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Research Article

Physicochemical and sensory evaluation of additive-free hot-air dried applemango (*Mangifera indica* L. var. Irwin) fruit leathers

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Abstract Applemango (*Mangifera indica* L. var. Irwin) has limited shelf life and distribution potential due to its high moisture content and rapid respiration rate. To improve storability and add value, hot-air dried fruit leathers were prepared from applemango juice in three formulations: a control with no additives (CON), 1% tapioca starch (TSG), and 1% gelatin (GLG). These were compared with commercial dried applemango slices (CAG). This study aimed to evaluate the physicochemical and sensory properties of the formulations. Moisture content was similar among the experimental leathers but significantly lower in CAG. No significant differences were observed in pH, soluble solids, or color among the groups. Texture analysis revealed a hardness trend of GLG > TSG > CON. Sensory evaluation indicated that CAG scored lowest in appearance and color but highest in chewiness, reflecting its firmer texture. CON leathers received higher scores for flavor and overall acceptability than TSG and CAG. These findings suggest that additive-free applemango leathers may be an effective formulation, offering advantages in processing simplicity, cost efficiency, and consumer preference.

Keywords applemango leather, *Mangifera indica* (Irwin cultivar), hot-air drying, fruit leather, additive-free formulation

1. Introduction

The Irwin mango (*Mangifera indica* L. var. Irwin), originally bred in the United States, is commercially known in Korea as "applemango" due to its apple-like skin color (Jung et al., 2016; Lim et al., 2016). Applemangoes are highly favored by consumers for their high sugar content, juiciness, and distinctive aroma. In recent years, domestic consumption has grown steadily, driven by increasing demand for premium tropical fruits (An et al., 2015; Cheon et al., 2024; Ji et al., 2018). Initially cultivated on Jeju Island, applemango production has expanded into inland regions due to climate change, with output expected to increase further (Jeong and Kim, 2021; Wijethunga et al., 2023).

Despite the projected growth in production, mangoes, including applemangoes, have a short shelf life due to their high moisture content, soft texture, rapid respiration, and ethylene production, all of which limit postharvest handling and distribution (Oh et al., 2023; Vilvert et al., 2022).

At storage temperatures of 10-18℃, mangoes typically show significant quality deterioration within two weeks (Oh et al., 2022a). According to Sarkar et al. (2020), improper postharvest processing contributes to considerable economic losses, with global mango waste estimated at USD 480 million annually. To overcome these challenges, it is essential to develop processed products that extend shelf life and utilize surplus or discarded applemangoes (Oh et al., 2022b; Yoo and Lee, 2021).

Drying is a widely used method for preserving fruits (Kim et al., 2024; Lee and Kim, 2015), as it lowers moisture content, inhibits microbial growth and chemical reactions, and facilitates storage and distribution (Da Silva Simao et al., 2020; Fathi et al., 2022). Various drying techniques—such as hot-air drying, freeze-drying, vacuum drying, and infrared drying—have been applied to mangoes and other tropical fruits (De Menezes Rodrigues et al., 2023; Sarkar and Chakraborty, 2018). When applied to fruit purée or juice, these methods can produce fruit leathers—thin, flexible sheets used as shelf-stable snacks (Diamante et al., 2014; Valenzuela and Aguilera, 2013). Fruit leathers are lightweight, portable, and have longer shelf lives than conventional dried fruits (Da Silva Simao et al., 2020; Srinivas et al., 2020), while also serving as an effective means of upcycling surplus or cosmetically imperfect fruits (Gomez-Perez et al., 2020).

Recent research has focused on improving the sensory and functional qualities of fruit leathers by incorporating additives such as dietary fiber, vitamins, and antioxidants (Bandaru and Bakshi, 2020; De Menezes Rodrigues et al., 2023). To mitigate quality degradation caused by nonenzymatic browning—including Maillard reactions and ascorbic acid oxidation—food-grade acids and antioxidants, such as citric acid and sulfites, have been commonly applied during processing and storage. These additives help preserve the visual and nutritional quality of fruit leathers by slowing browning in products such as papaya, apple, and quince (Chan and Cavaletto, 1978; Torres et al., 2015). In addition, various hydrocolloids—including starch, maltodextrin, gelatin, pectin, gums, alginate, and cellulose derivatives—have been employed to improve processability, texture, and stability (Da Silva Simao et al., 2020). These high-molecular-weight compounds reduce stickiness caused by organic acids and sugars, thereby enhancing drying efficiency and facilitating packaging (Prangpru et al., 2015; Valenzuela and Aguilera, 2015).

In particular, hydrocolloids like gelatin and tapioca starch have been used to enhance texture and palatability as gelling or thickening agents (Alam et al., 2024; Alam et al., 2025; Baziwane and He, 2003). Gelatin forms thermoreversible gels with good foaming stability and melts below body temperature, while tapioca starch increases moisture content and imparts elasticity and chewiness (Ahn, 2005; Kim and Park, 2013; Kim et al., 2022; Zuniga and Aguilera, 2009). These properties contribute to improved chewiness, mouthfeel, and structural integrity—key factors in consumer preference. However, most existing studies have focused on leathers produced from common mango cultivars, and research on applemango-based leathers remains limited. In particular, scientific evaluations of applemango leathers formulated with gelatin or tapioca starch are scarce.

Therefore, this study aimed to develop hot-air dried fruit leathers from applemango juice, formulated with or without 1% gelatin or tapioca starch. The physicochemical and sensory properties of the resulting leathers were compared with those of commercially available dried applemango slices. The findings aim to support the development of high-value-added products and promote the industrial utilization of applemango.

2. Materials and methods

2.1. Materials and pretreatments

Applemangoes (*M. indica* L. var. Irwin) cultivated in Haman, Gyeongsangnam-do, South Korea, were used in this study. The fruits were thoroughly washed under running water, peeled, and cut to collect the edible flesh (Fig. S1). The collected flesh was then homogenized using a blender to obtain applemango juice. To prepare the fruit leathers, 30 g of the homogenized juice was uniformly distributed into 90×15 mm Petri dishes and dried in a cabinet-type hot-air dryer (JSOF-150, JSR Co., Gongju, Korea) at 40℃ for 12 h. As illustrated in Fig. 1, three experimental formulations were prepared: a control group without additives (CON), a group with 1% tapioca starch (TSG), and a group with 1% gelatin (GLG), with additive concentrations based on the total juice weight. Additionally, a commercially available sliced dried applemango product was included for comparison and designated as the commercial group (CAG). In total, four groups were analyzed in this study. All experimental conditions were determined through preliminary trials (data not shown). After preparation, samples were sealed by group and stored

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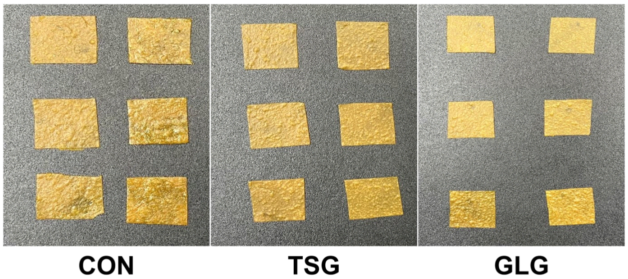

Fig. 1. Grouping of hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives. CON, hot-air dried applemango fruit leathers with no additives; TSG, hot-air dried applemango fruit leathers with tapioca starch; GLG, hot-air dried applemango fruit leathers with gelatin.

at -20℃ until analysis.

2.2. Moisture content measurement

Moisture content was determined using a hot-air oven-drying method under atmospheric pressure. Approximately 2.0 g of each sample was dried at 105℃ in a hot-air dryer (JSOF-150) until a constant weight was achieved. Moisture content was calculated based on the percentage of weight loss.

2.3. pH measurement

For pH analysis, 10 g of each sample was mixed with 90 mL of distilled water and homogenized at 10,000 rpm for 5 min using a homogenizer (JP/AM-9, Nihonseiki Kashima Co., Tokyo, Japan). The homogenate was then centrifuged at 7,000 ×*g* for 15 min at 4℃ using an ultracentrifuge (CP100WX & CS150NX, Hitachi Co., Tokyo, Japan). The pH of the supernatant was measured in triplicate using a calibrated pH meter (SevenCompact S210, Mettler-Toledo, China).

2.4. Measurement of soluble solids content

To determine the soluble solids content of the applemango leathers, 10 g of each sample was mixed with 90 mL of distilled water and homogenized at 10,000 rpm for 5 min using a homogenizer (JP/AM-9). The homogenate was then centrifuged at 7,000 ×*g* for 15 min at 4℃ using an ultracentrifuge (CP100WX & CS150NX). The °Brix of the supernatant was measured using a refractometer (MASTER-α, Atago Co., Tokyo, Japan).

2.5. Color analysis

Color measurements were performed using a calibrated colorimeter (CR-400, Konica Minolta Co., Tokyo, Japan) standardized with a white reference plate (L* = 97.79, a* = -0.38, b* = 2.05). The surface of each sample was measured at three randomly selected points, and the results were reported using the CIE color system as lightness (L*), redness (a*), and yellowness (b*).

2.6. Texture (hardness) analysis

The hardness of the applemango leathers was assessed using a rheometer (Compac-100II, SunScientific Co., Tokyo, Japan). The testing conditions included a penetration distance of 15 mm, adapter type No. 36, and a table speed of 60 mm/min. Hardness was selected as the primary textural parameter because it is one of the most widely standardized and representative indicators used in fruit leather research. It is also closely associated with consumer perceptions of chewiness and elasticity, which aligns with the key sensory attributes evaluated in this study. Hardness values were obtained from 24 replicates per sample group.

2.7. Sensory evaluation

Sensory evaluation was conducted with 16 trained student panelists from Kyungpook National University. Only samples dried on the same day were used to ensure safety and consistency. Panelists were briefed on the evaluation procedures beforehand. A 7-point hedonic scale was used to rate the following attributes: overall acceptability, appearance, color, flavor, sweetness, chewiness, and elasticity. Higher scores indicated greater preference for overall acceptability, appearance, color, and flavor, as well as greater intensity for sweetness, chewiness, and elasticity. The evaluation adhered to ethical standards and was exempt from review by the Institutional Review Board of Kyungpook National University (Approval Number: KNU-2024-0034).

2.8. Statistical analysis

All experimental data were analyzed using SPSS software (Ver. 29, IBM Corp., Armonk, NY, USA). One-way analysis of variance (ANOVA) was used to assess differences among groups. When significant effects were observed ($p<0.05$), either Tukey's HSD or the Games-Howell post hoc test was applied, depending on the homogeneity of variances. For non-normally distributed data, the Kruskal-Wallis test was used to evaluate statistical significance ($p<0.05$).

3. Results and discussion

3.1. pH, moisture content, and soluble solids of applemango leathers

To assess the effects of tapioca starch and gelatin on the moisture content of hot-air dried applemango leathers, four groups were analyzed: CON (control, no additives), TSG (1% tapioca starch), GLG (1% gelatin), and CAG (commercial dried slices). The results are summarized in Table 1.

The CAG group exhibited the lowest moisture content (3.92%), whereas the CON, TSG, and GLG groups showed higher values of 19.71%, 14.18%, and 13.95%, respectively. No statistically significant differences were observed among the CON, TSG, and GLG groups, and their moisture levels were in line with previous findings on mango leathers (Da Silva Simao et al., 2020). These results indicate that the addition of 1% tapioca starch or gelatin did not significantly influence the final moisture content of applemango leathers, likely because the concentration was too low to alter water retention meaningfully. In contrast, the markedly lower moisture content in the commercial sample (CAG) likely reflects differences in manufacturing conditions—such as higher drying temperatures, longer drying durations, or post-processing steps like vacuum packaging—that may have further reduced moisture to extend shelf life.

The soluble solids content (°Brix) ranged from 6.96 to 7.67 across all groups, with no statistically significant differences. This indicates that the addition of tapioca starch and gelatin did not notably alter sweetness levels. Similarly, a study on quince jelly sheets reported no significant correlation between the concentration of added tapioca starch and perceived sweetness (Kim and Park, 2013). Another study evaluating the quality characteristics of jelly prepared with various gelling agents found that gelatin had minimal impact on the soluble solids content (Kim et al., 2020), which is consistent with the present findings.

Regarding pH, values for the experimental groups (CON, TSG, and GLG) ranged from 4.60 to 4.72, with no significant differences. However, the CAG group exhibited a significantly lower pH of 4.33. This suggests that the addition of 1% tapioca starch or gelatin had negligible effects on the pH of applemango leather and that variations in pH were more likely due to differences in raw materials or industrial processing conditions. The significantly lower pH of the CAG group may also be attributable to factors such as the origin or ripeness of the raw fruits used or the incorporation of acidulants during commercial processing. In contrast, the fruit leather samples produced here originated from a single fruit source and were processed under controlled and uniform conditions, which may explain the minimal variation in the pH values of the three fruit leathers.

Table 1. Moisture content, total soluble solids, and pH of commercial dried applemango slices and hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives

Group[1)]	Moisture content (%)	Soluble solids (°Brix)	pH
CAG	3.92±0.13[2)b3)]	7.19±0.71[4)a]	4.33±0.13[b]
CON	19.71±2.58[a]	7.41±0.43[a]	4.60±0.06[a]
TSG	14.18±3.03[a]	6.96±0.27[a]	4.62±0.06[a]
GLG	13.95±2.56[a]	7.67±0.50[a]	4.72±0.08[a]

[1)]CAG, commercial dried applemango slices; CON, hot-air dried applemango fruit leathers with no additives; TSG, hot-air dried applemango fruit leathers with tapioca starch; GLG, hot-air dried applemango fruit leathers with gelatin.
[2)]Values are mean±SD (n=4).
[3)]Means with different superscript letters in the same column are significantly different ($p<0.05$) based on the Games-Howell test or the Tukey's HSD test.
[4)]Values are mean±SD (n=3).

3.2. Color and hardness of applemango leathers

The color parameters (L*, a*, and b*) of the applemango leathers and the commercial dried slices (CAG) are summarized in Table 2. Lightness (L*) ranged from 62.13 (CON) to 64.04 (CAG), redness (a*) from 12.02 to 12.86, and yellowness (b*) from 46.34 to 51.37, with no statistically significant differences among groups. These results indicate that neither tapioca starch nor gelatin significantly altered the color of the applemango leather, and the appearance remained comparable to that of the commercial product. This aligns with previous research showing no significant changes in L*, a*, or b* values after adding 5% cassava starch to mango leather (Da Silva Simao et al., 2019) and no color differences between gelatin-added and control samples in ponzu jelly with 1% gelatin (Lee, 2014).

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Table 2. Hunter color values of commercial dried applemango slices and hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives

Group[1)]	Hunter's color[2)]		
	L*	a*	b*
CAG	64.04±2.54[3)a4)]	12.02±1.12[a]	48.02±3.21[a]
CON	62.13±1.18[a]	12.86±1.69[a]	46.34±3.27[a]
TSG	63.89±0.82[a]	12.42±0.68[a]	51.37±0.95[a]
GLG	62.74±1.08[a]	12.86±1.05[a]	50.73±1.44[a]

[1)]CAG, commercial dried applemango slices; CON, hot-air dried applemango fruit leathers with no additives; TSG, hot-air dried applemango fruit leathers with tapioca starch; GLG, hot-air dried applemango fruit leathers with gelatin.
[2)]L*, lightness; a*, redness; b*, yellowness.
[3)]Values are mean±SD (n=3).
[4)]Means with different superscript letters in the same column are significantly different ($p<0.05$) based on the Tukey's HSD test or the Kruskal-Wallis test.

Hardness values, shown in Table 3, revealed that GLG (5.42 MPa) and TSG (5.03 MPa) were significantly harder than CON (3.29 MPa), although no significant difference was found between GLG and TSG. This suggests that the increased viscosity and elasticity imparted by tapioca starch and gelatin contributed to the greater hardness observed in the TSG and GLG samples. In contrast, the higher moisture content in the CON group likely accounted for its lower hardness, consistent with previous findings indicating that moisture is a key factor influencing the texture of dried foods (Lee et al., 2023; Mazumder et al., 2007). However, due to pronounced variability in slice thickness and excessive firmness in some pieces, hardness measurements for the commercial dried applemango slices (CAG) could not be reliably conducted using the same method as for the leathers and were therefore excluded from the analysis.

Table 3. Hardness of hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives

Group[1)]	Hardness (MPa)
CAG	ND[2)]
CON	3.29±0.97[3)b4)]
TSG	5.03±0.64[a]
GLG	5.42±0.97[a]

[1)]CAG, commercial dried applemango slices; CON, hot-air dried applemango fruit leathers with no additives; TSG, hot-air dried applemango fruit leathers with tapioca starch; GLG, hot-air dried applemango fruit leathers with gelatin.
[2)]ND, not determined.
[3)]Values are mean±SD (n=24).
[4)]Means with different superscript letters in the same column are significantly different ($p<0.05$) based on Tukey's HSD test.

3.3. Sensory properties of applemango leathers

Sensory evaluation was conducted to compare the quality characteristics of the applemango leathers and the commercially available dried applemango slices, with results summarized in Table 4. In terms of visual attributes such as appearance and color, no statistically significant differences were observed among the leather samples (CON, TSG, and GLG). However, the commercial product (CAG) received significantly lower scores in both categories, likely due to its irregular shape and unevenly thick slices, which made it appear less visually appealing compared to the uniform appearance of the fruit leathers. Notably, instrumental color analysis revealed no significant differences in L*, a*, and b* values among the leather groups, a finding that was consistently reflected in the sensory color evaluations.

For elasticity, no significant differences were observed among all groups, including the commercial product. Although the incorporation of tapioca starch and gelatin was expected to enhance elasticity, this effect was not perceptible to the sensory panel. This may be attributed to the inherent elastic texture of fruit leathers, which results from the presence of pectin and dietary fiber in fruit purée or juice (Alam et al., 2025; Azeredo et al., 2006; Valenzuela and Aguilera, 2013). To produce a noticeable increase in elasticity, a higher concentration of hydrocolloids may be required, as the 1% level used in this study appears to have been insufficient.

In contrast, chewiness scores were significantly higher for the commercial sample (CAG), while no significant differences were observed among the applemango leather groups. This is consistent with previous studies indicating that lower moisture content is closely associated with increased chewiness (Ansari et al., 2014; Mao et al., 2024). Thus, the greater chewiness observed in CAG likely stems from its lower moisture level. Sweetness scores did not differ significantly among the groups, which is consistent with the similar °Brix values measured across samples. The uniformity in soluble solids content likely contributed to the comparable sweetness perceptions.

In the flavor category, the CON sample received the highest score (5.69), followed by TSG (4.81), GLG (4.69),

Table 4. Sensory properties of commercial dried applemango slices and hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives

Group[1)]	Sensory properties						
	Appearance	Color	Flavor	Sweetness	Chewiness	Elasticity	Overall acceptability
CAG	3.31±2.02[2)b3)]	3.31±1.66[b]	3.63±1.67[b]	4.69±1.62[a]	5.31±1.58[a]	3.56±1.75[a]	4.13±2.13[b]
CON	5.06±1.29[a]	5.31±1.40[a]	5.69±1.49[a]	5.44±1.41[a]	4.38±1.03[b]	4.31±1.14[a]	5.75±1.00[a]
TSG	5.50±1.03[a]	5.06±1.24[a]	4.81±1.28[ab]	4.81±1.22[a]	4.88±0.72[ab]	4.81±1.28[a]	5.00±1.21[ab]
GLG	5.31±1.14[a]	5.19±1.17[a]	4.69±1.35[b]	4.56±1.37[a]	4.31±0.95[b]	4.31±1.54[a]	4.56±1.32[b]

1)CAG, commercial dried applemango slices; CON, hot-air dried applemango fruit leathers with no additives; TSG, hot-air dried applemango fruit leathers with tapioca starch; GLG, hot-air dried applemango fruit leathers with gelatin.
2)Values are mean±SD (n=16).
3)Means with different superscript letters in each column are significantly different ($p<0.05$) by the Kruskal-Wallis test.

and CAG (3.63). While CON was not significantly different from TSG, it showed statistically significant differences compared to GLG and CAG. These results suggest that the higher moisture content of CON may have enhanced flavor release, making it more palatable to panelists. In particular, the low moisture content of CAG may have restricted the diffusion of aromatic compounds, diminishing its characteristic applemango flavor. This result is consistent with previous research indicating that higher moisture content can promote the release of volatile flavor compounds (Menting et al., 1970; Voilley et al., 2011).

A similar pattern was observed in the overall acceptability scores, with CON again receiving the highest ratings and the remaining groups following the same trend as seen in the flavor category. This suggests that overall preference was largely driven by flavor perception. As extensively documented in the literature, olfactory cues play a central role in flavor perception (Spence, 2015), and the high flavor score of CON likely contributed to its superior overall acceptability. Although the difference was not statistically significant, it is worth noting that CON also received the highest sweetness score, further reinforcing the interpretation.

Overall, the sensory evaluation demonstrated that the applemango leather produced without added hydrocolloids (CON) achieved the highest consumer preference. This indicates that applemango leather produced by hot-air drying of juice without additives is more desirable than the commercially available dried slices. In addition to sensory advantages, the additive-free approach offers potential benefits in terms of flavor quality, reduced material costs, and process simplicity, underscoring its value from both consumer and production standpoints. However, an important point to acknowledge is that many food additives also play essential roles in other areas of food production, including extending shelf life, improving microbial safety, and enhancing nutritional value. Future studies should explore the incorporation of natural additives with multifunctional properties to balance improvements in processed food sensory quality with enhancements in preservation and health benefits.

4. Conclusions

This study demonstrated that applemango leathers can be successfully produced from juice formulations using hot-air drying, with or without the inclusion of hydrocolloids such as tapioca starch and gelatin. While the addition of hydrocolloids influenced certain texture attributes, particularly hardness, their impact on moisture content, pH, soluble solids, and color was negligible. Sensory evaluation results indicated that the additive-free formulation (CON) received the highest scores for flavor and overall acceptability, indicating a relatively greater preference among consumers. These findings suggest that omitting hydrocolloids from the formulation may not only streamline the production process and reduce material costs, but also enhance product appeal and consumer satisfaction. The superior performance of the additive-free leather highlights its potential as a competitive product in the dried fruit market. Future research should focus on optimizing drying parameters, exploring innovative packaging solutions, or incorporating natural ingredients to further improve the sensory quality and functional properties of applemango leathers.

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Supplementary materials

Supplementary materials are only available online from: https://doi.org/10.11002/fsp.2025.32.4.665.

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Conflict of interests

The authors declare no potential conflicts of interest.

Author contributions

Conceptualization: Kim M, Jung Y, Ku S, Choe D. Methodology: Kim M, Jung Y, Silva Pincay MJ, Kim J, Kim JS. Formal analysis: Kim M, Jung Y, Kim J, Kim JS, Ku S, Choe D. Validation: Ku S, Choe D. Writing - original draft: Kim M, Jung Y, Ku S, Choe D. Writing - review & editing: Lee SB, Jung YH, Lee SH, Moon KD, Son DS, Ku S, Choe D.

Ethics approval

The sensory evaluation of this research was safely carried out with the approval of exemption (No. KNU-2024-0034) from the IRB of Kyungpook National University.

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Supplementary materials

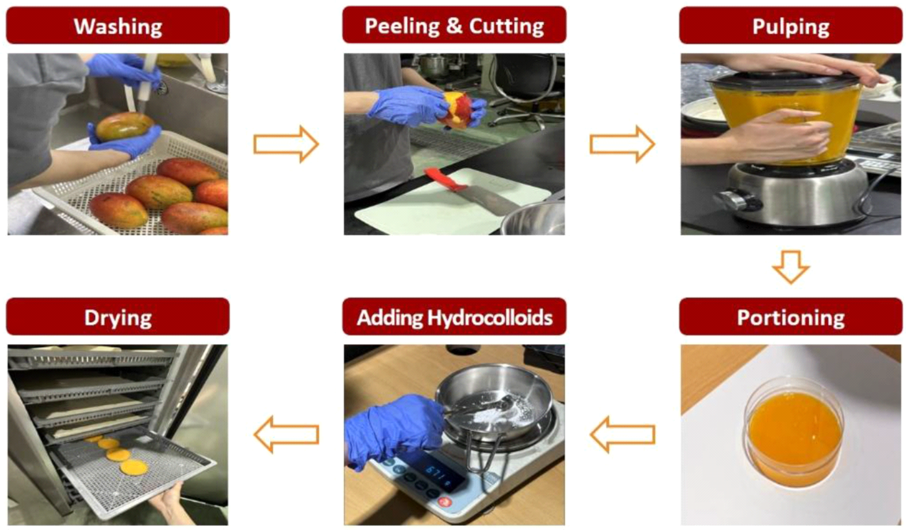

Fig. S1. Manufacturing process of hot-air dried applemango leathers prepared with tapioca starch, gelatin, or no additives.

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