p-ISSN: 1907-8056
e-ISSN: 2527-5410
AGROINTEK
Jurnal Teknologi Industri Pertanian
journal homepage: journal.trunojoyo.ac.id/agrointek

Physicochemical properties of vegetable leather made from broccoli stems *(Brassica oleracea var. italica)* with the addition of pectin

Safinta Nurindra Rahmadhia[1*], Ummu Nur Saadah[1], Ali Jebreen[2]

[1]*Food Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia*
[2]*Therapeutic Medical Nutrition, Palestine Ahliya University, Bethlehem, Palestine*

Article history
Received:
7 June 2024
Revised:
17 October 2024
Accepted:
31 December 2024

Keyword
Broccoli stems;
Pectin;
vegetable leather

ABSTRACT

Vegetable leather is a product that comes from dried vegetable puree in the form of flexible sheets. It has a chewy texture that can be consumed as a snack. Broccoli stems are vegetables that are rarely used to their full potential. The problem that often arises with vegetable leather is its poor elasticity. This research aims to determine the physicochemical properties of the broccoli stem vegetable leather. The production of vegetable leather was done by mixing broccoli stems and pectin in various concentrations (F1 (99.5% and 0.5%), F2 (99% and 1%), F3 (98.5% and 1.5%), F4 (98% and 2%).Furthermore, the mixture was dried to form a thin sheet. Then, broccoli stems and vegetable leather were analyzed for their physical and chemical properties such as texture, water content, ash content, reducing sugar, vitamin C, and crude fiber. The results showed that the addition of pectin had a significant effect on the physical properties of the texture, namely hardness 599.62N to 752.82N, gumminess 560.84N to 751.01N, chewiness 511.34N to 685.49N and do not show a significant effect for cohesiveness 0.9074 to 0.9750. Chemical properties have a significant effect on water content values 11.92% to 13.16%, reducing sugar 8.52% to 9.90%, vitamin C 40.15mg/100g to 44.58mg/100g, crude fiber 9.48% to 11.61%, and ash content 2.14% to 2.25%. The incorporation of broccoli stem with additional pectin to produce vegetable leather constitutes a food rich in fiber and vitamins. By-products of broccoli can be turned into nutritionally beneficial foods.

[*] Corresponding author
Email : safinta.rahmadhia@tp.uad.ac.id
DOI 10.21107/agrointek.v19i2.25870

INTRODUCTION

Vegetable leather is a dried vegetable-based product, eaten as a snack in strips or sheets that are flexible and have a chewy texture. Vegetable leather products are a practical way to increase the consumption of vegetables in solid form, both for children and adults (Handayani and Ayustaningwarno 2014, Ramadhani and Saidi 2021, Sarma et al. 2023). Vegetable leather is not as popular as fruit leather; nonetheless, fundamentally, both products are identical. The only difference is in the basic material. The principal processing stages in the production of fruit leather encompass transforming the fruit into puree or concentrated juice, amalgamating it with hydrocolloid and sugar (if necessary), and dehydrating it at temperatures ranging from 30 to 80 °C till achieving a moisture content of 12 to 20% (Raj et al. 2024). The production of vegetable leather frequently encounters an issue of insufficient flexibility. Consequently, a gelling agent is essential to enhance the texture of the created leather (Gómez-Pérez et al. 2020). Numerous fruits with significant nutritional and economic value were utilized in the production of fruit leather, including pomegranate (Tontul and Topuz 2018), papaya (Addai et al. 2016), dragon fruit (Raj and Dash 2022), and banana (Das et al. 2021).

Broccoli is a food ingredient which is a source of fiber. The function of fiber for the body is to help in the absorption and disposal of waste in the digestive tract (Dang et al. 2019, Gudiño et al. 2022). The advantageous impacts of broccoli and its derivatives have been extensively researched in recent years as a source of significant bioactive chemicals with potential use in the treatment and prevention of human diseases. The elevated levels of glucosinolates, phenolic compounds, carotenoids, vitamin C, dietary fiber, and minerals in broccoli and its derivatives confer advantageous effects against specific diseases, including cardiometabolic disorders and cancer (Coman et al. 2020, Quizhpe et al. 2024). Broccoli stems are a by-product of broccoli that are rarely used. Broccoli stems have the same nutrients as the flowers. So, it is necessary to utilize broccoli stems as food products. In consideration of the health advantages conferred by broccoli, which extends beyond basic nourishment owing to its exceptional abundance of phytochemicals, the by-products produced from its cultivation might be abundant in bioactive compounds and exhibit advantageous qualities (Ferreira et al. 2018, Shi et al. 2019). The use of broccoli stems as vegetable leather can produce a high-fiber and high-antioxidant food product. It is also one way to utilize food waste.

Pectin is a complex colloidal carbohydrate derivative extracted from plant tissue that can form gels. Pectin, primarily sourced from citrus peels or apple pomace, is a significant natural biomass resource that is widely plentiful globally. Commercial pectin is a comprehensive and safe hydrocolloid extensively utilized by the food and beverage sectors as a texturizer and gelling agent (Zeeb et al. 2021). Pectin is a water-soluble heteropolysaccharide mostly consisting of a backbone formed by the polymerization of galacturonic acid residues. As natural polymers, their gelation, biocompatibility, and non-toxicity facilitate the creation of films like vegetable and fruit leather (Roy et al. 2023). The advantage of pectin in vegetable leather products compared to other hydrocolloids is that it can form a soft texture. The gel structure formed is stronger than that of other hydrocolloids because it is stable and not easily degraded.

In making vegetable leather, acid is also added to accelerate gel formation so that it works synergistically with the characteristics of pectin, which can undergo a rapid gelatinization process when acid is added (Seisun and Zalesny 2021). Pectin has emerged as the third-largest food hydrocolloid by revenue, following gelatin and starches, and has become the most esteemed natural hydrocolloid (Ciriminna et al. 2022). Pectin is able to bind not only water molecules but also other molecules, such as color pigments contained in vegetable leather raw materials. It also maintains the original color of the raw material so that the product has an attractive and distinctive color from the raw material used. During gel formation, the pectin will clump together to form fine fibers that are able to hold liquid. The density of the fine fibers formed is determined by the high levels of pectin (Zeeb et al. 2021). In making vegetable leather, the best gel formation will be achieved if a pectin concentration of between 0.5–4% is added with the addition of appropriate sugar and acid (Astuti et al. 2015). This research contributed to determining the effect of pectin on the physical and chemical properties of broccoli stem vegetable leather. Developing broccoli stems into vegetable leather is anticipated to diminish food waste. Moreover, the resultant product may be a dietary item rich in fiber and vitamin C.

RESEARCH METHODS

Material

The materials used in this research were green Italian broccoli stems (3 - 4 cm from the base of the flower), orange peel pectin (Sentra Chemicals Indonesia), sugar (Gulaku), citric acid (Cap Gajah), aqudes, NaoH 1.5 N, H_2SO_4, ethanol 96%.

Broccoli stems puree production.

The stage of making puree bulbs is sorting, reducing the size of the broccoli bulbs, and washing the broccoli bulbs. Then, the broccoli bulb was steamed to reduce the initial amount of dirt. Subsequently, the steamed broccoli bulb was ground and ready to use in the next production (Maryati et al. 2018).

Broccoli stems vegetable leather production.

The production of broccoli stems vegetable leather refer to research by (Yılmaz et al., 2017) with modification. The process of producing broccoli stem vegetable leather begins with weighing the broccoli stem puree and incorporating additional components, including pectin, citric acid, and sugar (Table 1). The mixture is thereafter heated to 70°C for 2 minutes while being stirred. The mixture is then shaped on a baking sheet and dehydrated in a cabinet drier at 70°C for 17 hours until broccoli stem vegetable leather is formed.

Texture Analysis

The texture of broccoli stem vegetable leather was carried out using the TA-TX Plus Texture Analyzer. The analysis was conducted in triplicates (Fitriani et al. 2024).

Water Content Analysis

Water content analysis of broccoli stem vegetable leather was carried out using the thermogravimetry method (AOAC 2005, Makiyah et al. 2024). The analysis was conducted in triplicates and calculated as Equation (1), where A is the weight of the empty weighing bottle (g), B is the weight of the weighing bottle and sample (g), and C is the weight of weighing bottle and sample after oven (g).

$$\text{Water content (\% d.b)} = \frac{B-C}{B-A} \times 100\% \quad (1)$$

Ash Content Analysis

Ash content analysis of broccoli stem vegetable leather was carried out using a muffle furnace. The analysis was conducted in triplicates and calculated as Equation (2), where A is empty exchange weight (g), B is the weight of exchange rate and sample before ashing (g), and C is the weight of exchange rate and sample after ashing (g) (AOAC 2005, Wati et al. 2024).

$$\text{Ash content (\%)} = \frac{C-A}{B-A} \times 100\% \quad (2)$$

Reducing Sugar Analysis

Reducing sugar analysis of broccoli stem vegetable leather was carried out using titration methods. The analysis was conducted in triplicates and calculated as Equation (3).

$$\text{Reducing sugar (\%)} = \frac{Bt \times Df \times 0.1}{mg(sample)} \times 100\% \quad (3)$$

Note: Bt = blanko titration
Df = dilution factor

Vitamin C Analysis

Vitamin C analysis of broccoli stem vegetable leather was carried out using iodometric titration (Fitriana and Fitri 2020). The analysis was conducted in triplicates and calculated as Equation (4), where V is the volume of Iodine (ml), Fp is the dilution factor, and W is sample weight (g).

$$\text{Vitamin C} = \frac{(V \times 0{,}88 \times Fp) x\ 100}{W} \times 100\% \quad (4)$$

Table 1 The formulation of broccoli stem vegetable leather

Formulation	Broccoli stems (%b/b)	Pectin (%b/b)	Citric acid (%b/b)	Sugar (%b/b)
F1	76.37	0.38	0.23	23.02
F2	75.98	0.77	0.23	23.02
F3	75.60	1.15	0.23	23.03
F4	75.22	1.53	0.23	23.02

Crude Fiber Analysis

Determination of crude fiber in the broccoli stems vegetable leather was performed by (Cvrk et al. 2022). During the analysis, measure 1 g of the grounded sample and add 50 ml of 0.3 N H_2SO_4. Then heat it at 70 °C for 1 hour. After that, 25 ml of NaOH was added and continued heating for 30 minutes at 70°C. The solution was filtered, and the precipitate was added with distilled water, 50 ml of H_2SO_4, and 50 ml of ethanol. After filtration was complete, the filter paper containing the residue was placed in the oven for 1 hour at 105 °C, then cooled in a desiccator for 15 minutes and weighed. The analysis was conducted in triplicates and calculated as equation 5.

$$\text{Crude fiber analysis} = \frac{W_{dry+filter} - W_{filter}}{W_o} \times 100\% \quad (5)$$

Note:
$W_{dry+filter}$= dry residu weight + filter paper
W_{filter} = weight filter paper
W_o= initial sample weight

Data Analysis

The data obtained in this study were analyzed statistically using SPSS 25.0 with the One-way ANOVA (Analysis of Variance) method. If significant results are found, further analysis is carried out using the DMRT (Duncan Multiple Range Test) at a significance level of 95%.

RESULTS AND DISCUSSION

Texture of broccoli stems vegetable leather.

In Table 2, it can be seen that the hardness value of broccoli stems vegetable leather ranges from 599.62-752.82 N. The lowest hardness is found in F1, while the highest is in F4. The cohesiveness value of broccoli stems vegetable leather ranges from 0.9074-0.9750. The lowest cohesiveness was found in F1, while the highest value was found in F4. The gumminess value of broccoli stem vegetable leather ranged from 560.84-751.01 N. The lowest gumminess value was in F1, while the highest value was in F4. The chewiness value of broccoli stems vegetable leather ranged from 511.34 – 685.49 N. The lowest chewiness value was in F1, while the highest chewiness was in F4.

The decreasing amount of broccoli stem puree and the increasing amount of pectin added, the higher the hardness, cohesiveness, gumminess, and chewiness value. Pectin affects the formation of gel in a jam. The higher the pectin content, the denser the structure formed in the sample. This is because the higher the concentration of pectin, the higher the ability to bind water (Diamante et al. 2013, Schreuders et al. 2022). The increase in texture is caused by the mixture of pectin, sugar, and acid forming a strong gel that can increase the hardness of the gel in the product. Gel formation can occur with pectin levels between 0.5-4% (Petkowicz et al. 2017, Ayustaningwarno et al. 2024). Pectin can increase cohesiveness due to water absorption. The addition of sugar can affect the pectin-water balance in the material so that the pectin will coagulate and form a smooth matrix that is able to hold liquid, the higher the sugar content in the material, the less water is held by the matrix so that the texture is more compact. In addition, the addition of sugar and citric acid will bind the water contained in the ingredients so that when heated, the water does not evaporate much, and the resulting texture is chewy. Pectin is effective in thickening, altering the flexible texture, and maintaining the shape of dry materials (Srinivas et al. 2020, Wan-Mohtar et al. 2021).

In the research conducted by (Ayustaningwarno et al., 2024), dragon fruit leather with added watermelon rind as a source of pectin produced a plastic texture. The protons from citric acid will neutralize the negatively charged pectin, resulting in clumping and the formation of a fine, chewy fiber upon heating. Fruit leather produced in (Vázquez-Sánchez et al., 2021) research also has a soft and not hard texture. The more apple concentration is used, the more texture is produced that is not fragile and not easily broken. In this case, apples are fruits that are high in pectin.

The water content of broccoli stem vegetable leather.

The water content value of broccoli stem vegetable leather ranged from 11.92 –13.16% (Table 3), which has a significant increase between groups ($p<0.05$). The lowest water content value is found in F1, while the highest water content is in F4.

The reduction of broccoli stems puree and the increase of pectin concentration, together with the elevation of water content. Pectin serves to bind water, as pectin gel operates as a sponge-like matrix saturated with water; thus, an increase in pectin correlates with an increase in water binding capacity. The gel formation induced by pectin in conjunction with sugar and acid might enhance water retention in leather products due to its capacity to encapsulate water (Wan-Mohtar et al. 2021). The moisture level of high-quality leather products ranges from 10% to 20% (Blejan et al. 2024). The water content of vegetable leather is affected by the type of raw material, drying method, drying temperature, acidity, and total sugar content.

The moisture content of apple-blackcurrant fruit leathers escalates with elevated pectin levels, exhibiting more pronounced rises at higher concentrations of apple juice and blackcurrant concentrate, hence demonstrating interaction effects (Diamante et al. 2013). The water content of dragon fruit and watermelon fruit leather ranged between 7.95% and 13.99%. The increase in water content in fruit leather is caused by the increase in the amount of ingredients that contain hydrocolloids in the formulation (Ayustaningwarno et al. 2024). The minimal water level in fruit leather is essential to prevent bacterial proliferation and mitigate undesirable reactions, such as sugar crystallization, non-enzymatic browning, and lipid oxidation (da Silva Simão et al. 2020).

Ash Content

The ash content of broccoli stem vegetable leather ranges from 2.14 to 2.25% (Table 3), which has a significant increase between groups ($p<0.05$). F1 has the lowest ash content, while the highest ash content is in F4.

The less broccoli stem puree and the more pectin is added, the higher the ash content. The quantity of ash content recommended in processed foods has a maximum limit of no more than 5%. The measurement of ash content is directly correlated with the mineral content of food. A greater ash level in a food item signifies a higher mineral content of the substance. The ash content in fruit leather jicama and pineapple is lower than in this study, which is 0.31-0.49% (Riftyan et al. 2023). The ash content in food is influenced by its raw materials (Yaningsih and Rahmadhia 2023, Wati et al. 2024).

Reducing Sugar

The reducing sugar value of broccoli stem vegetable leather ranged from 8.52–9.90% (Table 3), which has a significant increase between groups ($p<0.05$). The lowest reducing sugar content was in F1, while the highest was in F4.

Table 2 Physical analysis of vegetable leather puree from broccoli heads with the addition of pectin

Formulations	Hardness (N)	Cohesiveness	Gumminess (N)	Chewiness (N)
F1	599.62±59.98^{a}	0.9074±0.04^{a}	560.84±54.41^{a}	511.34±54.09^{a}
F2	614.81±22.70^{a}	0.9358±0.02^{a}	583.12±42.68^{a}	527.47 ± 52.68^{a}
F3	743.72±25.68^{b}	0.9480±0.04^{a}	674.13±38.98^{b}	613.49 ± 24.77^{ab}
F4	752.82±33.86^{b}	0.9750±0.01^{a}	751.01±47.93^{b}	685.49 ± 73.93^{b}

Remarks: Different letter notations in test results (a, b) indicate different results based on the Duncan test with a significance level of 5%.

Table 3 Chemical analysis of vegetable leather puree from broccoli heads with the addition of pectin

Formulations	Water Content (%)	Ash Content (%)	Reducing sugar (%)	Vitamin C (mg/100 g)	Crude Fiber (%)
F1	11.92 ± 0.03^{a}	2.14 ± 0.02^{a}	8.52 ± 0.04^{a}	40.15 ± 0.09^{a}	9.48 ± 0.05^{a}
F2	11.92 ± 0.02^{a}	2.16 ± 0.02^{ab}	8.97 ± 0.01^{b}	41.52 ± 0.20^{b}	9.82 ± 0.02^{b}
F3	12.31 ± 0.03^{b}	2.20 ± 0.02^{b}	9.55 ± 0.04^{c}	42.99 ± 0.22^{c}	10.88 ± 0.02^{c}
F4	13.16 ± 0.03^{c}	2.25 ± 0.04^{c}	9.90 ± 0.02^{d}	44.58 ± 0.18^{d}	11.61 ± 0.03^{d}

Remarks: notes: Numbers followed by different letter notations on one line indicate a significant difference between treatments (F = p 0.05) based on Duncan's advanced test.

The reduction of broccoli stem puree and the addition of pectin correlate with an increase in lowering sugar values. The decreasing sugar content resulted from the addition of sucrose. Increased additions of sugar and citric acid result in elevated sugar content. This results from the inherent properties of pectin, which can create a gel in conjunction with sugar. The process of sucrose hydrolysis in sheet jam production might occur due to the presence of acid and heat during cooking (Diamante et al. 2013). The reduced sugar content of mango dregs fruit leather ranged from 33.82% to 44.70% (Nurhadi et al. 2023). The results are higher than those of reducing sugar in broccoli stems and vegetable leather. The reducing characteristics of a sugar molecule are dictated by the existence of free and reactive hydroxyl (OH), aldehyde (−CHO), or ketone (−CO) groups (Grembecka 2018).

Vitamin C

The vitamin C value of broccoli stem vegetable leather ranged from 40.15– 44.58 mg/100 g (Table 3), which has a significant increase between groups ($p<0.05$). The lowest vitamin C content was in F1, while the highest was in F4.

The reduction of broccoli stems puree results in an elevation of vitamin C levels. Pectin included in vegetable leather products does not directly enhance vitamin C levels; nevertheless, it aids in preserving vitamin C by binding water, hence lowering free oxygen in the product and mitigating vitamin C oxidation. Vitamin C in broccoli is relatively unstable and can decrease due to poor storage conditions (Rybarczyk-Plonska et al. 2014, Ayustaningwarno et al. 2024, Jebreen and Aznam 2024).

The vitamin C content of the three mixed fruit leather samples indicates that 60% banana, 20% pineapple, and 20% apple has the highest level at 22.33 g, followed by fruit leather with 20% banana, 40% pineapple, and 40% apple at 19.37 g (Offia-Olua and Ekwunife 2015). This value is higher than the vitamin C in broccoli stems vegetable leather because the fruit used is a fruit that is high in vitamin C, while broccoli has vitamin C around 106.4 mg/g.

Crude Fiber

The crude fiber value of broccoli stem vegetable leather ranged from 9.48 to 11.61% (Table 3), which has a significant increase between groups ($p<0.05$). The lowest crude fiber content was in F1, while the highest crude fiber content was in F4.

A decrease in broccoli stem puree and an increase in pectin result in elevated crude fiber levels. This indicates that an increase in pectin addition correlates with a rise in crude fiber content generated. Pectin is a fiber component belonging to the polysaccharide category; thus, an increase in pectin results in a higher fiber content (Ciriminna et al. 2022). The fiber content in fruit leather banana, pineapple, and apple ranges from 8.27-12.47% (Offia-Olua and Ekwunife 2015). These results are not much different compared to broccoli stems vegetable leather.

CONCLUSIONS

The incorporation of broccoli stem puree and pectin markedly influences the physical and chemical characteristics of vegetable leather. Broccoli stem vegetable leather possesses a chewy, rather than a firm, texture. Moreover, broccoli stem vegetable leather possesses a significant concentration of vitamin C and dietary fiber. Broccoli stem vegetable leather serves as a nutrient-dense food, mitigates agricultural waste, and enhances the economic worth of broccoli.

REFERENCES

Addai, Z. R., A. Abdullah, S. Abd. Mutalib, and K. H. Musa. 2016. Evaluation of fruit leather made from two cultivars of papaya. *Italian Journal of Food Science* 28(1):73–82.

AOAC, A. of O. A. C. 2005. *Officials Methods of Analysis*. 18 Edn. Association of Official Analytical Chemist Inc., USA.

Astuti, T., E. Widowati, and W. Atmaka. 2015. Kajian Karakteristik Sensoris, Fisik, Dan Kimia FruitT Leather Pisang Tanduk (Musa corniculata Lour.) Dengan Penambahan Berbagai Konsentrasi Gum Arab. *Jurnal Teknologi Hasil Pertanian* 8(1).

Ayustaningwarno, F., A. M. Ayu, D. N. Afifah, G. Anjani, N. Nuryanto, H. S. Wijayanti, D. Y. Fitranti, L. R. Tsaniya, S. Afiani, A. Razaq, and F. Zhu. 2024. Physicochemical and sensory quality of high antioxidant fruit leather of red dragon fruit and watermelon rind enriched with seaweed. *Discover Food* 4(1):92.

Blejan, A. M., V. Nour, and G. G. Codină. 2024. Physicochemical and Functional

Characterization of Pear Leathers Enriched with Wild Bilberry and Blackcurrant Pomace Powders. *Agronomy* 14(9):2048.

Ciriminna, R., A. Fidalgo, A. Scurria, L. M. Ilharco, and M. Pagliaro. 2022. Pectin: New science and forthcoming applications of the most valued hydrocolloid. *Food Hydrocolloids* 127:107483.

Coman, V., B.-E. Teleky, L. Mitrea, G. A. Martău, K. Szabo, L.-F. Călinoiu, and D. C. Vodnar. 2020. Bioactive potential of fruit and vegetable wastes. Pages 157–225.

Cvrk, R., H. Junuzović, A. Smajić-Bećić, A. Kusur, and T. Brčina. 2022. Determination of Crude Fiber Content and Total Sugars in Correlation with the Production Process and Storage Time. *International Journal for Research in Applied Sciences and Biotechnology* 9(3):1–6.

Dang, Y., T. Zhou, L. Hao, J. Cao, Y. Sun, and D. Pan. 2019. In Vitro and in Vivo Studies on the Angiotensin-Converting Enzyme Inhibitory Activity Peptides Isolated from Broccoli Protein Hydrolysate. *Journal of Agricultural and Food Chemistry* 67(24):6757–6764.

Das, A., B. N. Bora, H. Chutia, and C. Lata Mahanta. 2021. Processing of minerals and anthocyanins-rich mixed-fruit leather from banana (Musa acuminata) and sohiong (Prunus nepalensis). *Journal of Food Processing and Preservation* 45(9).

Diamante, L., S. Li, Q. Xu, and J. Busch. 2013. Effects of Apple Juice Concentrate, Blackcurrant Concentrate and Pectin Levels on Selected Qualities of Apple-Blackcurrant Fruit Leather. *Foods* 2(3):430–443.

Ferreira, S. S., C. P. Passos, S. M. Cardoso, D. F. Wessel, and M. A. Coimbra. 2018. Microwave assisted dehydration of broccoli by-products and simultaneous extraction of bioactive compounds. *Food Chemistry* 246:386–393.

Fitriana, Y. A. N., and A. S. Fitri. 2020. Analisis Kadar Vitamin C pada Buah Jeruk Menggunakan Metode Titrasi Iodometri. *Sainteks* 17(1):27.

Fitriani, A., M. N. Haliza, N. P. Utami, I. Nyambayo, S. Sanayei, and S. N. Rahmadhia. 2024. Texture Profile Analysis of Lamtoro Gung (Leucaena leucocephala ssp. Glabrata (Rose) S. Zarate) Tempeh. *Journal of Agri-Food Science and Technology* 5(1):65–72.

Gómez-Pérez, L. S., C. Navarrete, N. Moraga, A. Rodríguez, and A. Vega-Gálvez. 2020. Evaluation of different hydrocolloids and drying temperatures in the drying kinetics, modeling, color, and texture profile of murta (Ugni molinae Turcz) berry leather. *Journal of Food Process Engineering* 43(2).

Grembecka, M. 2018. Sugar Alcohols. Page *Reference Module in Chemistry, Molecular Sciences and Chemical Engineering*. Elsevier.

Gudiño, I., A. Martín, R. Casquete, M. H. Prieto, M. C. Ayuso, and M. G. Córdoba. 2022. Evaluation of broccoli (Brassica oleracea var. italica) crop by-products as sources of bioactive compounds. *Scientia Horticulturae* 304:111284.

Handayani, L., and F. Ayustaningwarno. 2014. Indeks Glikemik Dan Beban Glikemik Vegetable Leather Brokoli (Brassica oleracea var. Italica) Dengan Substitusi Inulin. *Journal of Nutrition College* 3(4):783–790.

Jebreen, A., and N. ʻIzzah B. K. Aznam. 2024. Enriched of Orange Jam (Marmalade) with vitamin C. *Journal of Agri-Food Science and Technology* 5(2):94–101.

Makiyah, S. N. N., I. Setyawati, S. N. Rahmadhia, S. Tasminatun, and M. Kita. 2024. Comparison of Yam Composite Cookies Sensory Characteristic Between Sugar and Stevia Sweeteners. *Journal of Agri-Food Science and Technology* 5(2):120–133.

Maryati, Y., A. Susilowati, and P. D. Lotulung. 2018. Perbandingan Karakteristik Kimiawi Ekstrak Brokoli Terfermentasi dengan Variasi Konsentrasi Kultur Kambucha Sebagai Minuman Fungsional. *Jurnal Sains dan Kesehatan* 1(10):570–579.

Nurhadi, B., I. P. Sari, Mahani, Y. Deliana, and H. Hariadi. 2023. Influence of Type and Concentration of Plasticizers on the Properties of Harumanis Mango Dregs Fruit Leather. *International Journal of Fruit Science* 23(1):116–134.

Offia-Olua, B. I., and O. A. Ekwunife. 2015. Production and evaluation of the physico-chemical and sensory qualities of mixed fruit leather and cakes produced from apple (Musa Pumila), banana (Musa Sapientum), pineapple (Ananas Comosus). *Nigerian Food Journal* 33(1):22–28.

Petkowicz, C. L. O., L. C. Vriesmann, and P. A. Williams. 2017. Pectins from food waste: Extraction, characterization and properties of watermelon rind pectin. *Food Hydrocolloids* 65:57–67.

Quizhpe, J., P. Ayuso, M. de los Á. Rosell, R. Peñalver, and G. Nieto. 2024. Brassica oleracea var italica and Their By-Products as Source of Bioactive Compounds and Food Applications in Bakery Products. *Foods* 13(21):3513.

Raj, G. B., and K. K. Dash. 2022. Development of Hydrocolloids Incorporated Dragon Fruit Leather by conductive hydro drying: Characterization and Sensory Evaluation. *Food Hydrocolloids for Health* 2:100086.

Raj, G. V. S. B., K. K. Dash, R. Shams, S. A. Mukarram, and B. Kovács. 2024. Development of kiwi fruit leather incorporated with hydrocolloids and betacyanin microcapsules: Rheological behaviour and release kinetics of betacyanin. *Applied Food Research* 4(2):100596.

Ramadhani, B., and I. A. Saidi. 2021. The Effect of The Proportion of Broccoli with Papaya, Pineaple, and Jackfruit on The Quality of Vegetable Leather. *Journal of Tropical Food and Agroindustrial Technology* 2(02):34–42.

Riftyan, E., M. C. Ivoni, Yusmarini, U. Pato, and V. S. Johan. 2023. The characterization and sensory assessment of fruit leather with a combination of puree jicama and pineapple. *IOP Conference Series: Earth and Environmental Science* 1182(1):012068.

Roy, S., R. Priyadarshi, Ł. Łopusiewicz, D. Biswas, V. Chandel, and J.-W. Rhim. 2023. Recent progress in pectin extraction, characterization, and pectin-based films for active food packaging applications: A review. *International Journal of Biological Macromolecules* 239:124248.

Rybarczyk-Plonska, A., M. K. Hansen, A.-B. Wold, S. F. Hagen, G. I. A. Borge, and G. B. Bengtsson. 2014. Vitamin C in broccoli (Brassica oleracea L. var. italica) flower buds as affected by postharvest light, UV-B irradiation and temperature. *Postharvest Biology and Technology* 98:82–89.

Sarma, O., M. Kundlia, H. Chutia, and C. L. Mahanta. 2023. Processing of encapsulated flaxseed oil-rich banana-based (Dwarf cavendish) functional fruit leather. *Journal of Food Process Engineering* 46(4).

Schreuders, F. K. G., M. Schlangen, I. Bodnár, P. Erni, R. M. Boom, and A. J. van der Goot. 2022. Structure formation and non-linear rheology of blends of plant proteins with pectin and cellulose. *Food Hydrocolloids* 124:107327.

Seisun, D., and N. Zalesny. 2021. Strides in food texture and hydrocolloids. *Food Hydrocolloids* 117:106575.

Shi, M., M. M. Hlaing, D. Ying, J. Ye, L. Sanguansri, and M. A. Augustin. 2019. New food ingredients from broccoli by-products: physical, chemical and technological properties. *International Journal of Food Science & Technology* 54(4):1423–1432.

da Silva Simão, R., J. O. de Moraes, B. A. M. Carciofi, and J. B. Laurindo. 2020. Recent Advances in the Production of Fruit Leathers. *Food Engineering Reviews* 12(1):68–82.

Srinivas, M. S., S. K. Jain, N. K. Jain, S. S. Lakhawat, A. Kumar, and H. K. Jain. 2020. A Review on the Preparation Method of Fruit Leathers. *International Journal of Current Microbiology and Applied Sciences* 9(5):773–778.

Tontul, I., and A. Topuz. 2018. Production of pomegranate fruit leather (pestil) using different hydrocolloid mixtures: An optimization study by mixture design. *Journal of Food Process Engineering* 41(3).

Vázquez-Sánchez, A. Y., R. Corfield, N. Sosa, D. Salvatori, and C. Schebor. 2021. Physicochemical, functional, and sensory characterization of apple leathers enriched with acáchul (Ardisia compressa Kunth) powder. *LWT* 146:111472.

Wan-Mohtar, W. A. A. Q. I., S. Abdul Halim-Lim, J. Pillai Balamurugan, M. Z. Mohd Saad, N. A. Z. Azizan, A. A. Jamaludin, and Z. Ilham. 2021. Effect of Sugar-Pectin-Citric Acid Pre-Commercialization Formulation on the Physicochemical, Sensory, and Shelf-Life Properties of Musa cavendish Banana Jam. *Sains Malaysiana* 50(5):1329–1342.

Wati, D. P., M. D. Fajrina, S. S. Putra, and T. Suryani. 2024. The Substitution of Purslane Weed (Portulaca oleracea L.) Flour and Glucomannan Powder on Organoleptic and Proximate Test of Instant Noodles. *Journal of Agri-Food Science and Technology* 5(1):44–56.

Yaningsih, A. R. T., and S. N. Rahmadhia. 2023. Karakteristik Fisik dan Kimia Flakes Tepung Kelopak Jantung Pisang Kepok Kuning (Musa paradisiaca Linn). *Agrointek* 17(2):219–226.

Yılmaz, F. M., S. Yüksekkaya, H. Vardin, and M. Karaaslan. 2017. The effects of drying conditions on moisture transfer and quality of pomegranate fruit leather (pestil). *Journal of the Saudi Society of Agricultural Sciences* 16(1):33–40.

Zeeb, B., M. Roth, and H.-U. Endreß. 2021. Commercial pectins. Pages 295–315 *Handbook of Hydrocolloids*. Elsevier.