A Thesis for the Degree of Master

Quality changes of pork loins during dry aging in scoria-containing *onggi*

화산송이석 함유 옹기를 이용한 건식 숙성 중 돈육 등심의 품질변화

August 2022

Sung-Su Kim

Department of Agricultural Biotechnology
Graduate School
Seoul National University

Quality changes of pork loins during dry aging in scoria-containing *onggi*

Advisor: Prof. Cheorun Jo, Ph.D.

Submitting a Master's Thesis of Agriculture

June 2022

Department of Agricultural Biotechnology
Graduate School
Seoul National University

Sung-Su Kim

Confirming the Master's Thesis written by
Sung-Su Kim

June 2022

화산송이석 함유 옹기를 이용한 건식 숙성 중 돈육 등심의 품질변화

Quality changes of pork loins during dry aging in scoria-containing *onggi*

지도교수 조 철 훈

이 논문을 농학석사학위논문으로 제출함
2022년 06월

서울대학교 대학원 농생명공학부
김 성 수

김성수의 석사학위논문을 인준함
2022년 06월

위 원 장 ______________________ (인)

부위원장 ______________________ (인)

위　　원 ______________________ (인)

Abstract

Quality changes of pork loins during dry aging in scoria-containing *onggi*

Sung-Su Kim

Program in Animal Science and Biotechnology

Department of Agricultural Biotechnology

Graduate School of Seoul National University

The objective of this study was to determine the effect of scoria powder in Korean earthenware (*onggi*) on meat quality of pork loins during 21 days of dry-aging periods [temperature, 3±1℃; relative humidity, 80-85%] and elucidate the mechanism of meat aging in *onggi* containing scoria powder. The samples (n=30) were randomly arranged into three groups: meat aged in vacuum-packaging (VP), meat aged in *onggi* containing red clay only (OR), and that containing 30% red clay and 70% scoria powder (OS). Microbial analyses (total plate count and *Lactobacillus* spp.) and physicochemical analyses [pH, shear force, volatile basic nitrogen (VBN), water activity, 2-thiobarbituric acid reactive substances, water content, water holding capacity, cooking loss, and color analysis] of aged meat were conducted, and the mechanism-related analyses of far infrared ray (FIR) irradiation, immobilization of *Lactobacillus* spp., and microstructural properties for *onggi*es were conducted. On day 21 of aging, the meat aged in OS exhibited lower pH, shear force, VBN, and water activity than that aged in OR, along with the increase in number of *Lactobacillus* spp. ($p<0.05$). From the comparison between OR and OS, OS had smaller pore diameters which implies the lower permeability than that of OR. This low permeability of OS could induce favorable condition for the growth of *Lactobacillus* spp. In conclusion, OS improved the quality and microbiological safety of pork loin from OR during dry aging by increasing number of *Lactobacillus* spp. possibly due to lower permeability of OS.

Keywords: *Onggi*, Scoria, Pork loin, Meat aging, Lactic acid bacteria

Student Number: 2020-29386

Contents

The effect of scoria-containing *onggi* on meat quality of pork loins

List of Tables

Chapter II.

List of Figures

Chapter II.

List of Abbreviations

VP	:	Vacuum-packaging
OR	:	*Onggi* containing red clay only
OS	:	*Onggi* containing 30% red clay and 70% scoria powder
TPC	:	Total plate count
VBN	:	Volatile basic nitrogen
TBARS	:	2-thiobarbituric acid reactive substances
WHC	:	Water holding capacity
a_w	:	Water activity
LAB	:	Lactic acid bacteria
PCR	:	Polymerase chain reaction
DDW	:	Deionized distilled water
BHT	:	3, 5-di-tert-butyl-4-hydroxytoluene
TBA	:	Thiobarbituric acid
TCA	:	Trichloroacetic acid
MDA	:	Malondialdehyde
SEM	:	Scanning electron microscopy
FIR		Far infrared ray

Chapter I.

Literature review

1.1. Korean earthenware (*onggi*)

1.1.1. Definition and functions of onggi

Korean earthenware (*onggi*) has been used for storing foods from 6000 BC (Lee, 1999). Since Korean traditional foods are mostly fermented foods, such as kimchi, doenjang, kochujang, etc., *onggi* has been used for fermentation and ripening, long-term maintenance of which gives beneficial conditions for the growth of useful bacteria (Yoo et al., 2001; Jung et al., 2004). In ancient literature, porous structure of *onggi* is said to contribute to providing the desired quality of the foods. (Seo et al., 2005). Porosity of *onggi* could be controlled by different clay composition ratio and glazing, and it affects air permeability of *onggi*. Proper permeability of *onggi* is quite important for appropriate quality of foods (Seo et al, 2006).

Degree of *onggi* barrier against water and gas need to be determined to assess the effectiveness of *onggi* in food preservation and ripening. It is because quality of foodstuffs in *onggi* relies on interactions between inner and outer environment (Kim et al., 2003). O_2 permeability of *onggi* gets involved in many chemical and biological changes of foods, such as microbial growth, rancidity, and respiration, and CO_2 permeability of *onggi* is associated with inhibition against microbial growth. The blend of O_2 and CO_2 permeabilities creates modified atmosphere inner side of container (Seo et al., 2005). In addition, water permeability controls moisture of contained foods in *onggi*. (Yang et al., 2016; Seo et al., 2005). Excessive humidity in *onggi* may promote food spoilage due to the growth of spoilage microbe (Mistriotis et al., 2011). Therefore, gas and water permeability of *onggi* are probably essential criteria for suitable modified atmosphere.

1.1.2. Application of onggi for foodstuff

Onggi affected positively the quality of soybean sauce and kimchi during fermentation or ripening but stainless container, glass container, and polypropylene container, and plastic vessle did not (Chung et al., 2004; Han et al., 2013). Chung et al. (2006) stated that *onggi* with onggito, which had lower porosity than *onggi* with red clay and ground soil, induced better quality of soybean sauce, such as lower pH and browning rate, and higher number of LAB, glutamic acid contents and sensory evaluation values than those with red clay and ground soil. *Onggi*, which were glazed on the exterior and interior, also rendered soybean sauce better quality than unglazed *onggi* due to the lower porosity of glazed *onggi* (Lee, Lee, Lee, & Chung, 2006). When it comes to kimchi fermentation, the higher numbers of LAB were identified in *onggi* rather than in plastic vessle (Han et al., 2013). Proper porosity, which is one of the traits of *onggi*, could cause conditions that is useful for the growth of beneficial bacteria (Ishizaki, et al., 1998). The early fermentation condition with aerobic state could be changed to anaerobic state during fermentation in *onggi*, which decreased the growth of aerobic microorganisms (Han et al., 2013). In addition, microorganisms can be immobilized into pores in *onggi*, accelerating fermentation in *onggi* (Chung et al., 2006).

1.2. Scoria

1.2.1. Definition of scoria

Scoria is bubbly glassy lava rock of alkalescent, which is ejected from a vent during explosive eruption. Thus, scoria is known as a kind of natural ceramics (Masoud et al, 2015; Cho et al, 2014; Kang, 2018). Scoria contains volcanic bombs, rock, gravel, and ashes (Kang, 2018), and its chemical compounds were confirmed as SiO_2 (67%), Al_2O_3 (15.6%), K_2O (5.4%), Fe_2O_3 (1.1%), Na_2O (3.7%), etc, that is, SiO_2 and Al_2O_3 were two paramount components (Masoud et al., 2015). It is related to physical properties of scoria, such as high far infrared radiation rate, antibacterial activity, and deodorization capacity (Jeon et al., 2018), plus high iron content is associated with dark gray to black in color of scoria (Masoud et al., 2015). Moreover, scoria is probably usable for various beauty materials, such as skin moisturizing, pore tightening, cleansing (Kang, 2018).

1.2.2. Functions of scoria

1.2.2.1. Modified atmosphere with scoria

Storage under modified and controlled atmosphere is affected by the concentration of O_2, CO_2, water vapor, and other gases. Especially, control of O_2 and CO_2 concentration around products has been confirmed in the prior roles to increased shelf life of stored foods (Christie et al., 1998). For example, O_2 concentration under about 1% or CO_2 concentration greater than approximately 15% could induce offensive off-odor and off-flavors for modified atmosphere research into broccoli. Optimum O_2 and CO_2 levels range for broccoli were 1-2.5% and 5-10%, respectively (Christie et al., 1998).

Inert porous filler is effective to reduce the ratio of CO_2 to O_2 permeability of film. The inert porous fillers might be naturally-occurred porous material, such as scoria, or synthetic porous material like metal oxides. Moreover, metal oxides, such as SiO_2 and Al_2O_3, were preferred as inorganic filler due to its better CO_2/O_2 permeability ratio-inducing property (Christie et al., 1998).

1.2.2.2. Lactobacillus immobilization on scoria

Cell immobilization is localization or physical restraint of cells to specific regions, and it has a number of benefits relative to free cell during fermentation or ripening (Martins et al., 2013). It can induce cells to have high productivity, reduce risk for microbial contamination, and improve resistance of cells to inhibitory substrates (Zhu, 2007). Cell immobilization is classified into two groups, adsorption and entrapment (Vega et al., 1988). First of all, adsorption is related to a direct binding of cells to water-insoluble carriers (porous and inert support materials) by physical adsorption or ionic bonds or covalent bonds (Zhu, 2007; Kilonzo et al., 2012). On top of that, entrapment contains enclosure of cells in support matrix or inside fibers, creating a protective barrier for immobilized microbes (Górecka et al., 2011).

Ceramics, such as scoria, can control pore sizes which are suitable for microbe immobilization, and are quite superior to affinity with microorganisms (Kang, 2018; Kang et al., 2011). Ceramic carrier for prevention of water pollution required 40% porosity and at least longer than 50 μm pore size. Pore, which has 10 times greater than microbe size for water purification, is stable as microbe habitat. Furthermore, surface charge of ceramic carrier is very important. With respect to solutions with lower pH than point of zero charge for carrier, carrier surface is positively charged, absorbing negative ions. However, in solutions with higher pH than point of zero charge of carrier, condition was reverse (Kang et al., 2011). Besides, *Lactobacillus* spp. was successfully encapsulated in SiO_2, main component of scoria (Zhao et al., 2016).

1.2.2.3. FIR irradiation of scoria

Electromagnetic wave has some kinds of energy and frequency. It is divided into the ultraviolet ray, visible light, infrared ray, microwave, and so on. The range of the infrared ray is 0.76 μm to 1,000 μm of wavelength (Robinson, 1973). Based on the wavelength, the infrared ray could be classified into near infrared ray (0.78-2.0 μm), middle infrared ray (2-5 μm), and far infrared ray (FIR) (5-15 μm) (Omori, 1994).

The composition of FIR radiator contains metal oxide, such as SiO_2 and Al_2O_3 (Iita, 1988). As these materials obtain energy, those radiate radiation, such as FIR. FIR radiated from the vibration of metal-O_2 bond, thus radiating more relative to compound with higher amounts of O_2 (Park, 1991). Scoria radiates FIR because SiO_2 and Al_2O_3 were two paramount components of scoria (Masoud et al., 2015).

1.3. FIR

1.3.1. Law of FIR irradiation

Kirchhoff's law means that ratio of emission to absorption is constant for same wavelength regardless of material properties, only depending on temperature (Kim, 1997). According to this law, when it comes to the same temperature and wavelength, the absorption rate is radiation rate for specific materials (Choi, 2001).

Stefan-Boltzman's law explains radiation energy of black body is proportional to the four squares of absolute temperature. Enormous energy is radiated by high temperature (Choi, 2001).

Wien's displacement law explains how the center wavelength of radiated energy changes depending on temperature. Irradiated wavelength with maximum intensity is inversely proportional to absolute temperature. In other words, the center wavelength of radiated energy moves from invisible FIR to visible rays as temperature increases (Choi, 2001).

Plank's radiation law is related to distribution of radiated energy. With respect to black body, its maximum radiated energy and wavelength lower according to increase of absolute temperature. In addition, based on Stefan-Boltzman's law, whole radiated energy from black body increases depending on increment of absolute temperature (Choi, 2001).

1.3.2. Application of FIR

In room temperature, FIR gives heat insulation effects, physicochemical substances activation, and promotion of antioxidant properties (Kim, 2001). To be specific, for food preservation and storage, plastic bowl, plastic bags, and ceramic pane could be used due to their FIR-radiating properties for maintenance of food freshness with long period (Kim, 1997). Choi (2001) stated that FIR-radiating ceramics prevents corrosion and degradation of a soluble emulsion. It was because evenly spread water molecules, surrounding proteins, nucleotides, and cells, could be activated by FIR, followed by delaying structural corrosions with good heat transfer ability. Moreover, FIR radiation-related plastic bowl, sheet, filters for water purifier, and kettle preserved water with long period, and increased sensory properties of water (Kim, 1997).

Chapter II.

Quality changes of pork loins during dry aging in scoria-containing *onggi*

This manuscript consists of part of a paper submitted to Food Packaging and Shelf Life as partial fulfillment of the Master's program of Sung-Su Kim.

2.1. Introduction

Aging is a method to enhance tenderness, flavor and overall acceptance of meat (Ha et al., 2019). Aging induces meat tenderization by its inherent proteolytic enzymes (e.g. cathepsins, proteasome, calpains) and increases formation of flavor compounds. The aging methods are majorly sorted by wet and dry aging, depending on the existence of vacuum packaging (Khan, Jung, Nam, & Jo, 2016).

Wet aging is a method using vacuum packaging at designated temperature (Ha et al., 2019). Vacuum packaging limited proliferation of aerobic bacteria in wet aged meat, flavor of which did not change during aging period (Khan et al., 2016). Dry aging is a preservation method in air under controlled relative humidity, air velocity, and temperature without vacuum packaging (Ha et al., 2019). Dry aged meats are recognized as premium products in restaurants due to its own characteristic flavor, such as beefy and roasted flavor (Lee, Choe, Yoon, Kim, Oh, Yoon, & Jo, 2018). However, dry aged meat is exposed to microbiological risks by fluctuating temperature and humidity, and cross contamination all the time as it is aged being exposed on the atmosphere (Lee et al., 2018). To commercialize the dry-aged meat with highly acceptable flavor and safety, there have been different dry-aging methods developed and applied in the industry but still it is difficult to confirm its safety.

Korean earthenware (*onggi*) has been utilized to store and ripen foodstuffs, such as cereal, vegetables (Seo, Chung, An, & Lee, 2005). Fermentation with *onggi* induced better product quality of food relative to the one without *onggi* (Chung, Lee, & Lee, 2006). It has been known that barrier properties against moisture and gas determined food quality in food preservation in *onggi*, relying on interactions between the inner and external environment (Kim, Park, & Lee, 2003). Seo et al. (2005) showed *onggi* with controlled permeability could create modified atmosphere for ripening products inside it, and the barrier traits of *onggi*, which are related to gas and moisture permeation, are able to be controlled and diversified by different clay formulations.

Scoria which is widely distributed over parasitic volcano area in Jeju Island is an alkalescent and volcanogenous soil that is composed of rocks, sand, and ash during the eruption of volcano. Main ingredients of scoria are SiO_2 (30-50%), Al_2O_3 (10-20%), F_2O_3 (10-20%) (Jo, Lee & Mok, 2014), thus making its own physical properties, such as high FIR and antibacterial activity (Kang, 2018). Scoria has been used due to its high FIR-radiating property (Choi, 2001; Joo & Won, 2019). Lin

(2003) stated that when FIR was irradiated, its wavelength caused vibrations in bacteria's tissues, which could deform its protein and nucleic acid to prevent meat corruption.

Some research papers introduced the effects of *onggi* with different clay ratio on the foods stored in it (Chung et al., 2006; Seo et al., 2005). However, no data is known regarding the effects of scoria-containing *onggi* on meat quality during dry aging and its mechanism of action. Therefore, this study aimed to investigate the effect of scoria powder in *onggi* on meat quality and microbiological property of pork loins for 21 days of dry-aging periods and elucidate its mechanism.

2.2. Materials and methods

2.2.1. Preparation

2.2.1.1. Preparation of onggi

In this study, two types of *onggi* were used. One was the *onggi* consisted of 100% red clay, and the other one was composed of 70% scoria power and 30% red clay. Pugging was made from each *onggi* soil and formed into 24 L cylinder-shaped jars, with a height of 37 cm, and a 1.7 cm thickness. After they were dried for 24 h in the shade, and then bisque fired at 750°C for about 7 h in an electric kiln (SI 700; Seil Inc., Ulsan, Korea), followed by cooling down naturally. The vessels were then coated with glazing on the exterior, and fired in a kiln with the temperature gradually increasing at 5°C/min to 450°C and to 1100°C for 5.5 h. Lastly, vessels were heated at 1190°C for 20 min, followed by cooling down slowly.

2.2.1.2. Raw material and aging process

Fig. 1 displayed overall experimental design and conditions. At 24 h post mortem, pork loins were obtained from a local slaughterhouse (Seoul, Korea). Nine samples (750 ± 10 g) were randomly assigned into three groups (n=3/group); meat aged in VP, meat aged in OR, and that aged in OS. Loins for VP were vacuum-packaged (HFV-600V, Hankook Fujee Co., Ltd., Siheung, Korea) with low density polyethylene/nylon bags (O_2 permeability of 22.5 mL/m^2/24 h atm at 60% RH/25°C and water vapor permeability of 4.7 g/m^2/24 h at 100% RH/25°C), and loins for OR and OS were put into each *onggi*. All groups were aged for 0, 7, 14, and 21 days in a walk-in cooler with specific conditions (temperature, 4°C; relative humidity, 80-

85%; air velocity, 2 m/s). At the sampling stage, the crust in dry aged loins was trimmed off and all samples were stored in vacuum packaged condition at - 70°C until further analyses.

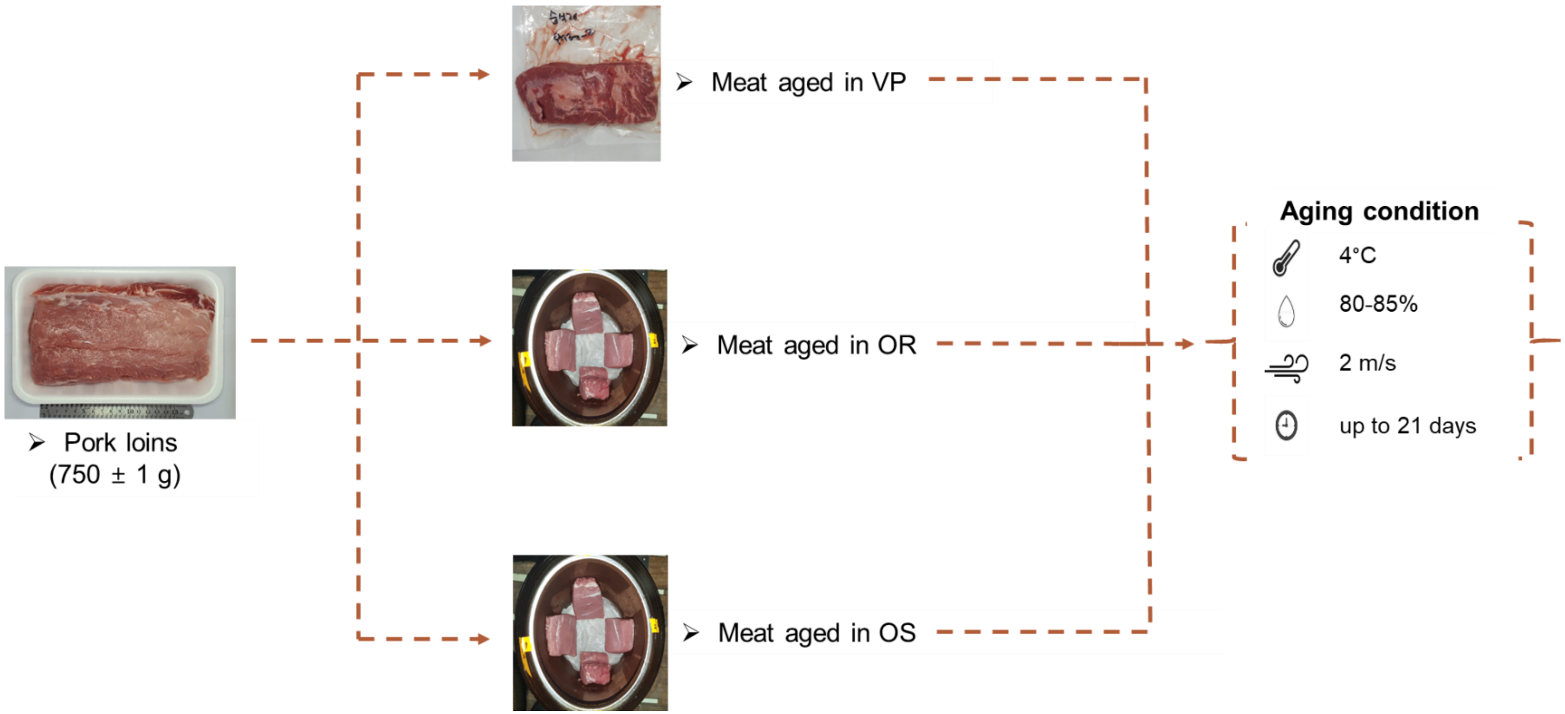

Fig. 1. Graphical illustration of the experimental design. VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder.

2.2.2. Microbial analysis

2.2.2.1. Microbial growth

Twenty-five grams of samples on each ripening condition were blended with 225 mL of 0.85% saline solution for 2 min using a stomacher (BagMixer® 400, Interscience Ind., St. Nom, France). One milliliter from each sample dilution was poured into each agar. TPC and *Lactobacillus* spp. were enumerated using plate count agar (Difco Laboratories, Detroit, MI, USA) and *lactobacilli* MRS broth with agar (Difco Laboratories, USA), respectively. The agar plates for TPC and *Lactobacillus* spp. were incubated at 37°C for 72 h and 96 h, respectively, and the number of colonies was enumerated (log CFU/g).

2.2.2.2. Microbial isolation and identification

The *Lactobacillus* spp. on *lactobacilli* MRS broth with agars at day 14 and 21 were used for microbial isolation, colonies of which were dissociated into different plates depending on their phenotype characteristics, such as shape, size, and color. The colonies which were separated to different plates were used for PCR analysis.

The colonies on each plate were identified using 16s rRNA sequencing for bacteria. RNA was extracted and amplified as follows: i) initial denaturation at 95°C for 5 min, ii) denaturation at 95°C at 0.5 min, iii) annealing at 55°C for 2 min, iv) extension 68°C for 1.5 min with 30 cycles, and v) final extension at 68°C for 10 min. Identification was based on RNA database (NCBI).

2.2.3. Physicochemical properties

2.2.3.1. pH and VBN

Meat samples (1 g) were homogenized with DDW (9 mL) and pH was measured by a pH meter (Seven2Go, Mettler-Toledo Inti., Inc., Switzerland) following a method of Lee (2018). Prior to the measurement, the pH meter was calibrated with the standard buffers at 4.01, 7.00, and 9.21 (Mettler-Toledo Inti., Inc.).

The VBN was analyzed by method of Lee et al. (2018). Each sample (3g) with 27 mL was homogenized for 30 s (T25 digital ULTRA TURRAX, IKA, Germany) followed by centrifugation (Continent 512R, Hanil Co., Ltd.) at 2,265×g for 10 min. After filtration, 0.01 N boric acid and indicator solution [0.66% methyl red in ethanol: 0.66% bromocresol green in ethanol=1:1 (v/v)] was placed individually in the inner section of a conway (Sibata Ltd., Sitama, Japan); then, 1 mL of sample and 50% potassium carbonate was added into the outer section of the conway, after which the lid was sealed immediately. Then, the conways were incubated at 37°C for 1 h and titrated with 0.01 N hydrogen chloride. The VBN values were expressed as mg/100 g.

2.2.3.2. TBARS

The TBARS was analyzed by method of Lee et al. (2018). Samples (5 g) were homogenized in 15 mL DDW with 50 μL BHT in ethanol at 9,600 rpm for 30 s (IKA, Germany) followed by being centrifuged at 4°C and 2,265×g for 15 min (Hanil Co., Ltd., Korea). After supernatants were filtered through No.4 filter paper (Whatman

No. 4, Whatman PLC., Kent, UK), TBA solution in TCA was added. Following voltex, the mixtures were heated at 90℃ for 30 min, then centrifuged at 4℃ and 2265 ×g for 15 min in centrifuge again (Hanil Co., Ltd.). The absorbance at 532 nm of the supernatants was measured with spectrophotometer (Otizen 2120 UV plus, Mecasys Co. Ltd., Seoul, Korea). Results were rendered as mg MDA/kg meat.

2.2.3.3. Shear force

The meat samples (100 ± 5 g) were boiled in a water bath until a core temperature was reached at 72°C. After heating, the cooked samples were cut parallel to the muscle fiber into rounded cores (1.27 cm diameter), and placed under a Warner-Bratzler shear probe, perpendicularly to the muscle fiber. Shear force (N) was measured by a texture analyzer (TA1, Lloyd Instruments Ltd., Fareham, UK) with a cell load of 0.1 N and a crosshead speed of 200 mm/min.

2.2.3.4. a_w, WHC, water content, and cooking loss

a_w was measured by Rotronic HygroPalm HP23-Aw-A meter (ROTRONIC AG, Switzerland). WHC of the ground pork loin was measured with the method from Lim, Cha, Jo, Lee, Kim, & Nam (2014). The water content was determined using the official methods of the AOAC International (Horwitz & Latimer, 2006). The cooking loss of meat blocks (100 ± 5 g) was defined as a percentage by proportion of the weight before and after cooking.

2.2.3.5. Color analysis

After 30 min blooming, instrumental color measurement on the surface-cut meat was conducted by a spectrophotometer (CM-5, Konica Minolta Censing Inc., Osaka, Japan). The colorimeter was calibrated utilizing a standard white and black plate before each measurement. CIE L* (lightness), a* (redness) and b* (yellowness) values were obtained from the average values of six readings on the surface of loin samples. Hue angle (tan−1 (b*/a*)) and chroma ((a*2+b*2)1/2) were calculated by CIE L*, a*, and b*.

2.2.4. Characteristics of onggi

2.2.4.1. FIR emissivity and radiant energy

To investigate the FIR properties of OR and OS, samples were prepared with a specific size (30 mm × 30 mm × 5 mm; width × length × height). FT-IR spectrometer was used over the range of 5-20 μm at 37°C according to the standard measurement method (KFIA-FI-1005), provided by Korea Far Infrared Association.

2.2.4.2. SEM

The SEM was performed according to the method described by Shin, Lee, Lee, Jo, and Cho (2020) with a few modifications. Broken pieces with size (1 mm × 1 mm × 1 mm; width × length × height) from each *onggi* were placed carefully on aluminum stubs with carbon tape and coated with platinum under vacuum for surficial visualization. Samples were obtained using a field emission SEM (AURIGA, Carl Zeiss Microscopy, Thornwood, NY, USA).

2.2.4.3. Quantification of immobilized L. sakei on onggi

Lactobacillus species on meat aged in OS were identified as *Lactobacillus sakei* (data not shown). To analyze the *L. sakei* immobilization, counts of *Lactobacillus* spp. on the inner surface of *onggi*es was conducted by swabbing method. The inner surface of *onggi* was gently swabbed with cotton swab soaked in 0.85% sodium chloride with 0.1% Tween-20. The swab head was immersed in 500 μL of sterile saline solution for shaking out the bacteria, followed by centrifugation at 5,600×g for 10 min to collect the bacterial pellet. The collected pellet was suspended in 200 μL of sterile saline solution, and then spread on *lactobacilli* MRS broth with agar (Difco Laboratories, USA). The plates were incubated at 37°C for 96 h.

To check the presence of *L. sakei* on cross-section of *onggi*es, pure cotton gauze (15 cm × 15 cm; width × length) was cut. Broken pieces with size (1 mm × 1 mm × 1 mm; width × length × height) from each *onggi* were wrap up with cut cotton gauze, followed by being hung by silk thread during aging in *onggi* (Fig. 4). The hung *onggi* pieces and pork loin in *onggi* were placed 5 cm apart. At day 21, hung pieces were blended with 0.85% saline solution for 2 min using a laboratory stomacher (Interscience Ind., St. Nom, France) to sperate *L. sakei* on the cross-section. One milliliter from each sample dilution was poured into *lactobacilli* MRS broth with agar, followed by being incubated at 37℃ for 96 h.

2.2.4.4. Microstructural property

Pore diameter, total pore area, porosity, and density of OR and OS, which are important factors controlling the barrier properties, were measured by a mercury porosimeter (AutoPore IV9500, Micromeritics, Norcross, GA, USA). Broken pieces with size (1 mm × 1 mm × 1 mm; width × length × height) from each *onggi* were used as samples. Before intruding mercury in step-wise pressure increments in the range from 0.52 to 59974.04 psia, the undisturbed pieces with open pore structures were oven-dried at 105°C and degassed in a vacuum under pressure 6.67 Pa at temperature of 20°C. Average pore diameter (4 V/A) was obtained by assuming that all pores are right cylinders, thus when the volume (V=πr2L) is divided by the pore area (A=2πrL), the average pore radius (r) is equal to 4V/A. Porosity was derived from the ratio of the total intruded volume of mercury at the highest pressure determined (59974.04 psia) to the total volume of a sample.

2.2.5. Statistical analysis

All experiments were performed in triplicate. A general linear model was used to perform the analysis using SAS 9.4 (SAS Institute Inc., Cary, NC, USA), and results were reported as mean values with standard error of means (SEM). After each ANOVA, significant differences among means were further tested by the Student–Newman–Keuls test.

2.3. Results and discussion

2.3.1. Microbial analysis

Meat aged in VP had the lowest TPC and *Lactobacillus* spp. number among the treatments during storage (Table 1). It was because meat aged in VP was isolated from external atmosphere by vacuum packaging. Sebranek and Houser (2006) mentioned plastic bags for vacuum package are effective gas barrier and has sealing characteristics.

At day 21, meat aged in OS displayed the topmost value of *Lactobacillus* spp. compared to that of others. The higher *Lactobacillus* number on meat aged in OS than those aged in others at day 21 might be due to alteration of atmosphere composition in *onggi*. Chung et al. (2006) mentioned that on soy sauce fermentation in *onggi*, low O_2 concentration made the growth of LAB active after 2 months. Another finding also referred that the early fermentation condition, aerobic state, could be changed to anaerobic state during fermentation of kimchi using *onggi* (Han, Kim, Kwon, Kim, Kim, & Han, 2013). The authors stated that this anaerobic condition increased the ratio of anaerobic bacteria number, such as LAB. Therefore, environment in OS at day 21 might be changed to comparatively anaerobic condition which was beneficial for the growth of *Lactobacillus* spp.

The highest TPC was shown meat aged in OR after longer than 7 days of storage, followed by that aged in OS and VP ($p<0.05$). Comparatively lower TPC on meat aged in OS than in OR at day 21 was also possibly due to the lower O_2 concentration in OS along with antibacterial activity of *Lactobacillus* spp. on meat aged in OS at day 21. Low O_2 concentration in OS could have created a lower aerobic bacterial count of meat aged in OS than in OR at day 21. The ratio of *Lactobacillus* spp./TPC displayed similar values between meats aged in OR and in OS except for that aged in OS at day 21 (70.04%) (Table 1). The increased the number of *Lactobacillus* spp. on meat aged in OS at day 21 lowered activity of other bacteria, which was agreed with da Costa et al. (2018). They demonstrated that *Lactobacillus* spp., which belongs to LAB, can excrete substances with antimicrobial attributes, such as bacteriocins, and organic acid.

High number of *Lactobacillus* spp. were identified on meat aged in OS, especially at day 21 (Table 1). In terms of that LAB were shown or its number was very low (1 Log CFU/g) in dry-aged beef (An, Hwang, & &Cho, 2020; Hulánková, Kameník, Saláková, Závodský, & Borilova, 2018), it might be meaningful to study *Lactobacillus* spp. on meat aged in OS. In this study, the *Lactobacillus* species on meat aged in OS were identified as *L. sakei* (data not shown). *L. sakei* produces lactic acid as a sole or main product of carbohydrate metabolism (Tannock, 2004; Zheng et al., 2020).

Table 1

Microbial analysis for meats aged in different methods

Traits	Treatment	Storage day 0	7	14	21	SEM
TPC (Log CFU/g)	VP	2.85^{c}	2.98^{cz}	4.52^{bz}	5.00^{az}	0.111
	OR	2.85^{d}	6.33^{cx}	8.22^{bx}	9.95^{ax}	0.075
	OS	2.85^{d}	5.38^{cy}	7.55^{by}	9.71^{ay}	0.088
	SEM		0.080	0.159	0.053	
Lactobacillus spp. (Log CFU/g)	VP	nd	1.79^{by}	2.63^{by}	4.34^{az}	0.401
	OR	nd	3.52^{cx}	3.97^{bx}	4.99^{ay}	0.129
	OS	nd	2.80^{cxy}	3.62^{bxy}	6.80^{ax}	0.164
	SEM		0.307	0.299	0.146	
The ratio of *Lactobacillus* spp./ TPC (%)	VP	0	60.07	58.19	86.80^{x}	11.117
	OR	0	55.61	48.30	50.15^{z}	1.756
	OS	0	52.05^{b}	47.95^{b}	70.04^{ay}	2.581
			9.344	6.399	2.253	

SEM, standard error of the mean; TPC, total plate count; VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder; nd, not detected.

$^{a\text{-}d}$Means within the same row with different superscript differ significantly (p<0.05).

$^{x\text{-}z}$Means within the same column with different superscript differ significantly (p<0.05).

2.3.2. Physicochemical properties

2.3.2.1. pH and VBN

Results of pH, and VBN of meat at day 21 was the highest on meat aged in OS, followed by that aged in OR and in VP (Table 2), which was the same trend with results of TPC (Table 1). The pH and VBN values of meat aged in VP were stable during all storage days whereas those in aged OR and OS significantly increased at day 21. The pH and VBN are the most definitive spoilage indicator for fresh meat. In Korea, the limitation of pH and VBN for sale is 6.2 and 20 mg/100 g, respectively, and meat with greater than these parameters were regarded as spoiled (Lee et al., 2018; Kim, 2022). Based on this information, the meat aged in OS at day 21 (pH, 6.2; VBN, 20 mg/100 g) might be acceptable to consumers while not that aged in OR at day 21.

Meat aged in VP displayed the lowest pH ($p>0.05$) and VBN values ($p<0.05$) among all treatments at day 21. Microbial growth affects both pH and VBN. In particular, the amounts of basic products derived from microorganism proteolysis, can increase pH as well as VBN contents in meat (Lee et al., 2018). Lee (2018) explained that lower pH in wet aged meat than that in dry aged meat was attributed to high production of amine and ammonia in dry-aged meat and/or the decrease of pH in wet aged meat by the growth of LAB. In the same manner, the lower pH and VBN values of meat aged in OS than in OR at day 21 would be due to the lower amount of amine and ammonia on meat aged in OS at day 21 or increased *L. sakei* on meat aged in OS at day 21. The results are consistent with those of Zhang et al. (2018) who found that *L. sakei* reduces the generation of VBN. In detail, *L. sakei* produces less basic compounds than other species of microorganisms due to its non-aminogenic and decarboxylase negative property (Latorre-Moratalla, Bover-Cid, Bosch-Fusté, Veciana-Nogués, & Vidal-Carou, 2014). *L. sakei* is effective in reducing amine accumulation with reduction of up to 91% for putrescine, and 74% for cadaverine, which are associated with the activity of food-borne pathogenic bacteria (Hernández-Macias et al., 2021). Latorre-Moratalla et al. (2014) also found that decarboxylase negative *L. sakei* induced much less amounts of amines, such as tyramine, cadavenine, and phenylethylamine, than those from decarboxylase positive *Lactobacillus curvatus*.

2.3.2.2. TBARS

TBARS values of meats aged in OR and OS were higher than that in VP during aging period ($p<0.05$, Table 2). With respect to 21 days of storage, values of meats aged in OR and OS were not significantly different. However, all treatment during aging period could be acceptable due to their values less than 2 mg MDA/kg, which is considered the threshold of rancid off-flavors (Ha et al., 2019).

Lower TBARS values for meat aged in VP than those aged in OR and OS would be attributed to less O_2 exposure on meat aged in VP. Since meats aged in VP were vacuum-packed, it was less exposed to O_2 than those aged in OR and OS. Zakrys, Hogan, O'sullivan, Allen, and Kerry (2008) mentioned that lipid oxidation is negatively correlated with O_2 concentration during storage.

The meat aged in OS displayed similar TBARS value with that aged in OR at day 21 (Table 2), maybe owing to the aforementioned low O_2 concentration in OS at day 21 and high level of *L. sakei* on meat aged in OS at day 21. The lower O_2 concentration in OS at day 21 could delay lipid oxidation. On the other hand, rather high lactic acid amount generated from *Lactobaillus* spp. might accelerate the lipid oxidation (Bralet, Bouvier, Schreiber, & Boquillon, 1991; Fauconneau, Tallineau, Huguet, Guillard, & Piriou, 1993; Groussard, Morel, Chevanne, Monnier, Cillard, & Delamarche, 2000). Increased H^+ concentration by lactic acid can generate high reactive radical hydroperoxyl radical (HO_2) and stimulate dissociation of protein-bound iron, promoting free radical generation (Groussard et al., 2000). Thus, the decrease in lipid oxidation from low O_2 concentration was probably offset by the increase in lipid oxidation from the high lactic acid amount on meat aged in OS at day 21.

Table 2

pH, volatile basic nitrogen, 2-thiobarbituric acid reactive substances for meats aged in different methods

Traits	Treatment	Storage day				SEM
		0	7	14	21	
pH	VP	5.55	5.77	5.56	5.70^{y}	0.092
	OR	5.55^{b}	5.80^{b}	5.94^{b}	6.45^{ax}	0.116
	OS	5.55^{b}	5.62^{b}	5.64^{b}	5.85^{ay}	0.056
	SEM	0.007	0.095	0.121	0.098	
VBN (mg/100 g)	VP	7.82	8.75^{y}	8.16^{y}	8.75^{z}	0.280
	OR	7.82^{d}	10.57^{cx}	13.3^{bx}	25.55^{ax}	0.276
	OS	7.82^{b}	8.63^{by}	10.38^{bxy}	16.57^{ay}	1.158
	SEM	0.309	0.296	0.894	1.006	
TBARS (mg MDA/kg)	VP	0.12^{b}	0.20^{ay}	0.18^{ay}	0.17^{ay}	0.012
	OR	0.12^{b}	0.41^{ax}	0.34^{ax}	0.34^{ax}	0.046
	OS	0.12^{b}	0.34^{axy}	0.40^{ax}	0.28^{axy}	0.041
	SEM	0.008	0.044	0.043	0.037	

SEM, standard error of the mean; VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder; VBN, volatile basic nitrogen; TBARS, 2-thiobarbituric acid reactive substances; MDA, malonaldehyde.

$^{a-d}$Means within the same row with different superscript differ significantly ($p<0.05$).

$^{x-z}$Means within the same column with different superscript differ significantly ($p<0.05$).

2.3.2.3. Shear force

The shear force of meat aged in OS was lower than those in OR and VP at day 21 (Table 3). It would also be owing to the higher *L. sakei* number on meat aged in OS at day 21. Meat tenderization is attributed to activity of proteolytic enzymes in animal muscle (i.e. caspase, proteasome, cathepsins, calpains) or/and from microorganisms (Huff-Loneran, Zhang, & Lonergan, 2010; Flores and Toldra, 2011). Lower pH and a_w of the meat aged in OS than others at day 21 (Table 2 and Fig. 2) could stimulate the activity of endogenous enzymes. Casaburi, Di Monaco, Cavella, Toldrá, Ercolini, & Villani, 2008; Xiao, Liu, Chen, Xie, & Li (2020) reported that low pH and a_w, induced by a number of *Lactobacillus* species, can activate endogenous proteinase in meat. The higher number of *L. sakei* on meat aged in OS at day 21 could also directly improve tenderness, probably due to proteolytic enzymes from *Lactobacillus* spp. (Kieliszek, Pobiega, Piwowarek, & Kot, 2021).

Table 3

Shear force for meats aged in different methods

Treatment	Storage day				SEM
	0	7	14	21	
VP	32.94^{a}	20.39^{b}	25.07^{b}	25.67^{bx}	1.391
OR	32.94^{a}	26.54^{b}	24.41^{b}	26.88^{bx}	1.500
OS	32.94^{a}	21.34^{b}	21.09^{b}	20.60^{by}	1.246
SEM	1.563	1.562	0.958	1.360	

SEM, standard error of the mean; VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder.

^{a,b}Means within the same row with different superscript differ significantly ($p<0.05$).

^{x,y}Means within the same column with different superscript differ significantly ($p<0.05$).

2.3.2.4. a_w

Meat aged in OS had a significantly lower a_w value than that aged in OR and VP at day 21 ($p<0.05$, Fig. 2). The lower a_w of meat aged in OS would be caused by the increased number of hydrolyzed proteins, such as small peptides and amino acids, which were proteolyzed by higher the number of *L. sakei* on meat aged in OS at day 21. a_w is a measure for amounts of water which is not bound to food molecules (Dave & Ghaly, 2011). In several studies (Law & Kolstad, 1983; Schlesser, Schmidt, & Speckman, 1992), more water was stabilized or held by hydrophilic groups on increased proteins amounts, such as small peptides and amino acids, from proteolysis of *L. sakei*. It might induce formation of much bound water that microorganisms cannot use for their growth (Mermelstein, 2009). Therefore, low a_w on meat aged in OS at day 21 was probably attributed to increase of bound water from small peptide and amino acids via proteolytic activity of *L. sakei*.

The lower a_w of meat aged in OS at day 21 could also affect TPC than that of that aged in OR at day 21. Decreased a_w withdraws water from microbe cells till inner and outer a_w values are in balance (Gibbs & Gekas, 1998). This water movement mechanism relies on a a_w gradient; water move from high a_w circumstance inside cells to lower a_w circumstances outside cells. When a_w on the external of cells changes low enough, it causes osmotic stress, followed by affecting negatively metabolic processes for cells (Meter food, 2016). In addition, osmotic stress induces cells to accumulate 'compatible solute', such as betaine and glutamine, to mitigate the stress. To make compatible solutes, metabolic energy must be used, thus lowering the growth rates of cells (Gibbs & Gekas, 1998).

L. sakei could be alive on the condition (a_w 0.92) of meat aged in OS at day 21 though it would not suitable condition for many bacteria species to survive. Shafiur Rahman (2007) demonstrated the minimal a_w for the growth of foodborne pathogens, 0.93 for *Bacillus cereus*, and 0.93-0.95 for *Clostridium botulinum* and *Clostridium perfringens*. *L. sakei* can grow even at a_w 0.91 (Silins, 2014). Therefore, although pathogenic bacteria, such as some *Clostridium* spp. and *Bacillus cereus*, are hard to grow on meat aged in OS at day 21 (a_w 0.92), *L. sakei* can grow even at the same condition. In addition, low a_w on meat aged in OS at day 21 combined with modified atmosphere in OS at day 21 could limit microbial growth more effectively relative to only low a_w on meat aged in OS at day 21. This result is consistent with the report of Meter food (2016) demonstrating that low a_w in combination with modified atmosphere packaging suppressed microbial growth more than only low a_w.

2.3.2.5. Water content and WHC

Water content displayed insignificant differences among all treatments during aging period (Fig. 2). Lee et al. (2006) reported that *onggi* with lower water permeability did not make a difference on water loss of products in *onggi* during fermentation of 3 month. Same to the previous study, the different permeability between OR and OS could have not influenced the dissimilarity of water content for 21 day.

WHC of meat aged in VP, OR, and OS showed an increasing tendency over the aging period (Fig. 2). There was increase of WHC in muscle through swelling of muscle fibers during aging (Purslow, Oiseth, Hughes, & Warner, 2016). Similar

WHC results between meat aged in OR and OS at day 21 (Fig. 2) were attributable to aforementioned increased bound water and lower pH of meat aged in OS than in OR at day 21. Increased bound water by proteolysis of *L. sakei* on meat aged in OS at day 21 might increase WHC (Law & Kolstad, 1983). However, pH (5.85) on meat aged in OS at day 21, which was nearer at isoelectric point than on that aged in OR at day 21, could cause lower WHC. Kang, Kim, Kim, and Ywang (2018) stated that pH, which is nearer to isoelectric point, decreases WHC. From cancellation effect between increased bound water and pH of meat aged in OS at day 21, WHC of meat aged in OS was probably not significantly different with that of meat aged in OR at day 21.

2.3.2.6. Cooking loss

Meat aged in VP showed much higher cooking loss compared to that aged in OR and OS at day 21 (Fig. 2). Other report (Ha, 2019) also found that the high cooking loss of wet aged beef occurred due to vacuum pressure. The higher cooking loss on meat aged in OS at day 21 than that aged in OR at day 21 could be attributed to the high proteolytic property from *L. sakei*. Purslow et al. (2016) mentioned that proteolysis produced protein fragments which are more easily lost from protein structure with water during cooking. In addition, sarcoplasmic proteins have an influence on networked linkage each other or with myofibrillar proteins, followed by trapping more water in the structure (Liu, Puolanne, and Ertbjerg, 2015). That is, stability reduction of myofilaments, and sarcoplasmic proteins by proteolysis incurs greater protein denaturation by cooking (Puslow et al., 2016). Vaskoska (2020) also stated that aged muscles had 3% higher cooking loss relative to unaged muscles for all cooking temperature and muscle type ($p < 0.01$).

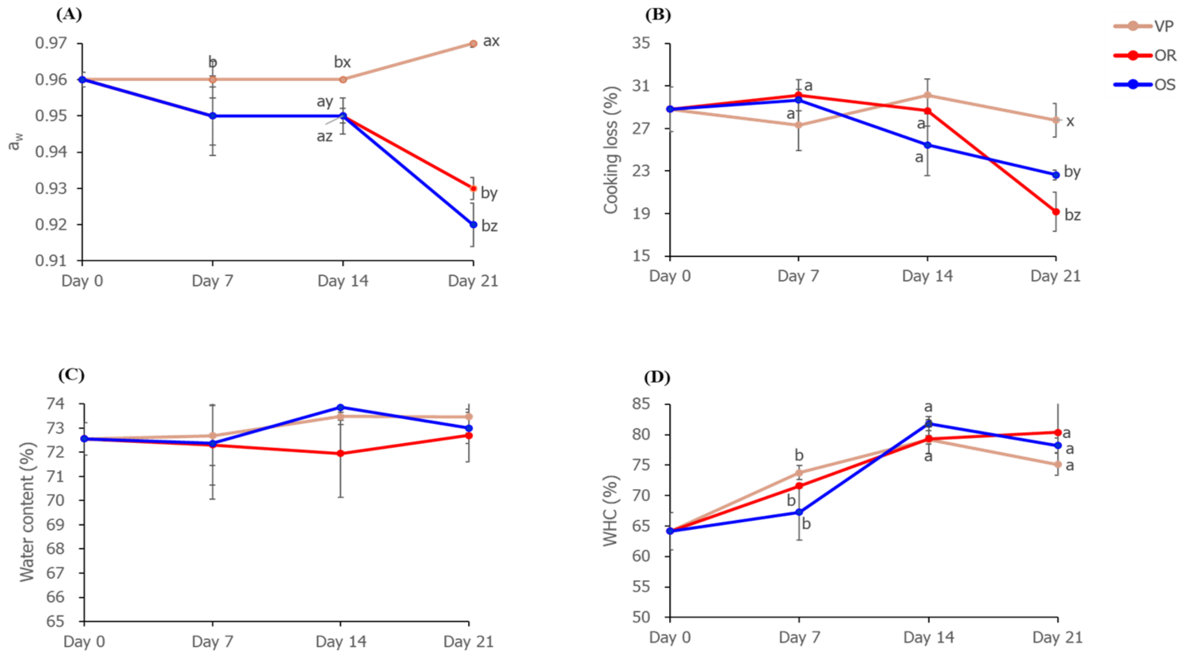

Fig. 2. Water-related quality properties of meats aged in different methods. (A) water activity (a_w), (B) cooking loss (%), (C) water content (%), and (D) water holding capacity (WHC) of pork loins. VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder. [a,b]Means within the same treatment with different superscript differ significantly ($p<0.05$). [x-z]Means within the same aging period with different superscript differ significantly ($p<0.05$).

2.3.2.7. Color analysis

As shown in Fig. 3A, yellow visual appearance appeared, which is consistent with results in Marcelino Kongo (2013), yellow discolorations by LAB on prepackaged refrigerated German ‘Weisswurst’. However, the colors of surface-cut meat were not significantly different among treatments at the same storage day (Fig. 3B).

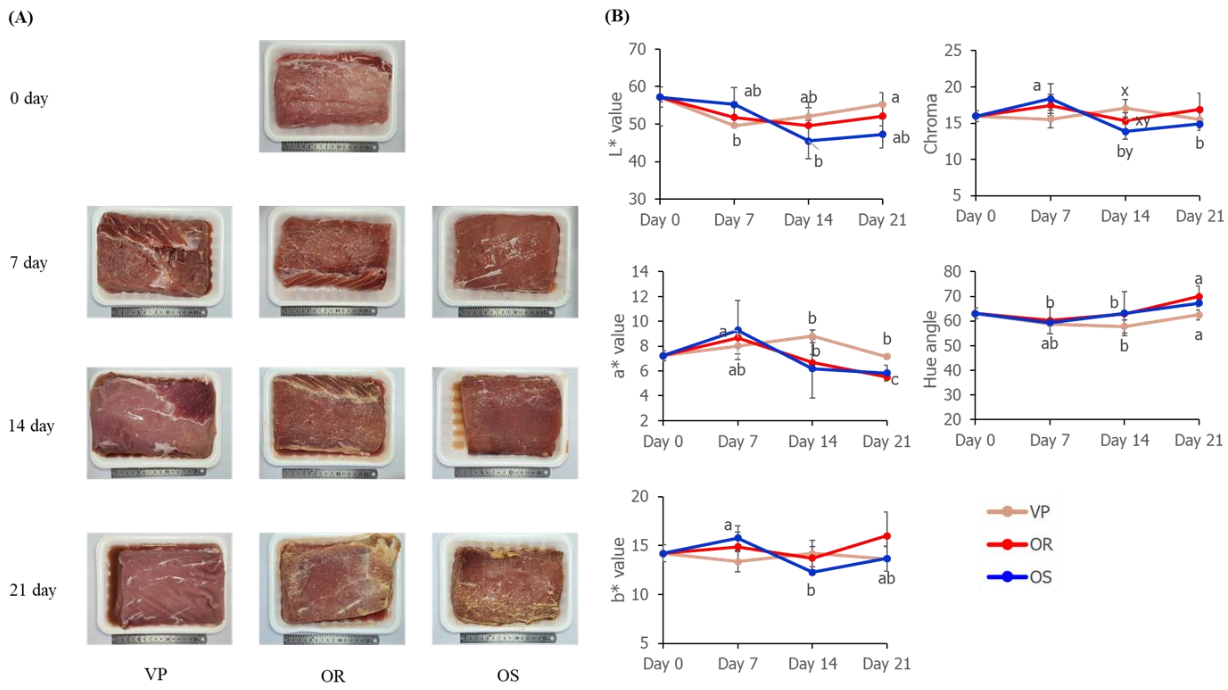

Fig. 3. Change in color of meats aged in different methods. (A) visual appearance and (B) color changes of surface-cut pork loin by CIE value. VP, vacuum-packaging; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder. [a-c]Means within the same treatment with different superscript differ significantly ($p<0.05$). [x,y]Means within the same aging period with different superscript differ significantly ($p<0.05$).

2.3.3. Characteristics of onggi

2.3.3.1. FIR

FIR promotes meat aging and sterilize pathogens (Joo & Won, 2019). Lin (2003) found that lower pH, TPC, and VBN when FIR-irradiating ceramic powder was added for package at 4°C, which was assumed that FIR of ceramic power had bacteriostatic effects. In addition, *L. sakei* was supposed to have different sensitivity for FIR, compared to that of other bacteria due to ability of LAB to survive in environmental stress (Cordero & Zumalacarregui, 2000). Thus, emissivity and radiant energy of FIR were measured for OR and OS to elucidate the mechanisms for the higher *L. sakei* number and lower TPC in meat aged in OS compared to that aged in OR at day 21.

Table 4 displayed similar emissivity (0.9080, 0.9065) and radiant energy (3.500 x 10^2, 3.495 x 10^2 w/m^2) between the OR and OS at 37°C, which is the minimal temperature to analyze them by commercial emissivity detector (KFIA-FI-1005). The values need to be considered as those at 4°C which was the aging condition in this study.FIR emissivity means the ratio of FIR radiant emittance of object to that of black body. Radiant emittance is radiated energy per unit area of object surface. According to Plan's law, the wavelength of radiated energy with topmost intensity is inversely proportional to absolute temperature (Choi, 2001). Therefore, now that emissivity of OR and OS might be equally affected by the shifts of emittance spectrum peak to longer wavelengths according to the decrement of absolute temperature based on Plan's law, the emissivity values for OR and OS would show similar values between 37°C and 4°C.

The difference in radiant energy at 4°C and 37°C could be predicted by Stefan-Boltzman's law. Radiant energy signifies the energy density of FIR. That is, a higher energy density denotes a higher FIR irradiation per unit area (Lee, Lee, & Ham, 2019). The calculation of radiant energy according to Stefan-Boltzmann's law (1) is as below (Choi, 2001; Ceramicx, 2020):

(1) $P = \psi\, abT^4$ (w/m^2)

where P is radiant energy; ψ is the emissivity; a is the Stefan-Boltzmann constant (5.7 x 10^{-8} W/m^2•k^4; b is surface area of emitter (m^2); T is absolute temperature (K). Based on this law, only ψ (emissivity) and T (absolute temperature) would be different between 4°C and at 37°C. That is, radiant energies of OR and OS would decrease equally in lined with the decrement of the emissivity and the four squares of absolute temperature from those at 37°C to 4°C. Thus, radiant energies of OR and OS at 4°C would be similar to those at 37°C.

Also, the same emissivity and radiant energy of OR and OS would be attributed to similar constitution ratio of metal oxides for OR and OS. The constitution ratio of red clay-contained components was SiO_2 40-50%, Al_2O_3 20-30%, FeO_3 5-6%, and MgO 2% etc. (Lee et al., 2019), and that of scoria was SiO_2 30-50%, Al_2O_3 10-20%, and FeO_3 10-20% etc. (Cho, Lee, & Mok, 2014).

In this study, OR and OS radiated high FIR, which was similar to previous studies where both red clay and scoria radiated high FIR in high temperature condition (Kang, 2018; Lee et al., 2019; Park, 1991). However, these results could have a limitation because of aging conditions for low temperature and dark site. According to Park (1991), absorbable energy source, such as high temperature or lots of strong light, must exist for ceramics to radiate high FIR. Thus, ceramics in low temperature (4°C) or in dark site radiate less FIR because there was a little energy source for ceramics to absorb. Therefore, we assumed that FIR in OR and OS considered as a minor factor affecting number of *L. sakei* on meat aged in OS at day 21.

Table 4

Far-infrared irradiation for different *onggi*es

Treatment	Emissivity (5-20 μm)	Radiant energy ($W/m^2 \cdot \mu m$, 37°C)
OR	0.9080	3.500×10^2
OS	0.9065	3.495×10^2
SEM	0.000	0.354

SEM: Standard error of the mean; OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder.

2.3.3.2. Quantification of immobilized L. sakei on onggi

According to previous study, increase in microbes can alter atmosphere composition in *onggi* (Seo et al., 2005). Since *Lactobacillus* spp. was classified as air-born microorganisms (Kim, 2000), there was possibility for *L. sakei* in pork loin to move to *onggi*. Therefore, the difference for counts of immobilized *L. sakei* in the surface and cross-section of OR and OS were evaluated (Fig. 4).

The immobilization can be affected by pore size, and surface characteristics of porous material and attached proteins (Lie et al., 2004). Fig. 5 shows larger pore size in OR compared to that in OS. Different pore sizes between OR and OS might create different immobilization of *L. sakei* for OR and OS. Pores on the surface of *onggi* provided microhabitat which LAB can proliferate (Han et al., 2013) and pore size relative to protein molecule size influences protein immobilization (Lei et al., 2004). Liu, Xu, Feng, Zhu, and Hou (2007) found that increase in pore size up to 30 nm rendered enzyme immobilization on porous sieve more suitable. In porous ceramics for microbe immobilization, pore size which was 10 times longer than microbe size, was stable for microbial habitat (Kang & Kim, 2011).

L. sakei might have high affinity to OR and OS. The ceramic material, such as *onggi*, has remarkable affinity with microorganisms (Kang & Kim, 2011), and *Lactobacillus* spp. were successfully immobilized in a shell composed mainly with SiO_2, the major ingredient of scoria (Zhao et al., 2016). The surface charges of porous SiO_2 were complementary to proteins such as surface protein of *Lactobacillus* spp., that is, electrostatic interaction between porous SiO_2 and proteins influenced immobilization (Lei et al., 2004). Therefore, similar SiO_2 contents in OR and OS would not affect the difference of *L. sakei* immobilization.

However, contrary to expectation in this study, *L. sakei* was not detected in any inner surface and cross-section of OR and OS (data not shown), which meant *L. sakei immobilization* would not be confirmed. Perhaps it was because *L. sakei* from pork loins did not move to *onggi*es through the air for immobilization. Thus, *L. sakei* immobilization would not be related to the results of meat aged in OS at day 21.

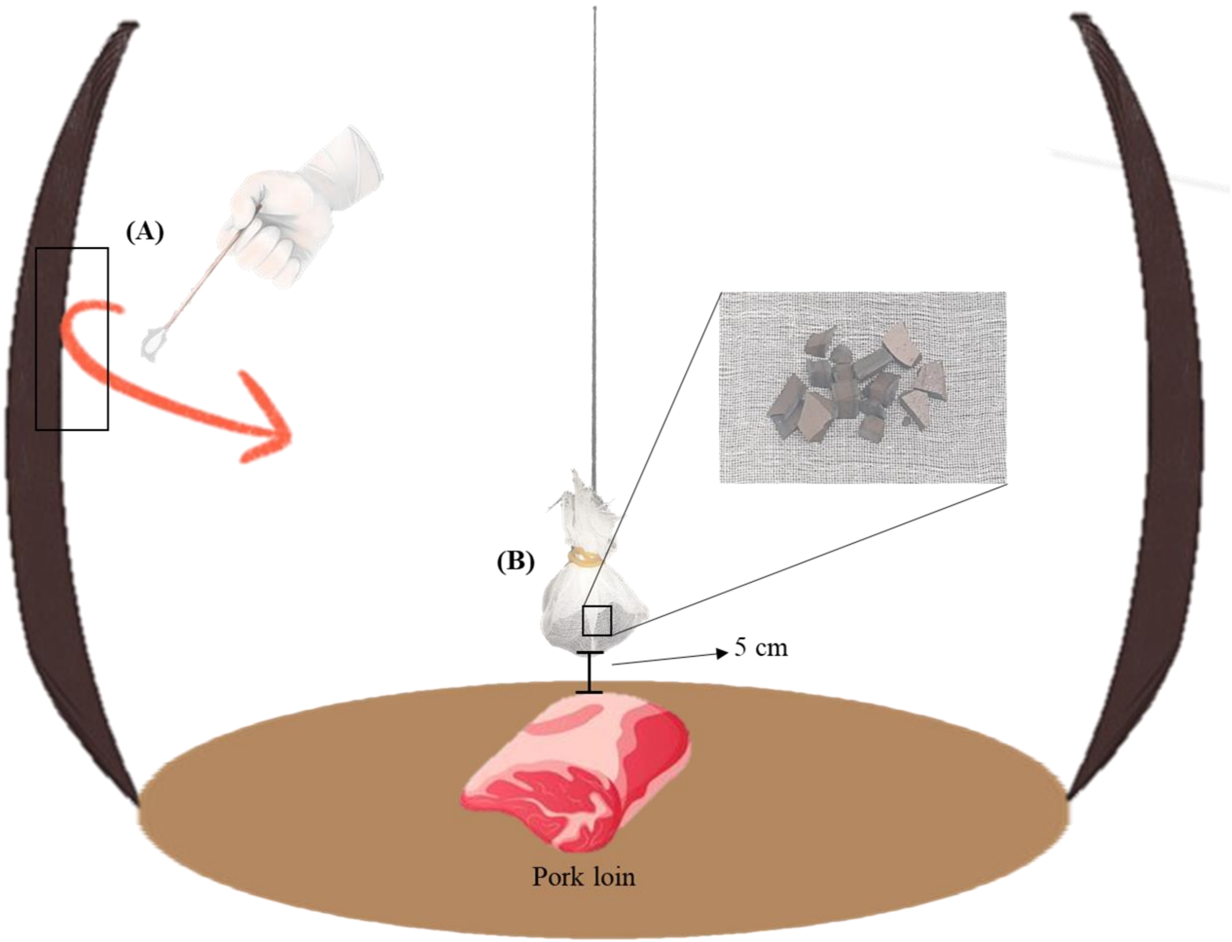

Fig. 4. Schematic representation for collection of immobilized *L. sakei*. (A) swabbing method using sterilized cotton swab and (B) hung broken pieces to check the presence of *L. sakei* on cross-section of *onggi*.

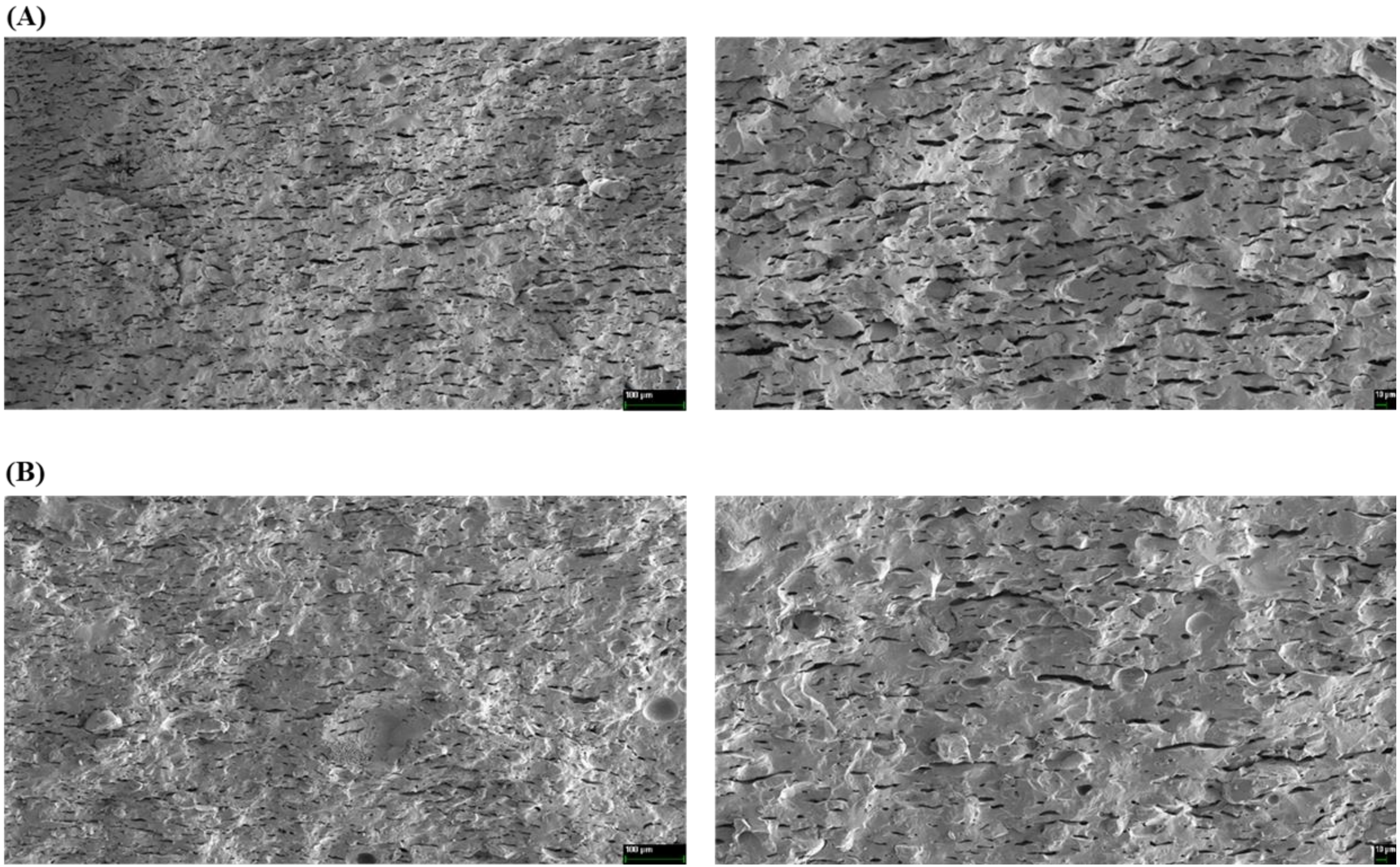

Fig. 5. Scanning electron micrographs of the earthenware surface. (A) Inner cross-section of OR (× 250, left side; × 500, right side), (B) Inner cross-section of OS (× 250, left side; × 500, right side). OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder.

2.3.3.3. Microstructural property

Microstructural property, such as pore diameter, porosity and permeability, of *onggi* can control the growth of microorganisms of products in *onggi* (Chung, Lee, & Lee, 2006; Park, 1991). Porosity implies the amounts of openings within a material (Lee, Lee, Lee, & Chung, 2006). In this study, OS had the higher values for total pore area and porosity, and smaller pore diameter compared to those of OR (Table 5). It means that OS had a larger number of smaller pores which induces higher porosity compared to OR. Different microstructural property of OS than that of OR could affect differently to the growth of microbes on the products in *onggi*.

There are several studies introducing that *onggi* having smaller pore size promoted the growth of LAB in the food. When kimchi, soy sauce, and grape were fermented in *onggi*, the *onggi* with smaller pore size made lower O_2 and higher CO_2 condition in it, followed by increase in the growth of LAB in stored foods (Chung et al., 2006; Han et al., 2013; Seo et al., 2005). Composition of gases in *onggi* can be changed depending on interplay of product respiration rate and material permeability characteristics (Qu, Zhang, Fan, & Guo, 2022; Hussein, Caleb, & Opara, 2015). Respiration of a product made decreasing O_2 and increasing CO_2 concentrations in its container (Lee, 2007). Permeability of *onggi* allowed the outer sufficient O_2 to pass though the *onggi*, avoiding anerobic respiration, and inner excessive CO_2 to permeate the *onggi* to prevent physiological disorders (Seo et al., 2005; Yun, An, Lee, Jun, & Lee, 2006). In addition, water permeability of *onggi* helped to avoid moisture saturation, and to maintain appropriate relative humidity for storing fresh products (Seo et al., 2005). Therefore, gas and water permeability of *onggi* are essential criteria for appropriate modified atmosphere for products (Hussein et al., 2015).

In this study, it was assumed that smaller pore size in OS induced lower permeability in OS, increasing the number of LAB in pork loins. Permeability of a material is expressed as a function of porosity and mean pore diameter. Wang, Zhang, Phuong, Jin, Yang, and Ishizaki (2015) explained an equation to calculate permeability as follows (2).

(2) $\psi = pd^2/16f_{CK}\tau^2$

where ψ is the Darcian permeability; p is the efficient porosity; d is the mean pore diameter; f_{CK} is Carman-Kozeny coefficient; and τ is the tortuosity of pore channels, the ratio between fluid-traveled mean length through porous medium and the thickness of the porous medium. Permeability equation (2) can elucidate the discrepancy of permeability relative to OR and OS *onggi*. When pores change into smaller pore, tortuosity increased. In this case, porosity could be neglectable because porosity made a little effect on permeability under pore diameter shorter than 6 μm (Wang et al., 2015). As a result, permeability of OS was in direct proportion to the square of mean pore diameter and inversely proportional to the square of tortuosity. It was suggested that OS had the smaller mean pore diameter and higher tortuosity than OR. Thus, permeability of OS was much lower than of OR. Fig. 6 shows a schematic diagram for the mechanism of high number of *L. sakei* on meat aged in OS at day 21.

Table 5

Microstructural properties for different *onggies*

Treatment	Pore diameter (nm)	Total pore area (m^2/g)	Porosity (%)	Density (g/mL)
OR	169.0	0.78	7.86	2.58
OS	91.4	1.79	9.28	2.51

OR, *onggi* containing red clay only; OS, *onggi* containing 30% red clay and 70% scoria powder.

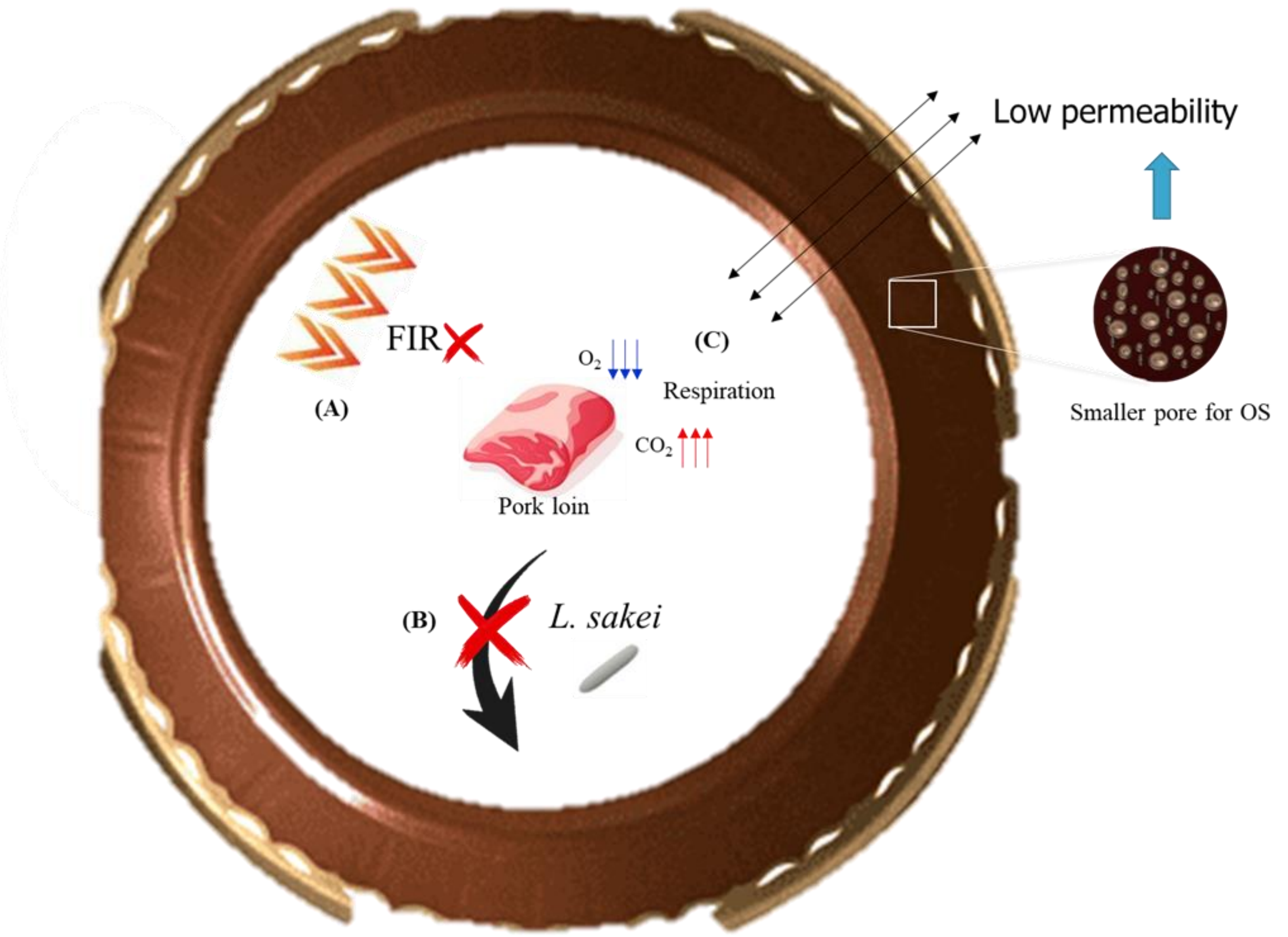

Fig. 6. Schematic representation of mechanism for high number of *L. sakei* on meat aged in OS at day 21. (A) far infrared ray (FIR) irradiation, (B) quantification of immobilized *L. sakei*, and (C) change of atmospheric composition according to low permeability of *onggi* and respiration of stored products. OS, *onggi* containing 30% red clay and 70% scoria powder.

2.4. Conclusion

Onggi with scoria powder improved meat quality of pork loin by increasing the number of *L. sakei*. At day 21, the meat aged in OS exhibited lower pH, shear force, VBN, and a_w than that aged in OR at day 21, along with the increase in *L. sakei*. *L. sakei* accounted for 6.8 Log CFU/g in 9.72 CFU/g TPC in meat aged in OS at day 21. FIR and *L. sakei* immobilization seemed rarely affected the difference between OR and OS. Rather, lower permeability of OS than that of OR might create favorable environment that *L. sakei* could easily proliferate. Therefore, *onggi* with scoria powder improved quality and microbiological safety for dry aged pork loins. The findings of the present study suggest novel meat aging process with high *L. sakei* number. For further study, sensory evaluation, optimum ratio of scoria and glazing for *onggi* should be confirmed.

References

An, S. B., Hwang, S. H., & Cho, Y. S. (2020). Storage stability of raw beef, dry-aging beef, and wet-aging beef at refrigeration temperature. *Journal of Food Hygiene and Safety*, *35*(2), 170-176. https://doi.org/10.13103/JFHS.2020.35.2.170.

Bralet, J., Bouvier, C., Schreiber, L., & Boquillon, M. (1991). Effect of acidosis on lipid peroxidation in brain slices. *Brain Research*, *539*(1), 175-177. https://doi.org/10.1016/0006-8993(91)90703-X.

Casaburi, A., Di Monaco, R., Cavella, S., Toldrá, F., Ercolini, D., & Villani, F. (2008). Proteolytic and lipolytic starter cultures and their effect on traditional fermented sausages ripening and sensory traits. *Food Microbiology*, *25*, 335-347. https://doi.org/10.1016/j.fm.2007.10.006

Ceramicx. (2020). Far infrared ray:the law of heating. Retrieved from https://www.ceramicx.com/ko/information/support/why-infrared-laws-of-infrared-heating/. Accessed Mar 26, 2022.

Cho, J. O., Lee, H. W., & Mok, Y. S. (2014). Sterilization of scoria powder by corona discharge plasma. *Applied Chemistry for Engineering*, *25*, 386-391. https://doi.org/10.14478/ace.2014.1046.

Choi, T. S. (2001). Application of infrared rays radion packaging material resource. *The Monthly Packaging World*, *103*, 119-143.

Christie, G. B., Turney, T. W., Hardin, S. G., Christov, V., & Wu RY. (1998). Controlled permeability film. *US Patent*, 5,807, 630.

Chung, S. K., Lee, K. S., & Cho, S. H. (2004). Effect of fermentation vessel on quality of anchovy soy sauce. *Korean Journal of Food Preservation*, *11*, 233-239.

Chung, S. K., Lee, K. S., & Lee, D. S. (2006). Fermentation of Kanjang, Korean soy sauce, in porosity-controlled earthenwares with changing the mixing ratio of raw soils. *Food Science and Technology, 38*, 215-221.

Cordero, M. R. & Zumalacarregui, J. M. (2000). Characterization of *Micrococcaceae* isolated from salt used for Spanish dry-cured ham. *Letters in Applied Microbiology*, *31*, 303-306. https://doi.org/10.1046/j.1472-765x.2000.00818.x.

da Costa, W. K. A., de Souza, G. T., Brandão, L. R., de Lima, R. C., Garcia, E. F., dos Santos Lima, M., & Magnani, M. (2018). Exploiting antagonistic activity of fruit-derived Lactobacillus to control pathogenic bacteria in fresh cheese and chicken meat. *Food Research International, 108*, 172-182. https://doi.org/10.1016/j.foodres.2018.03.045.

Dave, D., & Ghaly, A. E. (2011). Meat spoilage mechanisms and preservation techniques: a critical review. *American Journal of Agricultural and Biological Sciences*, *6*, 486-510.

Fauconneau, B., Tallineau, C., Huguet, F., Guillard, O., & Piriou, A. (1993). Iron-and lactic acid-induced lipid peroxidation in rat kidney homogenates and slices. *Biochemistry and Molecular Biology International, 31*, 421-427.

Flores, M., & Toldra, F. (2011). Microbial enzymatic activities for improved fermented meats. *Trends in Food Science and Technology*, *22*, 81-90. https://doi.org/10.1016/j.tifs.2010.09.007.

Gibbs, P., & Gekas, V. (1998). *Water activity and microbiological aspects of foods: a knowledge base*. Leather Food Research Association.

Górecka, E., & Jastrzębska M. (2011). Immobilization techniques and biopolymer carriers. *Biotechnology and Food Science. 75*, 65-86. https://doi.org/10.34658/bfs.2011.75.1.65-86.

Groussard, C., Morel, I., Chevanne, M., Monnier, M., Cillard, J., & Delamarche, A. (2000). Free radical scavenging and antioxidant effects of lactate ion: an in vitro study. *Journal of Applied Physiology, 89*, 169-175. https://doi.org/10.1152/jappl.2000.89.1.169.

Ha, M., McGilchrist, P., Polkinghorne, R., Huynh, L., Galletly, J., Kobayashi, K., & Warner, R. D. (2019). Effects of different ageing methods on colour, yield, oxidation and sensory qualities of Australian beef loins consumed in Australia and Japan. *Food Research International, 125*, 108528. https://doi.org/10.1016/j.foodres.2019.108528.

Han, K. I., Kim, M. J., Kwon, H. J., Kim, Y. H., Kim, W. J., Han, M. D. (2013). The effect of container types on the growth of bacteria during kimchi fermentation. *The Korean Journal of Food and Nutrition, 26*, 249-257. https://doi.org/10.9799/ksfan.2013.26.2.249.

Hernández-Macias, S., Martín-Garcia, A., Ferrer-Bustins, N., Comas-Basté, O., Riu-Aumatell, M., López-Tamames, E., Jofre, A., Latorre-Moratalla, M. L., Bover-Cid, S., & Vidal-Carou, M. C. (2021). Inhibition of biogenic amines formation in fermented foods by the addition of cava lees. *Frontiers in Microbiology*, *12*. https://doi.org/10.3389/fmicb.2021.818565.

Horwitz, W., & Latimer, G. (2006). *Official methods of analysis of AOAC International* (18th ed.). Association of official analytical chemists international.

Huff-Loneran, E., Zhang, W., & Lonergan, S. M. (2010). Biochemistry of postmortem muscle - Lessons on mechanisms of meat tenderization. *Meat Science, 86,* 184-195. https://doi.org/10.1016/j.meatsci.2010.05.004.

Hulánková, R., Kameník, J., Saláková, A., Závodský, D., & Borilova, G. (2018). The effect of dry aging on instrumental, chemical and microbiological parameters of organic beef loin muscle. *LWT*, *89*, 559-565. https://doi.org/10.1016/j.lwt.2017.11.014.

Hussein, Z., Caleb, O. J., & Opara, U. L. (2015). Perforation-mediated modified atmosphere packaging of fresh and minimally processed produce—a review. *Food Packaging and Shelf Life*, *6*, 7-20. https://doi.org/10.1016/j.fpsl.2015.08.003.

Iita, K. (1988). Film made of FIR. *Food Industry, 12*, 27-34.

Ishizaki, K., Komarneni, S. & Nanko, M. (1998). *Porous materials: process technology and applications*. Kluwer Academic Publishers.

Jeon, H. Y., Jung, H. J., Shin, J. S., An, S. A., & Kang, B. Y. (2018). Mousse-type cosmetic composition containing scoria. *US Patent*, 006,217.

Joo, I. S. & Won, J. H. (2019). Container for meat aging. *ROK Patent*, 10-2019-0134015.

Jung, S. K., Lee, K. S., & Cho, S. H. (2004). Changes in quality during the aging of fish soy sauce according to fermentation and immersion containers. *Journal of the Korean Society for Food Storage and Distribution*, *11*, 233-239.

Kang, H. (2018). Effect of mixture composed of Jeju' scoria and Ecklonia cava on anti-inflammation. *Biomedical Science Letters, 24*, 329-333. https://doi.org/10.15616/BSL.2018.24.4.329.

Kang, S. G., & Kim, Y. T. (2011). Porous ceramic carrier for microorganisms using sawdust and method for manufacturing the ceramic carrier. *ROK Patent,* 10-2010-0019523.

Kang, S. N., Kim, I., S., Nam, K. C., Min, B. R., Lee, M. H., Yim, D. K., Jang, Y. R., & Jo, C. (2018). *Meat science*. Yuhansa.

Khan, M. I., Jung, S., Nam, K. C, & Jo, C. (2016). Postmortem aging of beef with a special reference to the dry aging. *Korean Journal for Food Science of Animal Resources, 36,* 159-169. https://doi.org/10.5851/kosfa.2016.36.2.159.

Kieliszek, M., Pobiega, K., Piwowarek, K., & Kot, A. M. (2021). Characteristics of the proteolytic enzymes produced by lactic acid bacteria. *Molecules, 26,* 1858. https://doi.org/10.3390/molecules26071858.

Kilonzo, P., & Bergougnou, M. (2012). Surface modifications for controlled and optimized cell immobilization by adsorption: applications in fibrous bed bioreactors containing recombinant cells. *Journal of Microbial and Biochemical Technology. 4*, 22-30.

Kim, B. S. (2000). *Air cleaning technology*. Korean air cleaning association.

Kim, G. T., Park, H. D., & Lee, D. S. (2003). Effect of different oxygen permeability packaging films on the quality of sous-vide processed seasoned spinach soup. *Food Science and Biotechnology*, *12*, 312-315.

Kim, H. J., Kim, H. J., Kim, K. W., Lee, J., Lee, S. H., Lee, S. S., Choi, B. H., Shin, D. J., Jeon, K. H., Choi, J. Y., & Jang, A. (2022). Effect of feeding alfalfa and concentrate on meat quality and bioactive compounds in Korean native black goat loin during storage at 4° C. *Food Science of Animal Resources*, *42*(3), 517-535. https://doi.org/10.5851/kosfa.2022.e21.

Kim, J. B. (2002). The development of the refrigerator using a pottery vessel. *Journal of the Korea Academia-Industrial Cooperation Society*, *3*, 44-48.

Kim, K. B. (2001). Current status and challenges of the domestic far infrared industry. *The Korean Institute of Illuminating and electrical Installation Engineers*, *2*, 38-45.

Latorre-Moratalla, M. L., Bover-Cid, S., Bosch-Fusté, J., Veciana-Nogués, M. T., & Vidal-Carou, M. C. (2014). Amino acid availability as an influential factor on the biogenic amine formation in dry fermented sausages. *Food Control*, *36*, 76-81. https://doi.org/10.1016/j.foodcont.2013.07.038.

Law, B. A., & Kolstad, J. (1983). Proteolytic systems in lactic acid bacteria. *Antonie Van Leeuwenhoek*, *49*(3), 225-245. https://doi.org/10.1007/BF00399500.

Lee, C. H. (1999). Characteristics of primitive earthenware culture age in northeast Asia and importance of food history. *Research on National Culture*, *32*, 325-357.

Lee, D. S. (2007). Modeling fresh produce respiration and designing modified atmosphere package. *Korean Journal of Packaging Science & Technology*, *13*(3/4), 113-120.

Lee, H. J., Choe, J., Yoon, J. W., Kim, S., Oh, H., Yoon, Y., & Jo, C. (2018). Determination of salable shelf-life for wrap-packaged dry-aged beef during cold storage. *Korean Journal for Food Science of Animal Resources*, *38*, 251-258. https://doi.org/10.5851/kosfa.2018.38.2.251.

Lee, K. S., Lee, Y. B., Lee, D. S., & Chung, S. K. (2006). Quality evaluation of Korean soy sauce fermented in Korean earthenware (*Onggi*) with different glazes. *International Journal of Food Science and Technology*, *41*, 1158-1163. https://doi.org/10.1111/j.1365-2621.2006.01161.x.

Lee, K. Y., Lee, H. H., & Ham, S. C. (2019). A study on far-infrared radiation and proliferation of ocherous cotton quilt fabrics. *Journal of Naturopathy*, *8*, 71-77. https://doi.org/10.33562/JN.2019.8.2.3.

Lei, J., Fan, J., Yu, C., Zhang, L., Jiang, S., Tu, B., & Zhao, D. (2004). Immobilization of enzymes in mesoporous materials: controlling the entrance to nanospace. *Microporous and Mesoporous Materials, 73*, 121-128. https://doi.org/10.1016/j.micromeso.2004.05.004.

Lim, D. G., Cha, J. S., Jo, C., Lee, K. H., Kim, J. J., & Nam, K. C. (2014). Comparison of physicochemical and functional traits of Hanwoo steer beef by the quality grade. *Korean Journal for Food Science of Animal Resources, 34*(3), 287-296. https://doi.org/10.5851/kosfa.2014.34.3.287.

Lin, L. C. (2003). The new storage technology: effect of far infrared ray (FIR) ceramic sheet package on storage quality of pork loin. *Asian-Australasian Journal of Animal Sciences, 16*, 1695-1700. https://doi.org/10.5713/ajas.2003.1695.

Liu, J., Puolanne, E., & Ertbjerg, P. (2015). *A new hypothesis explaining the influence of sarcoplasmic proteins on the water-holding of myofibrils*. Proceedings of 61st international congress of meat science and technology, Clermont-Ferrand, France.

Liu, Y., Xu, Q., Feng, X., Zhu, J. J., & Hou, W. (2007). Immobilization of hemoglobin on SBA-15 applied to the electrocatalytic reduction of H_2O_2. *Analytical and Bioanalytical Chemistry, 387*(4), 1553-1559.

Marcelino Kongo, J. (2013). *Lactic acid bacteria*. Intechopen.

Maresca, D., Zotta, T., & Mauriello, G. (2018). Adaptation to aerobic environment of *Lactobacillus johnsonii/gasseri* strains. *Frontiers in Microbiology*, *9*, 157. https://doi.org/10.3389/fmicb.2018.00157.

Martins, S. C. S., Martins, C. M., Fiúza, L. M. C. G., & Santaella, S. T. (2013). Immobilization of microbial cells: A promising tool for treatment of toxic pollutants in industrial wastewater. *African Journal of Biotechnology*, *12*(28). https://doi.org/10.5897/AJB12.2677.

Mermelstein, N. H. (2009). *Measuring moisture content and water activity*. Food technology.

Meter food. (2016). Microorganisms rely on water for growth-without it, they are forced to go dormant. Retrieved from https://www.metergroup.com/en/meter-food/expertise-library/microbial-growth. Accessed March 25, 2022.

Mistriotis, A., Giannoulis, A., Giannopoulos, D., & Briassoulis, D. (2011). Analysis of the effect of perforation on the permeability of biodegradable non-barrier films. *Procedia Food Science, 1*, 32-38. https://doi.org/10.1016/j.profoo.2011.09.006.

Omori, Y. (1994). The application in food fields of electromagnetic wave. *Food and Development*. *28*:6-11.

Park, M. Y. (1991). Far infrared irradiation ceramic technology. *Bulletin of Food Technology, 4,* 51-56.

Purslow, P. P., Oiseth, S., Hughes, J., & Warner, R. D. (2016). The structural basis of cooking loss in beef: Variations with temperature and ageing. *Food Research International*, *89,* 739-748. https://doi.org/10.1016/j.foodres.2016.09.010.

Qu, P., Zhang, M., Fan, K., & Guo, Z. (2022). Microporous modified atmosphere packaging to extend shelf life of fresh foods: a review. *Critical Reviews in Food Science and Nutrition*, *62,* 51-65. https://doi.org/10.1080/10408398.2020.1811635.

Robinson, L. C. (1973). *Physical principles of far-infrared radiation*. Academic Press Inc.

Schlesser, J. E., Schmidt, S. J., & Speckman, R. (1992). Characterization of chemical and physical changes in Camembert cheese during ripening. *Journal of Dairy Science*, *75*(7), 1753-1760. https://doi.org/10.3168/jds.S0022-0302(92)77934-X.

Sebranek, J. G., & Houser, T. A. (2006). *Modified Atmospheric Processing and Packaging of Fish: Filtered Smokes, Carbon Monoxide, and Reduced Oxygen Packaging*. Wiley-Blackwell (Chapter 6).

Seo, G. H., Chung, S. K., An, D. S., & Lee, D. S. (2005). Permeabilities of Korean earthenware containers and their potential for packaging fresh produce. *Food Science and Biotechnology*, *14*, 82-88.

Seo, G. H., Song, B. S., An, D. S., Chung, S. K., & Lee D. S. (2006). Physical properties of Korean Earthenware (*Onggi*) as food container. *Journal of Korea Society of Packaging Science and Technology, 12*(2), 87-90.

Shafiur Rahman, M. (2007). *Handbook of food preservation* (2th ed.). CRC Press.

Shin, D. J., Lee, H. J., Lee, D., Jo, C., & Cho, J. (2020). Fat replacement in chicken sausages manufactured with broiler and old laying hens by different vegetable oils. *Poultry Science*, *99,* 2811-2818. https://doi.org/10.1016/j.psj.2020.01.008.

Silins, I. (2014). *The effects of pH, a_w, and lactic acid bacteria on Listeria monocytogenes in fermented sausages*. Baltic Conference on Food Science and Technology, Latvia.

Tannock, G. W. (2004). A special fondness for lactobacilli. *Applied and Environmental Microbiology, 70*, 3189-3194. https://doi.org/10.1128/AEM.70.6.3189-3194.2004.

Vaskoska, R., Ha, M., Naqvi, Z. B., White, J. D., & Warner, R. D. (2020). Muscle, ageing and temperature influence the changes in texture, cooking loss and shrinkage of cooked beef. *Foods*, *9*(9), 1289. https://doi.org/10.3390/foods9091289.

Vega, J. L., Clausen, E. C., & Gaddy, J. L. (1988). Biofilm reactors for ethanol production. *Enzyme and Microbial Technology*. *10*, 390. https://doi.org/10.1016/0141-0229(88)90033-6.

Wang, B., Zhang, H., Phuong, H. T., Jin, F., Yang, J. F., & Ishizaki, K. (2015). Gas permeability and adsorbability of the glass-bonded porous silicon carbide ceramics with controlled pore size. *Ceramics International*, *41*, 2279-2285. https://doi.org/10.1016/j.ceramint.2014.10.032.

Xiao, Y., Liu, Y., Chen, C., Xie, T., & Li, P. (2020). Effect of *Lactobacillus plantarum* and *Staphylococcus xylosus* on flavour development and bacterial communities in Chinese dry fermented sausages. *Food Research International*, *135*, 109247. https://doi.org/10.1016/j.foodres.2020.109247.

Yoo. S. M., Kim, J. S., & Shin, D. H. (2001). Changes in quality during ripening according to the immersion container of traditional soybean paste. *Journal of the Korean Society of Agricultural Biochemistry*, *44*, 230-234.

Yun, J. H., An, D. S., Lee, K. E., Jun, B. S., & Lee, D. S. (2006). Modified atmosphere packaging of fresh produce using microporous earthenware material. *Packaging Technology and Science*, *19*(5), 269-278. https://doi.org/10.1002/pts.730.

Zakrys, P. I., Hogan, S. A., O'sullivan, M. G., Allen, P., & Kerry, J. P. (2008). Effects of oxygen concentration on the sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science*, *79*, 648-655. https://doi.org/10.1016/j.meatsci.2007.10.030.

Zhang, Y., Zhu, L., Dong, P., Liang, R., Mao, Y., Qiu, S., & Luo, X. (2018). Bio-protective potential of lactic acid bacteria: Effect of *Lactobacillus sakei* and *Lactobacillus curvatus* on changes of the microbial community in vacuum-packaged chilled beef. *Asian-Australasian Journal of Animal Sciences*, *31*, 585-594. https://doi.org/10.5713/ajas.17.0540.

Zhao, Z., Xie, X., Wang, Z., Ao, Y., Niu, X., Huang, X., & Li, Z. (2016). Immobilization of *Lactobacillus rhamnosus* in mesoporous silica-based material: an efficiency continuous cell-recycle fermentation system for lactic acid production. *Journal of Bioscience and Bioengineering, 121*, 645-651. https://doi.org/10.1016/j.jbiosc.2015.11.010.

Zheng, J., Wittouck, S., Salvetti, E., Franz, C. M., Harris, H., Mattarelli, P., & Lebeer, S. (2020). A taxonomic note on the genus *Lactobacillus*: Description of 23 novel genera, emended description of the genus

Lactobacillus Beijerinck 1901, and union of *Lactobacillaceae* and *Leuconostocaceae*. *Microbiology Society*, *70*(4). https://doi.org/10.1099/ijsem.0.004107.

Zhu, Y. (2007). Immobilized cell fermentation for production of chemicals and fuels. *Bioprocessing for Value-Added Products from Renewable Resources*, 373-396. https://doi.org/10.1016/B978-044452114-9/50015-3.

Summary in Korean

화산송이석 함유 옹기를 이용한

건식 숙성 중 돈육 등심의 품질변화

김성수
서울대학교 대학원
농생명공학부 동물생명공학전공

본 연구의 목적은 21일의 건식 숙성기간 동안 화산송이석을 함유한 옹기가 돈육 등심의 품질에 미칠 수 있는 영향을 알아보고(온도, 3±1℃; 상대 습도, 80-85%), 그와 관련한 메커니즘을 규명하는 것이다. 시료들은 진공 포장(VP)된 돈육 등심, 황토만으로 구성된 일반 옹기(OR)에서 숙성된 돈육 등심, 그리고 70%의 화산송이석을 함유한 옹기(OS)에서 숙성된 돈육 등심, 이 세 가지 처리군에 무작위로 배치되었다. 미생물학적 분석(총균과 젖산균), 물리화학적 분석(pH, 전단력, 휘발성 염기태 질소, 수분활성도, 지방산패도, 수분함량, 보수력, 가열 감량, 그리고 색도), 그리고 메커니즘 분석(원적외선 방사, 젖산균 고정, 그리고 옹기의 미세구조 특성)이 시행되었다. 숙성 21일차, OS에서 숙성된 고기는 OR에서 숙성된 고기보다 더 낮은 pH, 전단력, 휘발성 염기태 질소, 그리고 수분 활성도를 가졌으며, 이는 해

당 처리군에서의 젖산균의 급격한 증가와 연관이 있다. OS는 OR보다 기공 크기가 작았는데, 이는 OS가 OR보다 더 낮은 투과도를 가지고 있음을 암시하였다. OS의 더 낮은 투과도는 젖산균의 성장을 촉진시켰다. 결론적으로 낮은 투과도를 가지고 있는 OS가 돈육 등심에서의 젖산균 증가를 이끌어 냄으로써 미생물학적 안정성과 품질을 향상시켰다.