Processing Strategies to Improve Animal Protein Digestibility for Age-Specific Customization

정 사 무 엘
Jung, Samooel
(충남대학교)
(Chungnam National University)

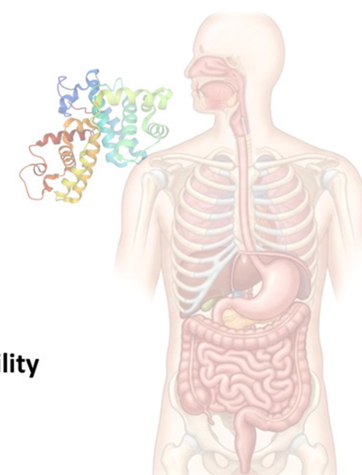
Curriculum Vitae

- 2014~현재 충남대학교 동물자원생명과학과 교수
- 2013~2014 충남대학교, 서울대학교 박사후 연구원
- 2010~2013 충남대학교 축산학과 농학박사
- 2008~2010 충남대학교 축산학과 농학석사
- 2001~2008 충남대학교 동물자원생명과학과 농학사

Processing Strategies to Improve Animal Protein Digestibility for Age-Specific Customization

SAMOOEL JUNG
CHUNGNAM NATIONAL UNIVERSITY

Contents

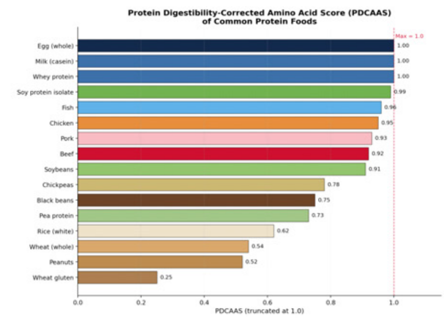


Animal Foods_Ideal Protein Sources

CNU

Nutritional Advantages of Meat & Eggs

- **High quality, complete protein**
  - All essential amino acid & high BCAA (leucine, isoleucine, valine)contents
  - High bioavailability with high digestibility
- **Highly bioavailable micronutrients**
  - Meat: heme iron, zinc, Vit. B12
  - Eggs: choline, Vit. D, Vit. A
- **Bioactive peptides and non-protein nitrogen compounds**
  - Various peptides from protein digestion
  - Carnosine, anserine, creatine, taurine, and L-carnitine



MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY

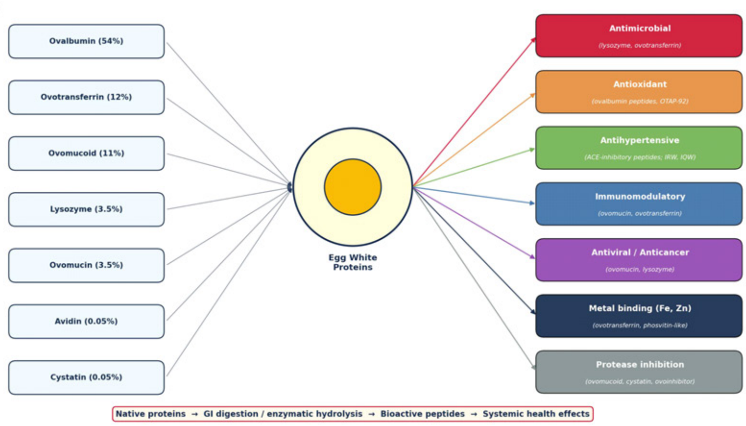
02

Animal Foods_Ideal Protein Sources

CNU

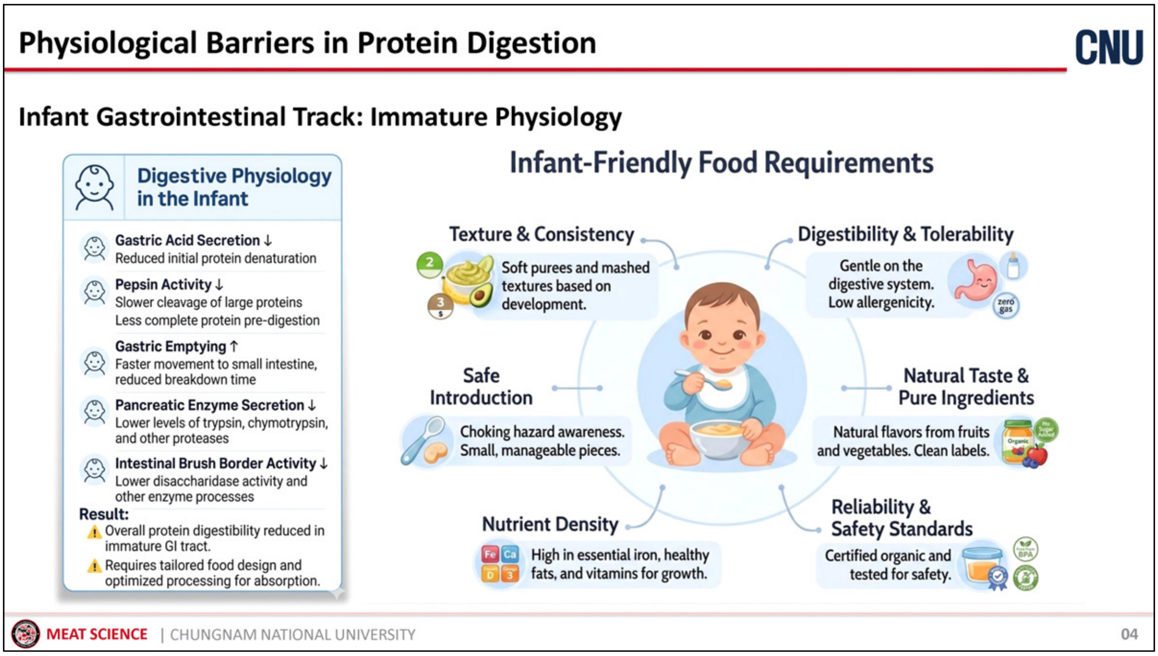
Nutritional Advantages of Meat & Eggs

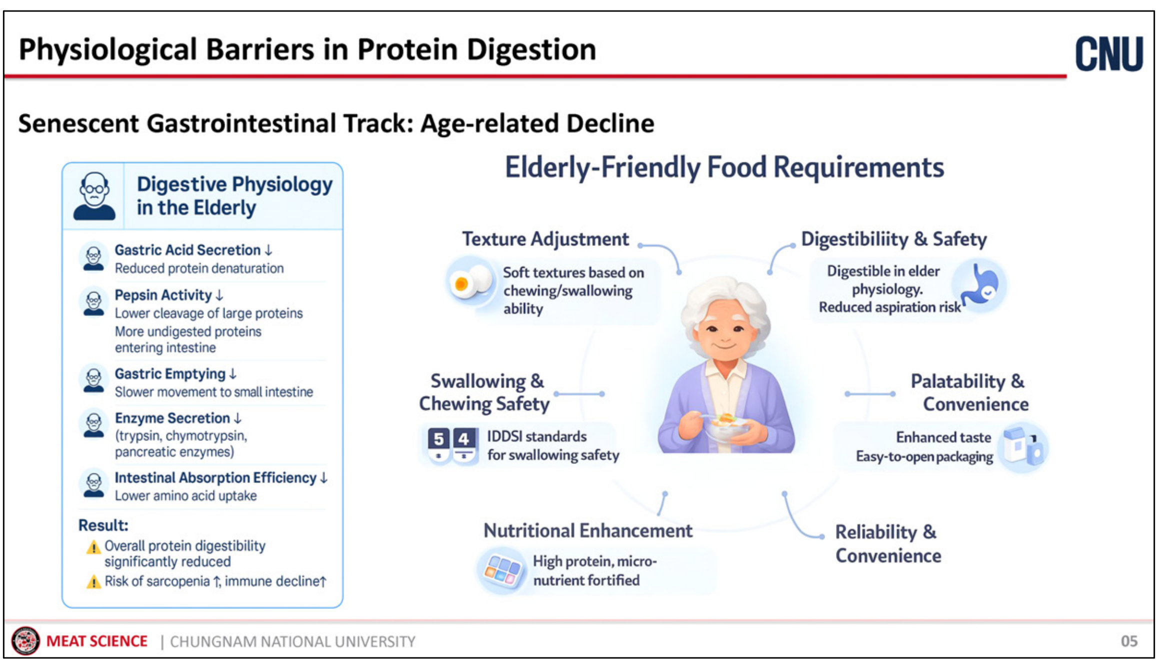
- **Bioactivity of egg white proteins**
  - Ovalbumin
  - Ovotransferrin
  - Ovomucoid
  - Lysozyme
  - Ovomucin
  - Avidin
  - Cystatin



MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY

03


Physiological Barriers in Protein Digestion
CNU
Infant Gastrointestinal Track: Immature Physiology
Digestive Physiology in the Infant
Gastric Acid Secretion ↓
Reduced initial protein denaturation
Pepsin Activity ↓
Slower cleavage of large proteins
Less complete protein pre-digestion
Gastric Emptying ↑
Faster movement to small intestine, reduced breakdown time
Pancreatic Enzyme Secretion ↓
Lower levels of trypsin, chymotrypsin, and other proteases
Intestinal Brush Border Activity ↓
Lower disaccharidase activity and other enzyme processes
Result:
Overall protein digestibility reduced in immature GI tract.
Requires tailored food design and optimized processing for absorption.
Infant-Friendly Food Requirements
Texture & Consistency
Soft purees and mashed textures based on development.
Digestibility & Tolerability
Gentle on the digestive system. Low allergenicity.
Safe Introduction
Choking hazard awareness. Small, manageable pieces.
Natural Taste & Pure Ingredients
Natural flavors from fruits and vegetables. Clean labels.
Nutrient Density
High in essential iron, healthy fats, and vitamins for growth.
Reliability & Safety Standards
Certified organic and tested for safety.
MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY
04

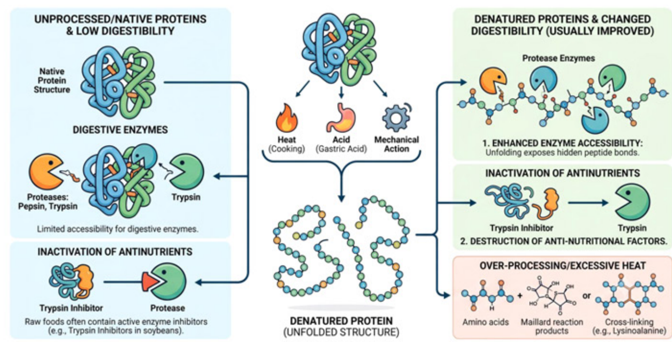

Physiological Barriers in Protein Digestion
CNU
Senescent Gastrointestinal Track: Age-related Decline
Digestive Physiology in the Elderly
Gastric Acid Secretion ↓
Reduced protein denaturation
Pepsin Activity ↓
Lower cleavage of large proteins
More undigested proteins entering intestine
Gastric Emptying ↓
Slower movement to small intestine
Enzyme Secretion ↓
(trypsin, chymotrypsin, pancreatic enzymes)
Intestinal Absorption Efficiency ↓
Lower amino acid uptake
Result:
Overall protein digestibility significantly reduced
Risk of sarcopenia ↑, immune decline↑
Elderly-Friendly Food Requirements
Texture Adjustment
Soft textures based on chewing/swallowing ability
Digestibiliity & Safety
Digestible in elder physiology. Reduced aspiration risk
Swallowing & Chewing Safety
IDDSI standards for swallowing safety
Palatability & Convenience
Enhanced taste Easy-to-open packaging
Nutritional Enhancement
High protein, micro-nutrient fortified
Reliability & Convenience
MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY
05

Molecular Mechanisms: Denaturation & Oxidation

CNU

Double-Edged Sword of Protein Denaturation

- **Protein digestibility increased**
  - Increase in protease accessibility by exposing buried cleaving sites with unfolding
  - Inactivation of protease inhibitors
- **Protein digestibility decreased**
  - Decreased in protease accessibility by aggregations (physical or non-covalent clumping) of proteins
  - Unrecognition of protease by chemical side reactions (covalent cross-linking or Maillard reaction) of proteins

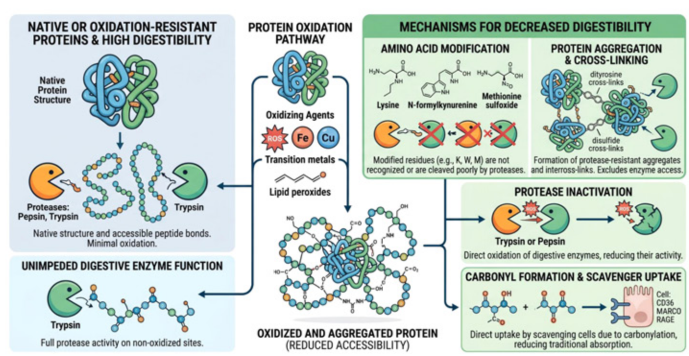


Molecular Mechanisms: Denaturation & Oxidation

CNU

Detrimental Impact of Protein Oxidation

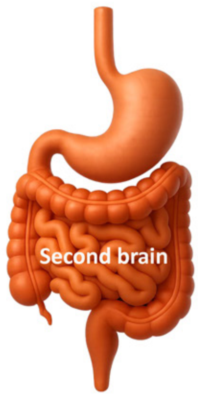
- **Structural collapse and aggregation**
  - Formation of protein-carbonyl compounds by chemical oxidation
- **Steric hindrance**
  - Oxidized proteins to re-collapse into highly compact, rigid polymers
  - Blocking protease access to binding pockets



Clinical Implications

CNU

Consequences of Poor Proteolysis in Infants



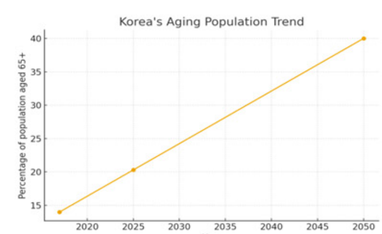
- **Growth faltering and nutritional deficiencies**
  - Amino acid deficiencies: Decrease in protein synthesis
  - Stunted growth: Delayed physical growth, poor weigh gain
- **Gastrointestinal distress and discomfort**
  - Fermentation and gas: Fermentation of undigested protein in the large intestine (severe abdominal discomfort with the production of excess gas)
  - Altered stool patterns: Leading to diarrhea or constipation by causing osmotic imbalances

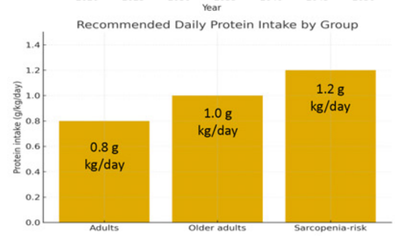
Clinical Implications

CNU

Consequences of Poor Proteolysis in the Elderly

- **Acceleration of sarcopenia and frailty**
  - Blunted muscle synthesis: Low absorption of essential amino acids
  - Increased frailty: Decrease in muscle mass
- **Impaired immune function and wound healing**
  - Delayed healing: Decrease in repairing skin barrier matrices
  - Higher infection risk: Low cellular immunity
- **Colonic fermentation and gut discomfort**
  - Toxic metabolites generated in the large intestine



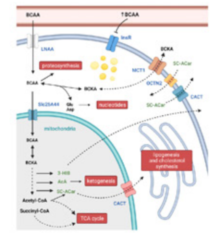


Advanced Processing Strategies for Improving Digestibility

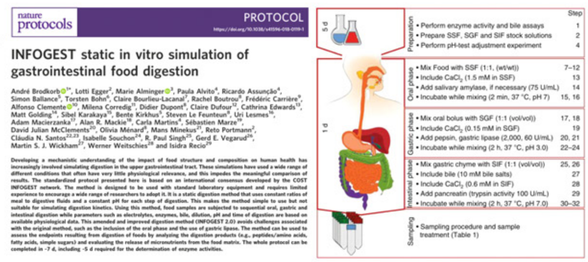
CNU

Materials and Methods

- **Samples**
  - Beef for infant complementary foods
  - Egg white for elderly-friendly foods



- **Static in-vitro digestion model**
  - INFOGEST protocol: young adult, infants, the elderly
  - Digestibility: < 3 kDa via cut-off filter



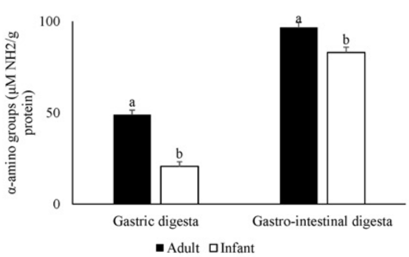
- **Protein structure**
  - Circular dichroism analysis
  - Surface hydrophobicity, Fluorescence intensity

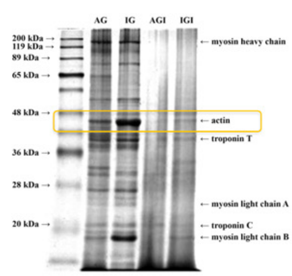
MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY 10

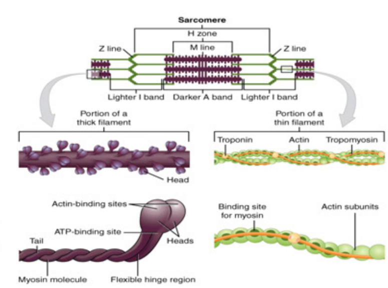
Advanced Processing Strategies for Improving Digestibility

CNU

Beef Protein Digestion: Adult vs. Infant



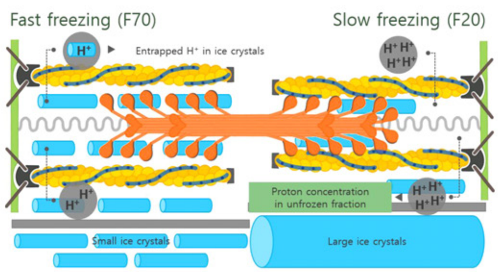


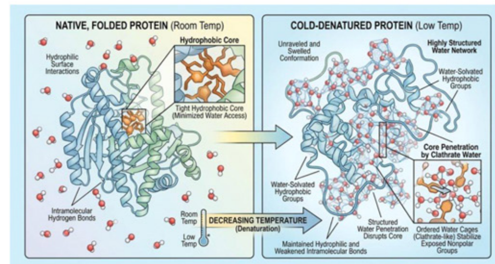


- **Results**
  - Beef protein digestibility was lower in both the gastric and gastrointestinal phases of the infant simulated digestion model than in the adult model.
  - Actin is the main protein with **digestive resistance** because the trypsin or chymotrypsin can not cleave **F-actin** since the cleaving sites are buried by the actin-actin interaction (Hozumi, The Journal of Biochemistry 104, 285).

MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY 11

Beef Protein Digestion: Freezing-then-aging

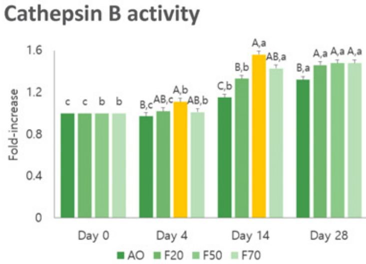




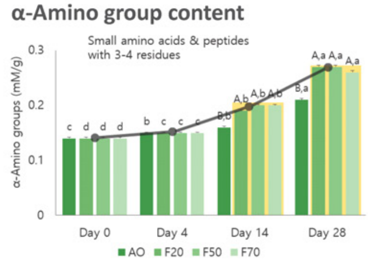
- **Hypothesis**
  - During the freezing process, the ice crystal formation results in the physical damage of the **lysosome** and release of **cathepsin**. **Cold denaturation of muscle protein** may change the behavior of protein digestibility.
  - During the aging of beef, the **degradation of muscle protein** may improve the digestibility.

Beef Protein Digestion: Freezing-then-aging

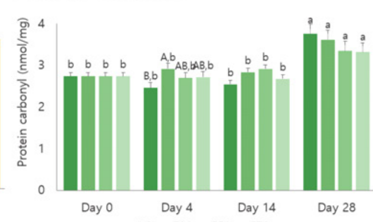
Cathepsin B activity



α-Amino group content



Protein oxidation



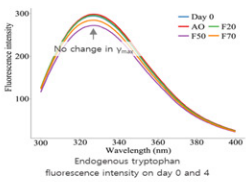
- **Results**
  - **Cathepsin B activity** was increased in the frozen-thawed beef, especially in F50 at day 14.
  - Degradation of muscle proteins was increased in the frozen-thawed beef.
  - Protein oxidation was increased after the 28-days aging process. However, no significant effect of freezing on the protein oxidation was found.

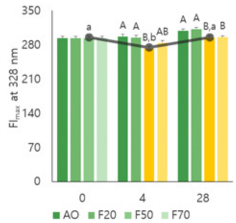
Advanced Processing Strategies for Improving Digestibility

CNU

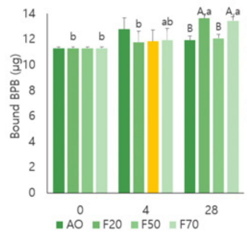
Beef Protein Digestion: Freezing-then-aging

Fluorescence intensity

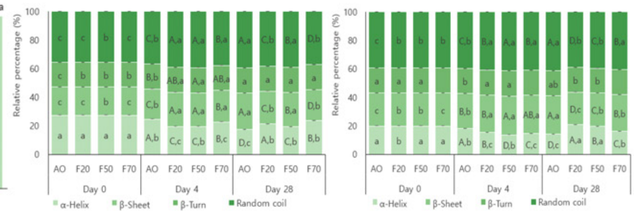




Surface hydrophobicity



Secondary structure of myosin and actin fractions



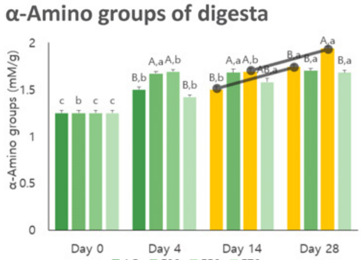
- **Results**
  - Fluorescence intensity of F50 was low at day 14 and 28. However, the surface hydrophobicity showed no consistent results.
  - In myosin and actin, denaturation and renaturation properties were observed on day 14 and 28, respectively, in frozen-thawed beef except for F50 myosin.

Advanced Processing Strategies for Improving Digestibility

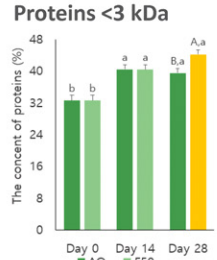
CNU

Beef Protein Digestion: Freezing-then-aging

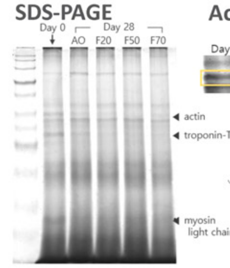
α-Amino groups of digesta



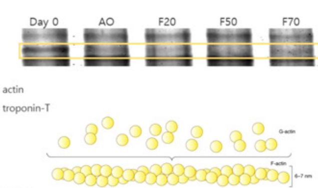
Proteins <3 kDa



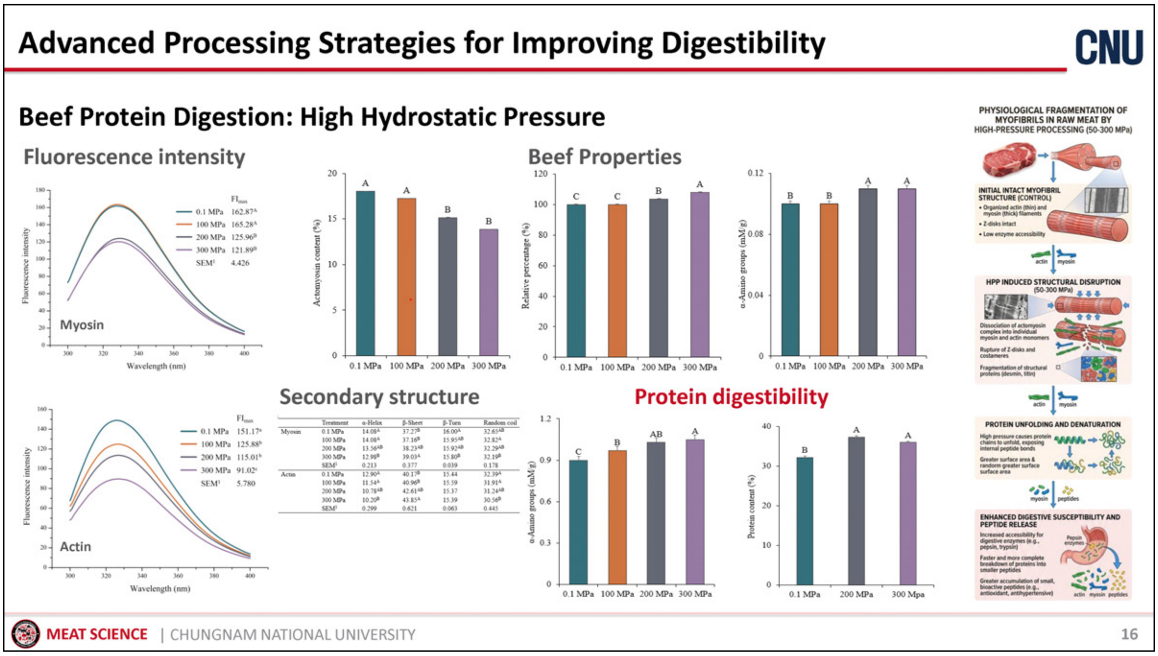
SDS-PAGE

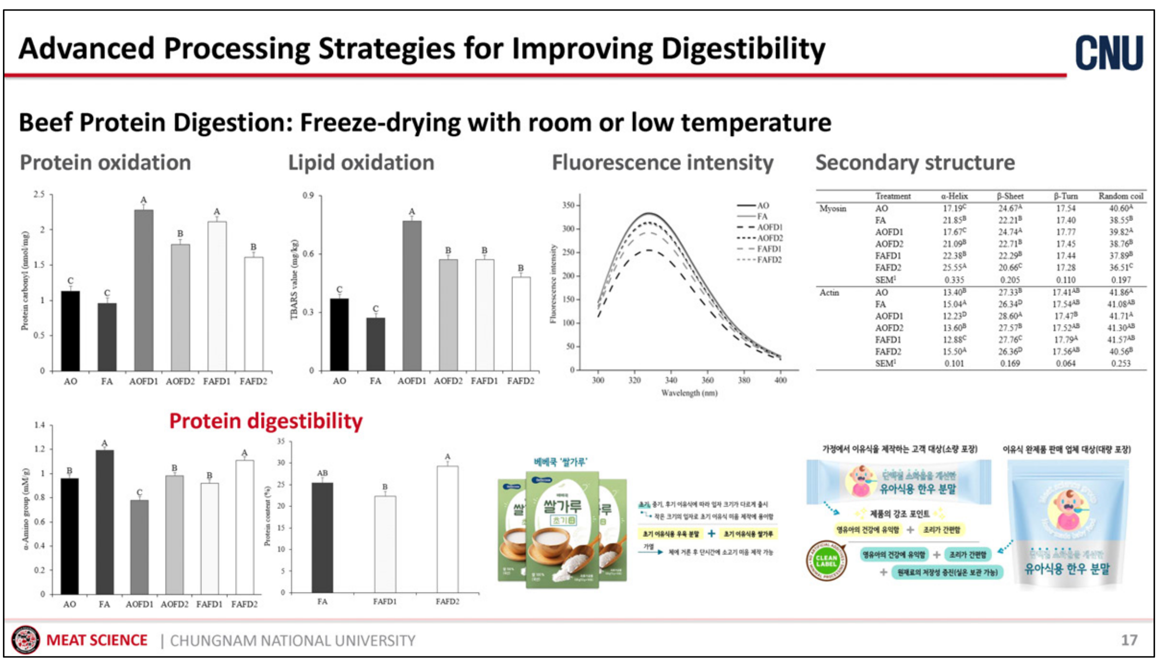


Actin band



- **Results**
  - After aging, the **actin** band disappeared in the freezing-then-aging beef.
  - Aging and the pre-freezing process resulted in an increase in beef protein digestibility.
  - F50 (frozen at -50°C) with 28 days of aging showed the highest protein digestibility.


Advanced Processing Strategies for Improving Digestibility
CNU
Beef Protein Digestion: High Hydrostatic Pressure
Fluorescence intensity
Myosin
Actin
Wavelength (nm)
Fluorescence intensity
0.1 MPa 162.87A
100 MPa 165.28A
200 MPa 125.96B
300 MPa 121.89B
SEM 4.426
0.1 MPa 151.17a
100 MPa 125.88b
200 MPa 115.01b
300 MPa 91.02c
SEM 5.780
Beef Properties
Actomyosin content (%)
Relative percentage (%)
α-Amino groups (mM/g)
0.1 MPa
100 MPa
200 MPa
300 MPa
Secondary structure
Protein digestibility
Protein content (%)
PHYSIOLOGICAL FRAGMENTATION OF MYOFIBRILS IN RAW MEAT BY HIGH-PRESSURE PROCESSING (50-300 MPa)
INITIAL INTACT MYOFIBRIL STRUCTURE (CONTROL)
HPP INDUCED STRUCTURAL DISRUPTION (50-300 MPa)
PROTEIN UNFOLDING AND DENATURATION
ENHANCED DIGESTIVE SUSCEPTIBILITY AND PEPTIDE RELEASE
MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY
16

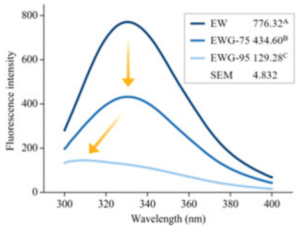

Advanced Processing Strategies for Improving Digestibility
CNU
Beef Protein Digestion: Freeze-drying with room or low temperature
Protein oxidation
Lipid oxidation
Fluorescence intensity
Secondary structure
Protein carbonyl (nmol/mg)
TBARS value (mg/kg)
Fluorescence intensity
Wavelength (nm)
AO
FA
AOFD1
AOFD2
FAFD1
FAFD2
Protein digestibility
α-Amino group (mM/g)
Protein content (%)
베베쿡 '쌀가루'
쌀가루
가정에서 이유식을 제작하는 고객 대상(소량 포장)
이유식 완제품 판매 업체 대상(대량 포장)
유아식용 한우 분말
제품의 강조 포인트
영유아의 건강에 유익함
조리가 간편함
CLEAN LABEL
MEAT SCIENCE | CHUNGNAM NATIONAL UNIVERSITY
17

Advanced Processing Strategies for Improving Digestibility

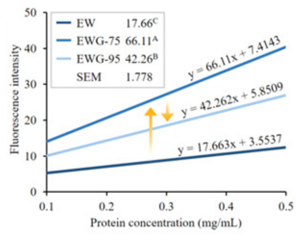
CNU

Egg White Protein Digestion: Different heating temperature

Fluorescence intensity



Surface hydrophobicity



Secondary structural components

Treatment	α-Helix	β-Sheet	β-Turn	Random coil
EW	41.81^{A}	14.11^{B}	17.60^{B}	26.49^{A}
EWG-75	42.15^{A}	13.13^{B}	16.93^{C}	27.80^{A}
EWG-95	30.57^{B}	25.85^{A}	19.53^{A}	24.05^{B}
SEM	0.870	0.681	0.127	0.633

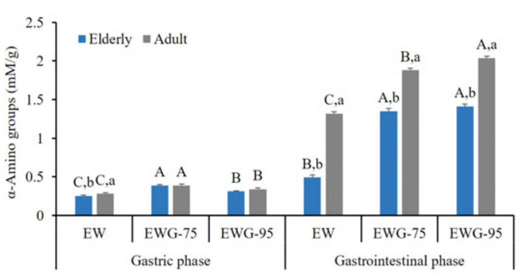
- **Results**
  - EWG-95 showed the lowest fluorescence intensity with a blue shift.
  - The surface hydrophobicity was increased in EWG-75 and 95 compared to EW. However, EWG-95 showed lower surface hydrophobicity than EWG-75.
  - EWG-95 consisted of lower α-helix and higher β-sheet content compared to EW and EWG-75.

Advanced Processing Strategies for Improving Digestibility

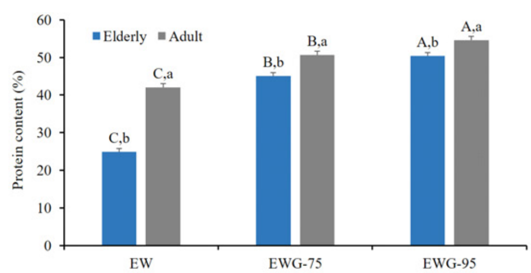
CNU

Egg White Protein Digestion: Different heating temperature

α-Amino groups of digesta



Contents of protein < 3 kDa



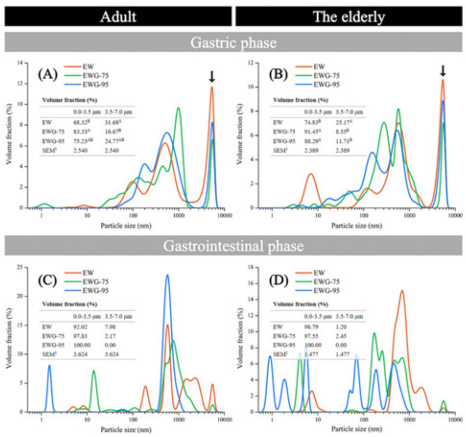
- **Results**
  - Amino group contents in the gastrointestinal phase were higher in the adult model than in the elderly model.
  - Protein digestibility increased in EWG compared to EW.
  - EWG-95 had higher protein digestibility than EWG-75.

Advanced Processing Strategies for Improving Digestibility

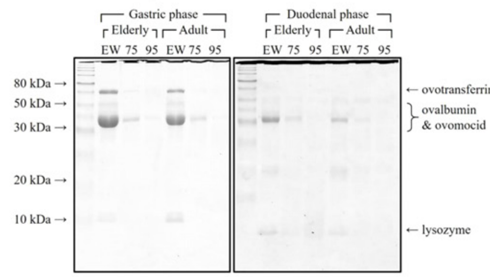
CNU

Egg White Protein Digestion: Different heating temperature

Particle size distribution of digesta



SDS-PAGE of digesta



- **Results**
  - ➢ Disruption of native EWPs including protease inhibitor, may play a more significant role in enhancing protein digestibility despite severe aggregation.

Conclusion & Future Outlook

CNU

- **Conclusion**
  - ➢ Animal food proteins (meat and eggs) possess excellent initial nutritional profiles, but their dense, native macromolecular networks limit actual bioaccessibility in underdeveloped or declining gastrointestinal tracts.
  - ➢ Optimizing structural processing conditions can significantly enhance *in vitro* protein digestibility and kinetics.
  - ➢ Animal foods provide maximum nutritional value when custom-tailored to the physiological needs of specific target consumers.

- **Future Outlook**
  - ➢ *In vivo* translation and clinical dietary trials
  - ➢ Comprehensive peptidomic mapping and bioactivity tracking
  - ➢ Industrial scale-up and development of age-specific medical foods

Thank you

Appendix

CNU

List of Published Core Research (Our Publications)

- Low protein digestibility of beef puree in infant in vitro digestion model. 2019. Food Sci. Ani. Resour. 39:1000-1007.
- Improvement of meat protein digestibility in infants and the elderly. 2021. Food Chem. 356, 129707.
- Freezing-then-aging treatment improved the protein digestibility of beef in an in vitro infant digestion model. 2021. Food Chem. 350, 129224.
- Changes in beef protein digestibility in an in vitro infant digestion model with prefreezing temperatures and aging periods. 2023. Heliyon, 9, e15611.
- High-pressure processing of beef increased the in vitro protein digestibility in an infant digestion model. 2023. Meat Sci. 205, 109318.
- Characterization of peptides released from frozen-then-aged beef after digestion in an in vitro infant gastrointestinal model. 2024. Meat Sci. 212, 109468.
- Heat-induced gelation of egg white proteins depending on heating temperature: Insights into protein structure and digestive behaviors in the elderly in vitro digestion model. 2024. Int. J. Bio. Macromol. 262, 130053.