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Smart Maillard Intermediate Driving Tunable Color and Flavor Formation: Thermal Responsiveness and Processing Adaptability of an Alanine–Xylose Amadori Rearrangement Product in Model and Meat Systems

Junhe Yu [1], Heping Cui [2], Imre Blank [3], Frank Oliver [4], Xiaoming Zhang [2]

[1] Laboratory for Functional Foods and Human Health, Center for Excellence in Post-Harvest Technologies, North Carolina Agricultural and Technical State University, 500 Laureate Way, Kannapolis, North Carolina 28081, USA

[2] State Key Laboratory of Food Science and Technology, School of Food Science and Technology, Jiangnan University, 1800 Lihu Road, Wuxi, Jiangsu 214122, China.

[3] Zhejiang Yiming Food Co., LTD., Jiuting Center Huting North Street No.199, Shanghai 201600, China

[4] Chair of Food Chemistry and Molecular Sensory Science, Technical University of Munich, Lise-Meitner-Strasse 34, D-85354 Freising-Weihenstephan, Germany.

INTRODUCTION & AIM

The Maillard reaction governs the flavor and color development in thermally processed foods, but uncontrolled reactions often lead to off-flavors and color instability. Amadori rearrangement products (ARPs), as stable intermediates of the Maillard pathway, represent a new strategy for controlled flavor generation and color modulation. Here, we focus on an alanine–xylose ARP (AX-ARP) as a model compound to:

a) Elucidate its flavor and color formation pathways under diverse processing conditions;
b) Examine its thermal adaptability in both aqueous models and meat systems;
c) Evaluate its potential as a functional flavor precursor and color modulator for practical food applications.

From Chemistry to Cuisine
Maillard Reaction Intermediates
What you really need to know?
How Maillard Intermediates Shape the Taste, Color, and Character of Great Food.

METHOD

i. Model Systems: A Maillard reaction intermediate (AX-ARP) was synthesized by an aqueous vacuum-dehydration reaction (yield > 90%) and compared with its precursors (alanine + xylose, AX) and classical Maillard reaction products (MRPs).

ii. Meat Systems: Chicken sausage model (roasting, frying, microwaving, steaming, boiling).All tests were performed in triplicate, and statistical significance was assessed by ANOVA ($p < 0.05$).

iii. Experimental Variables:
- Temperature: 100–160 °C
- pH: 4.5–10.5
- Precursor ratios:

ARP : alanine / xylose = 1:0–3:0

iv. Analytical methods:
Volatiles: HS-SPME–GC–MS
Odor profile: Ultrafast GC E-nose + PCA
Color: A_{420}, CIE L^* a^* b^*

RESULTS & DISCUSSION

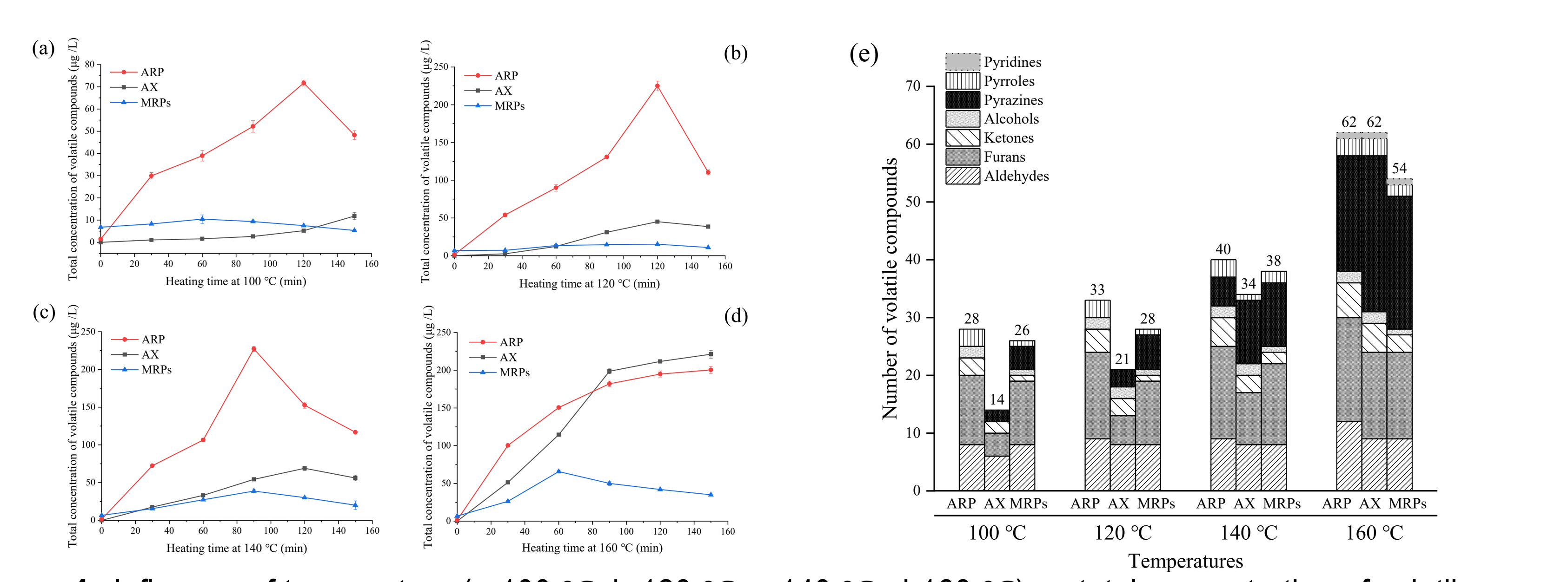
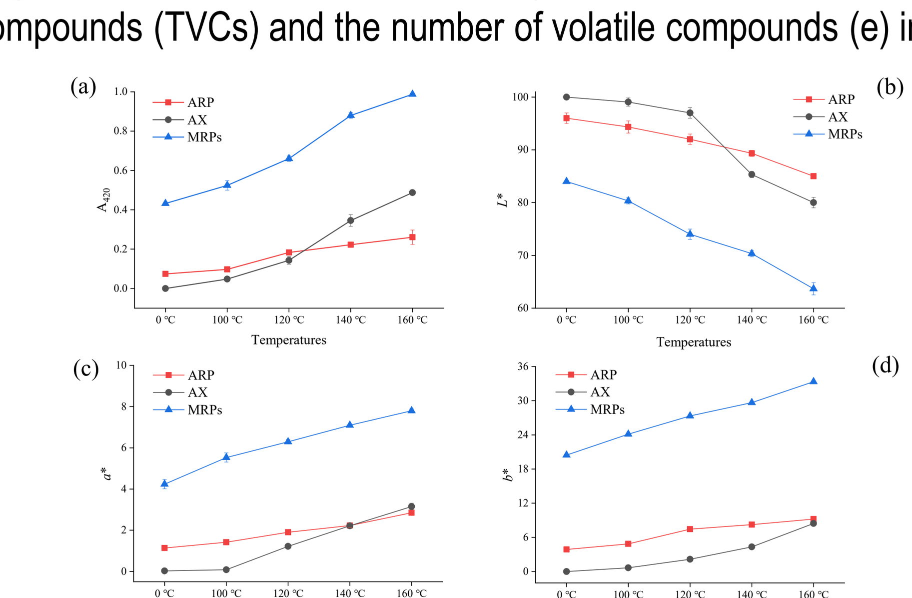


Figure 1. Influence of temperature (a-100 °C, b-120 °C, c-140 °C, d-160 °C) on total concentration of volatile compounds (TVCs) and the number of volatile compounds (e) in ARP, AX and MRPs model systems.



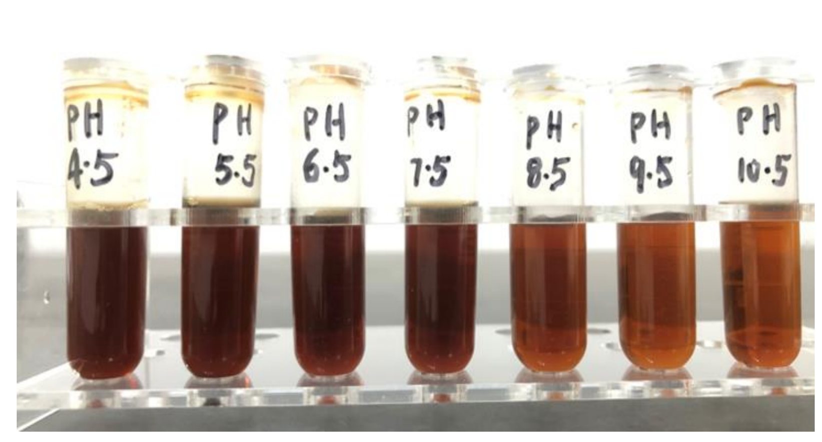


Figure 2. Influence of temperature on browning intensity (a) and color values L^* (b), a^* (c), b^* (d) in ARP, AX and MRPs model systems

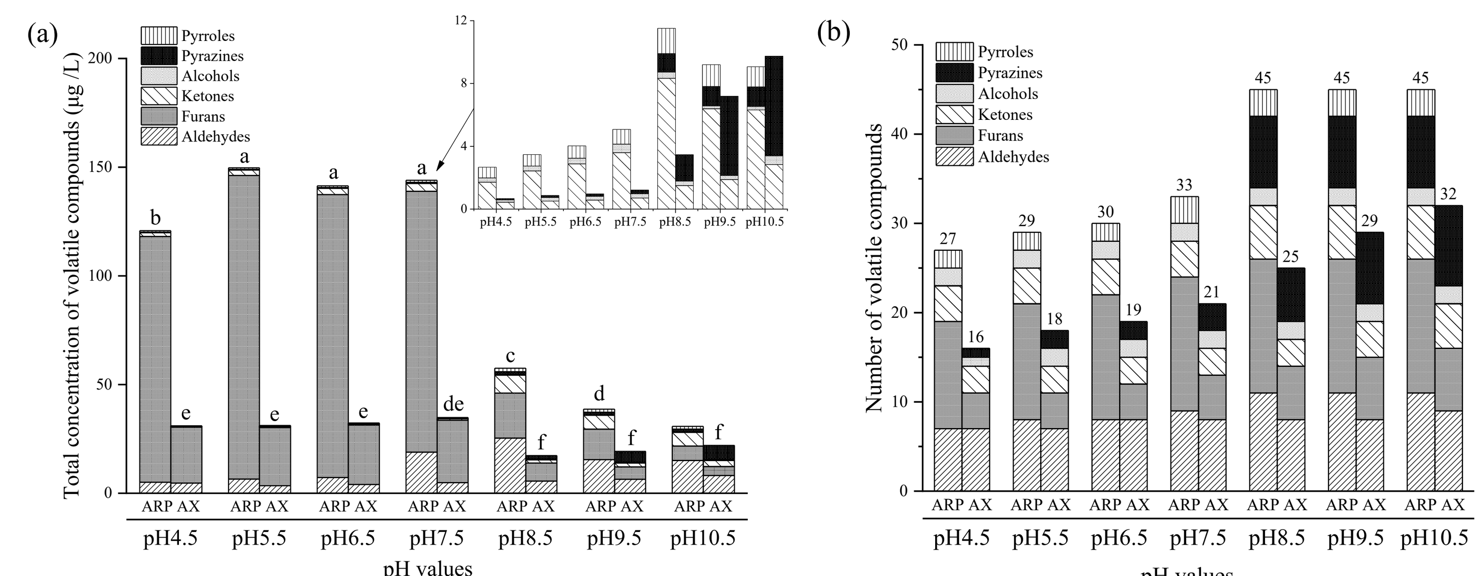


Figure 3. Influence of pH values on TVCs (a) and the number of volatile compounds (b) in ARP and AX model systems. Columns denoted with different letters are significantly different ($p < 0.05$), the numbers above columnar strips represent the total number of aroma-active compounds.

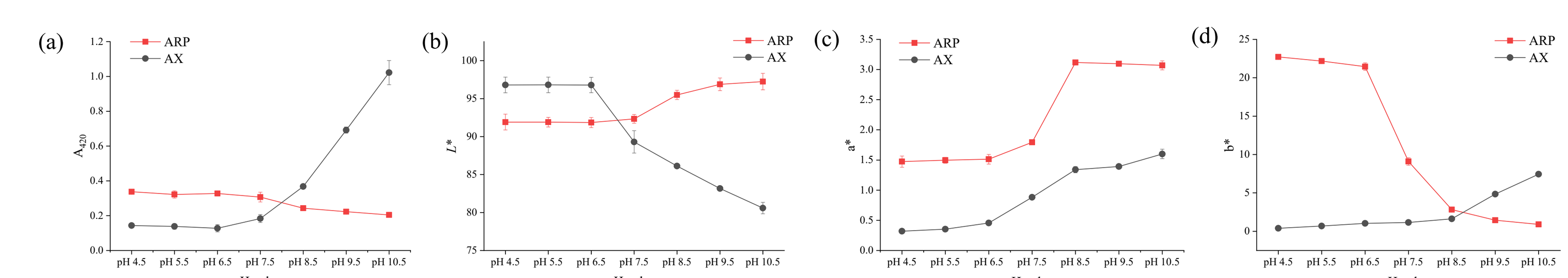


Figure 4. Influence of pH values on browning intensity (a) and color values L^* (b), a^* (c), b^* (d) in ARP and model systems.

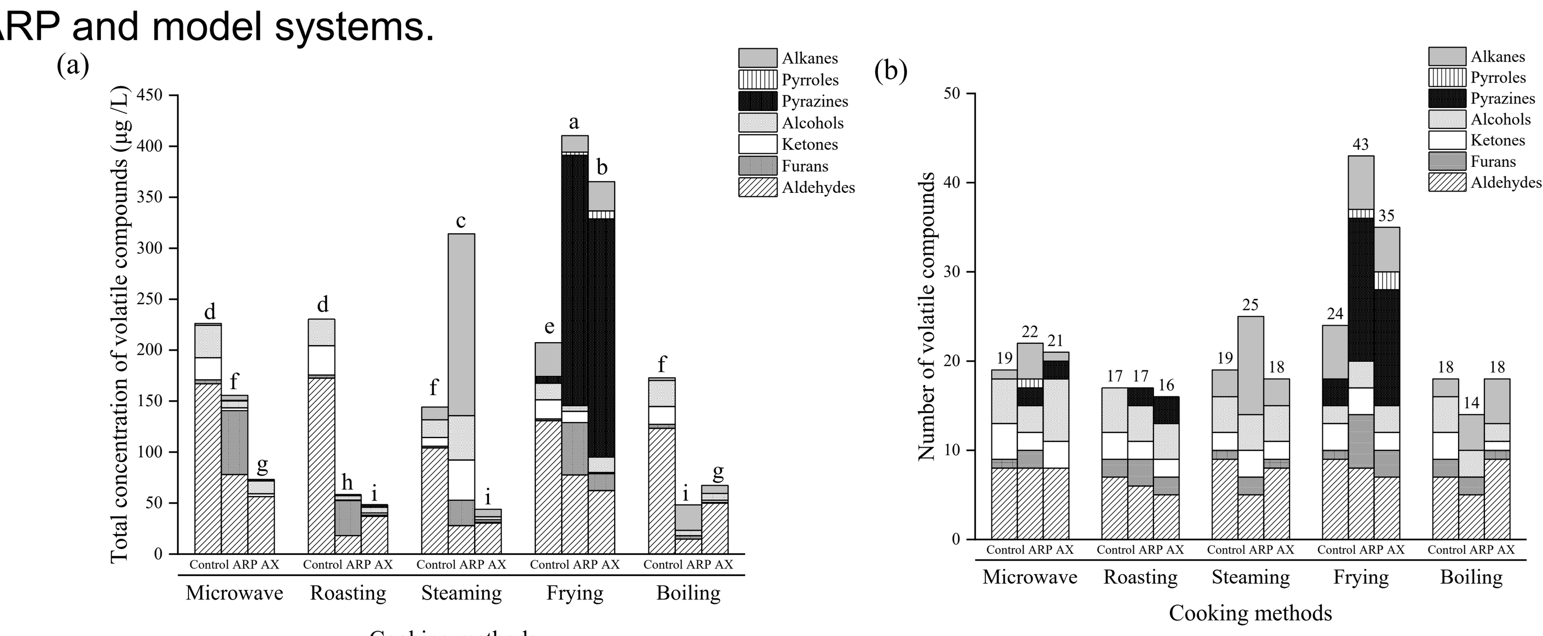


Figure 5. Influence of adding different ratios of precursors on TVCs (a) and the number of volatile compounds (b). Columns denoted with different letters are significantly different ($p < 0.05$), the numbers above columnar strips represent the total number of aroma-active compounds.

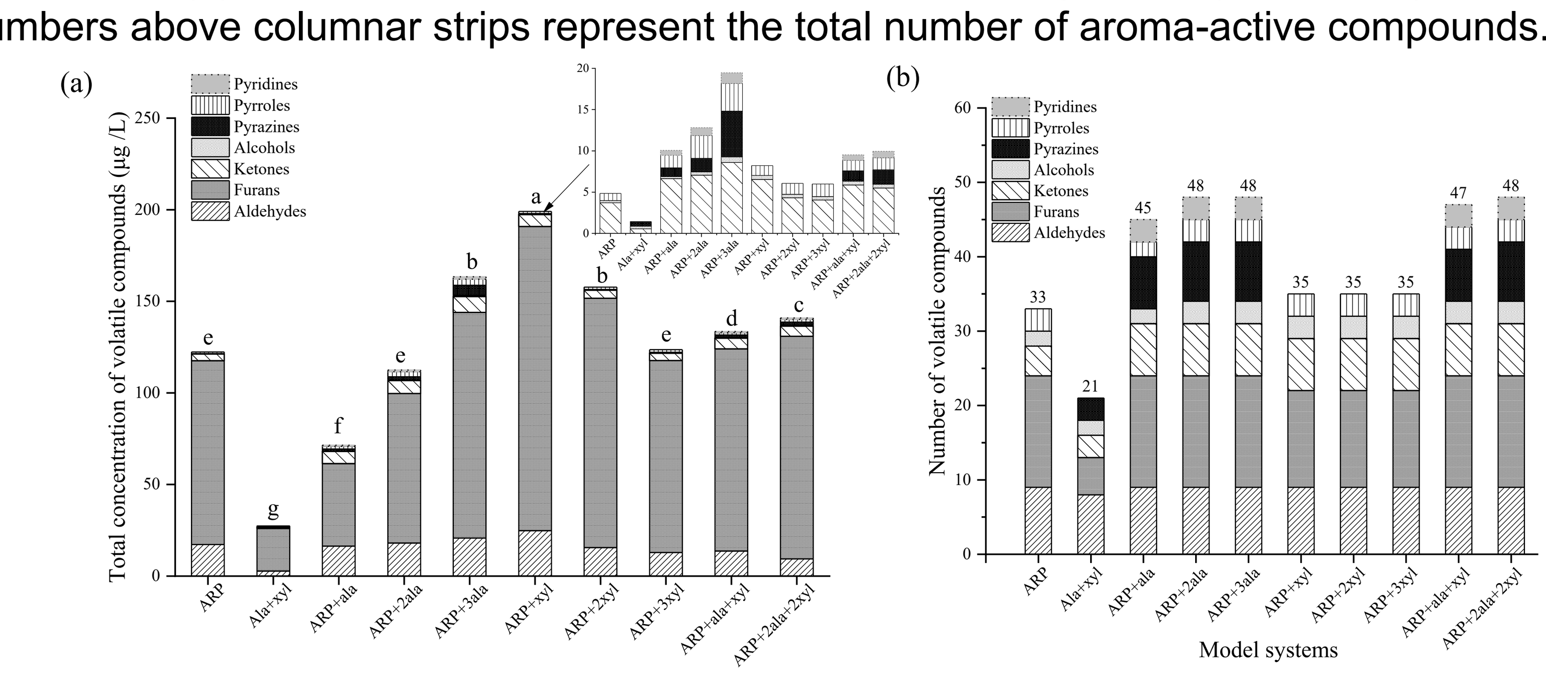


Figure 6. Influence of different cooking methods on TVCs (a) and the number of volatile compounds (b) in sausages. Columns denoted with different letters are significantly different ($p < 0.05$), the numbers above columnar strips represent the total number of aroma-active compounds.

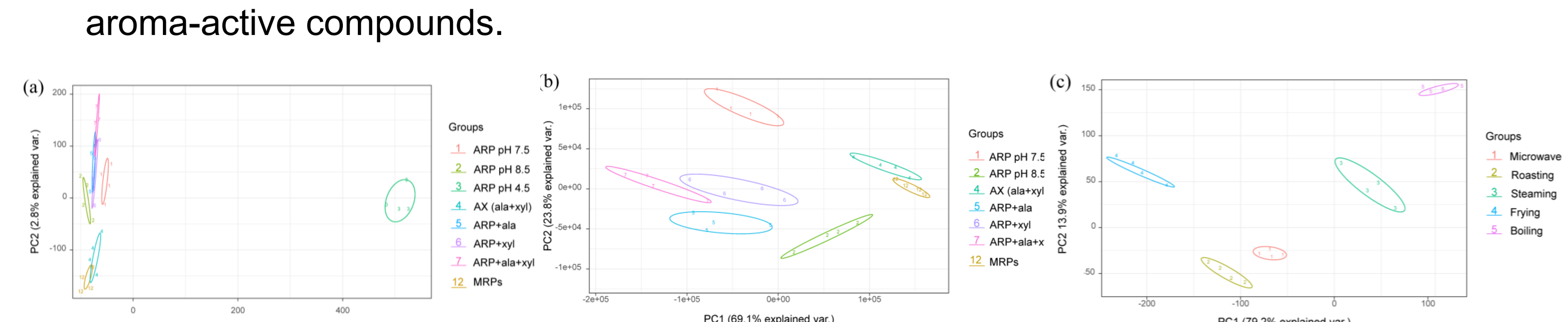
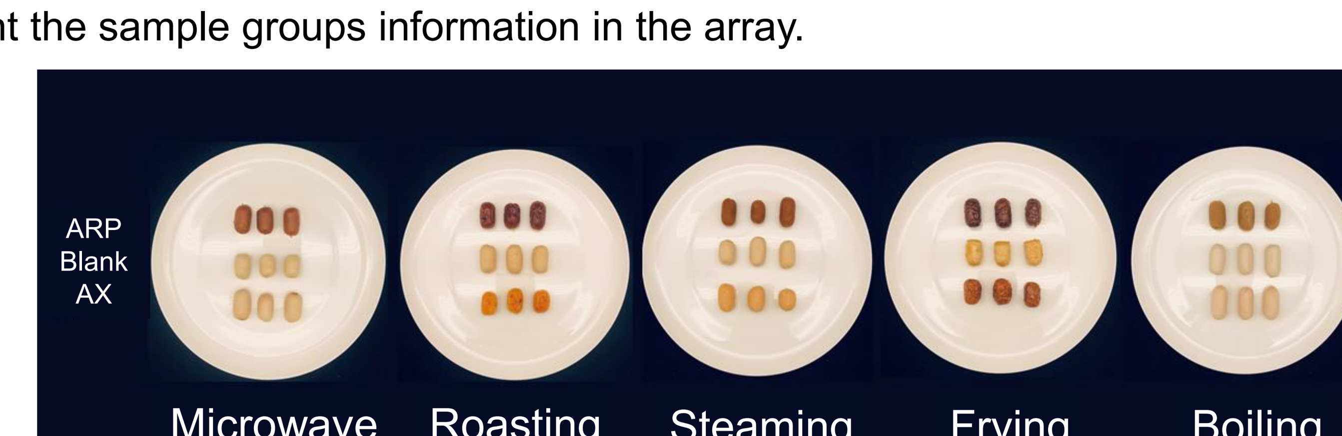


Figure 7. Principal component analysis (PCA) for different model reaction systems (a and b) in aqueous, and for real food systems with addition of 0.25 % ARP (c). The numbers 1 to 12 represent the sample groups information in the array.



CONCLUSION

AX-ARP acts as a smart Maillard intermediate capable of controlled flavor–color modulation. ARP could enhance color under acidic pH and boosting roasted notes with amino acid supplementation. Its thermal adaptability across multiple cooking modes suggests strong industrial feasibility. cooking modes supports industrial application. It improves flavor richness, color uniformity, and inhibits lipid oxidation in meat systems.

FUTURE WORK / REFERENCES

- Expand ARP reactions with diverse amino acids/sugars to broaden aroma spectra.
- Develop ARP-based flavor enhancers for microwave & air-fried foods.

(1) Cui H., Yu J., et al. Trends Food Sci. Technol., **2021**, 115, 391–408;
(2) Yu J., Cui H., et al. Agric. Food Chem., **2020**, 68, 10902–10911;
(3) Zhang X., Yu J., et al. U.S. Patent 11,903,401 (**2024**).