3.13 ± 0.19^{f}	3.85 ± 0.40^{Be}	4.77 ± 0.06^{Bd}	5.38 ± 0.16^{Bc}	6.36 ± 0.14^{Bb}	6.64 ± 0.26^{a}
	−2	3.13 ± 0.19^{d}	3.37 ± 0.32^{Bd}	4.60 ± 0.24^{Bc}	5.47 ± 0.43^{Bb}	6.25 ± 0.41^{Ba}	6.52 ± 0.37^{a}

All values are mean ± standard deviation.

$^{a-f}$ Means in the same row with different numbers are significantly different ($p < 0.05$).

^{A,B} Means in the same column with different numbers are significantly different ($p < 0.05$).

Figure

Figure 1. Electric field supercooling refrigerator (Outside / Inside)