Characterization of roll-pulps: a functional snack from co-products of apple juice production

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Supporting Information

1.Apple pulp leathers formulations methodology

Table A1 shows all samples and respective abbreviations used in the roll-pulps designations within this document.

Table A1. Abbreviations used for roll-pulps designations.

Abbreviation	**Description**
Po	Pulp
Pu	Puree
W	Water
D	Dehydrator (T = 70 ºC)
A	Air fryer (T = 80 ºC)
E	Drying cabinet (T = 80 ºC)
S	Sun
O	Household oven (T = 100 ºC)
Ag	Agave syrup
Al	Carob syrup
M	Maltodextrin

Many formulations for the roll-pulps were devised, with varying percentages of apple pulp, apple puree and water. Sweeteners (agave syrup and/or carob syrup or molasses) and/or maltodextrin were also added. The total mass of the roll-ups was weighted and thinly spread out on top of a rectangular piece of baking paper. These slabs were then dried using different methods: a dehydrator (DR-3525, Clatronic, Kempen, Germany) at 70 ºC, an air fryer at 80 ºC (FR-6980 Mini Crispy, Tristar, Dubai, UAE), a household oven at 100 ºC (BMO4134, Becken, Portugal), a laboratory drying cabinet (Heraeus, Hanau, Germany) at 80 ºC, and sun drying (Figure A1). When the slabs dried up enough to be detached from the baking paper without cracking or splitting, they were manually removed and rolled to form the product.

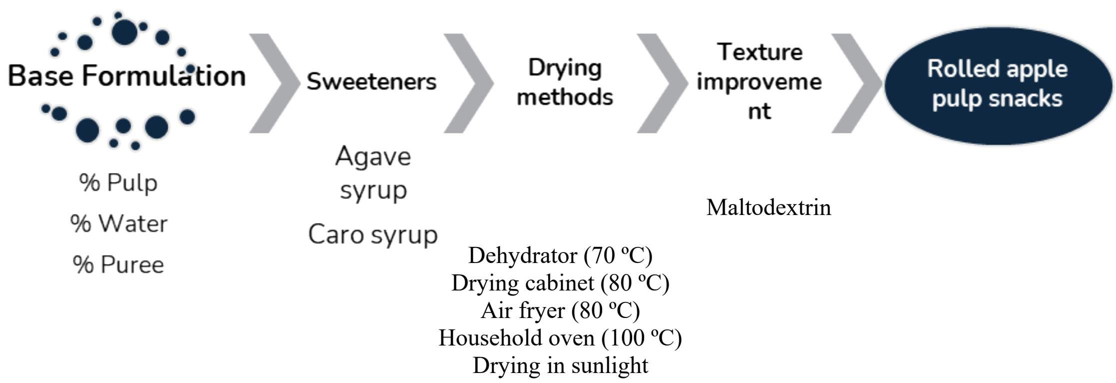

Figure A1. Initial possible approaches and formulations followed for roll-pulp development.

1.1. Apple roll-pulp formulation and batches

As an initial step to the development of the fruit roll-pulps, some research was conducted on common additives and drying techniques used for this kind of food product. Cast-tape drying, refractance window drying and convective drying were some techniques found to be efficient.[1]

However, the latter emerged as a favored method due to its cost-effectiveness, simplicity and availability. Moreover, additives like sweeteners and acids are frequently incorporated into the formulations according to published literature.[2,3]

One of the key objectives was maximizing apple pulp for its nutritional benefits and minimizing puree and water percentages in the formulations. A large percentage of water was avoided to not lengthen drying times and dilute nutritional properties. Puree addition was also unwanted, as the focus was to utilize co-products rather than the primary intermediaries themselves.

The development process was divided into three phases, or batches, which addressed key aspects such as formulation percentages, drying methods and durations, sweeteners, and texture-enhancing additives, to achieve the optimal formulation.

1.1.1. First batch: formulation percentage and drying methods

The first phase of development focused on finding the best content ratio of pulp, water and puree and drying method (dehydrator, air fryer, drying cabinet, sun and household oven). The formulations tested in this batch are present in Table A2.

Table A2. First batch roll-ups formulations and workflow approaches.

Designation	Pulp/Water/Puree (%)	Drying method	Drying time (h:min)
Po100D	100/0/0	Dehydrator	1:40
Po100A80	100/0/0	Air fryer	0:45
Po100E80	100/0/0	Drying cabinet	2:25
Po100O100	100/0/0	Household oven	0:50
Po100S	100/0/0	Sun	n/a*
Po95W5D	95/5/0	Dehydrator	2:00
Po95W5A80	95/5/0	Air fryer	0:42

Po95W5E80	95/5/0	Drying cabinet	2:10
Po95W5O100	95/5/0	Household oven	1:00
Po90W10D	90/10/0	Dehydrator	2:15
Po90W10E80	90/10/0	Drying cabinet	2:25
Po90W10O100	90/10/0	Household oven	1:15
Po50Pu50D	50/0/50	Dehydrator	1:40

n/a* not applicable

Convective drying is one of the most used techniques for fruit leather due to its simplicity and economic advantages when compared to other types of drying such as infra-red, vaccum and freeze-drying.[1]The literature is pointed mostly towards dehydrators at temperatures of around 30-80 degrees Celsius for a different number of hours depending on the formulation with optimum temperatures usually around 60°C.[3,4] An incorrect drying method can result in irreversible damage to the quality of the final product, and various studies have pointed to a consumer preference of roll-ups dried at lower temperatures with longer drying times rather than high temperatures in short times.[3,5] Drying at high temperatures adversely affects the flavor, color and texture of the product, leading to an increase in hardness, with negative effects on the nutritional and physicochemical properties of the roll-pulps, commonly due to ascorbic acid and polyphenol degradation and nonenzymatic browning.[1]

Among the tested methods, the dehydrator produced the most desirable results, yielding rolls with appropriate chewiness, minimal stickiness, and good rollability. The air fryer and household oven resulted in brittle, paper-like textures, while the drying cabinet produced darker products with prolonged drying times and poor texture. Sun drying was ineffective, showing early signs of oxidation without sufficient dehydration.

Regarding formulation, the addition of water did not significantly improve texture and resulted in nutritional dilution; therefore, it was excluded from subsequent batches.

1.1.2. Second batch: sweeteners

In the second batch, carob syrup and agave syrup (5% w/w) were evaluated as alternative sweeteners to reduce refined sugar use while maintaining added nutritional value. Both syrups contain bioactive compounds with reported antioxidant properties. Formulations were prepared using 100% pulp and dehydrator drying, based on batch 1 results. The addition of syrups did not significantly affect texture (chewiness, elasticity, stickiness), although a slightly shinier appearance was observed. Sensory assessment indicated a preference for the agave syrup formulation. Considering overall performance and pulp valorization, the 100% pulp with 5% agave syrup (Po100DAg) was selected for further development.

1.1.3. Third batch: texture optimization

Fruit pulps and roll-ups are rich in low molecular weight carbohydrates, which have low glass transition temperatures and high hygroscopicity, often resulting in stickiness at ambient conditions. To improve texture and stability, hydrocolloids are commonly incorporated to increase total solids and modify rheological properties. [1,6,7]

In this batch, maltodextrin (5% w/w, relative to pulp mass) was added to the base formulation, as reported in previous fruit leather studies.[6,7,8] Maltodextrin can increase glass transition temperature, reduce stickiness and hygroscopicity, and limit oxygen permeability.[9] Formulations containing maltodextrin required slightly longer drying times, likely due to increased total solids and water binding capacity. Six replicates per formulation were evaluated through texture profile analysis, mechanical testing, and water activity measurements.

2. Polyphenol quantification

Peak	Identification [M-H]$^-$	Time (min)	m/z

Table A3. MS polyphenol tentative identification with retention times and respective m/z. nd: non-determined.Green: catechin equivalents, pink: chlorogenic acid equivalents, orange: quercetin equivalents, blue: dihydrochalcone equivalents.

1	Quinic acid	8.28	190.99
2	Hydroxytyrosol hexose	11.21	315.16
3	*nd*	11.69	658.2
4	Procyanidin dimer	14.04	577.17
5	Chlorogenic acid	18.32	353.08
6	Procyanidin dimer	20.83	577.17
7	Chlorogenic acid derivative	23.13	353,08
8	(-)-epicatechin	23.8	289
9	*nd*	24.83	351.08
10	Procyanidin tetramer	26.21	1153.17
11	Procyanidin trimer	26.55	865.21
12	Double charged procyanidin pentamer	27.64	720.44
13	Rutin	31.17	609.18
14	Procyanidin dimer	33.00	577.17
15	Quercetin-3-O-galactoside	33.63	463.15
16	*nd*	34.47	723.51
17	Quercetin-3-*O*-pentoside	37.63	433.15
18	Quercetin-3-*O*-pentoside	41.44	433.14
19	Phloretin xylosyl-glucoside	42.67	567.22
20	Quercetin-3-*O*-rhamnoside	44.41	447.17
21	Phloretin	53.62	273.04

Table A4. Polyphenol concentration in Pulp (Po) and Roll-pulp (Po100D) in mg polyphenol equivalents (E PP) per g of Fresh Weight (FW) Nd*: not detected .Green: catechin equivalents, pink: chlorogenic acid equivalents, orange: quercetin equivalents, blue: dihydrochalcone equivalents.

Peak	Identification $[M\text{-}H]^-$	**Pulp (Po)** mg E PP / g FW	**Roll-pulp (Po100D)** mg E PP / g FW
1	Quinic acid	0.046±0.01	0.048±0.002
2	Hydroxytyrosol hexose	0.01±0.001	0.006±0.0004
3	*nd*	0.02±0.002	0,019±0,0004
4	Procyanidin dimer	0.02±0.004	0,018±0,00003
5	Chlorogenic acid	0.11±0.01	0,079±0,0004
6	Procyanidin dimer	0.14±0.02	0,09±0,0001
7	Chlorogenic acid derivative	0.01±0.003	0,005±0,0009
8	(-)-epicatechin	0.08±0.01	0,041±0,0004
9	*nd*	0.01±0.002	0,011±0,0001
10	Procyanidin tetramer	0.05±0.01	0,029±0,0002

11	Procyanidin trimer	0.05±0.01	0,018±0,0001
12	Double charged procyanidin pentamer	0.06±0.01	0,035±0,0003
13	Rutin	Nd*	0,005±0,001
14	Procyanidin dimer	0.02±0.003	0,007±0,00007
15	Quercetin-3-O-galactoside	0.02±0.002	0,009±0,00009
16	*nd*	0.004±0.001	0,003±0,00003
17	Quercetin-3-*O*-pentoside	0.004±0.001	0,002±0,00002
18	Quercetin-3-*O*-pentoside	0.01±0.001	0,002±0,00001
19	Phloretin xylosyl-glucoside	0.02±0.002	0.01±0.00004
20	Quercetin-3-*O*-rhamnoside	Nd*	0,001±0,00002
21	Phloretin	0.03±0.01	0.022±0.00004

3.Fracturability and Adhesiveness

Table A5. Fracturability and Adhesiveness for roll-pulps with pulp only (**Po100D**), pulp with agave (**Po100DAg**), pulp with maltodextrin (**Po100DM**) and pulp with agave and maltodextrin (**Po100DAgM**). No significant differences were detected between samples for either parameter

Batch	Adhesiveness (g.s)	Fracturability
Po100D	-1.79 ± 1.86	-1.69 ± 0.04
Po100DAg	-0.26 ± 0.46	-1.08 ± 1.37
Po100DM	-1.29 ± 1.61	-1.30 ± 1.07
Po100DAgM	-0.40 ± 0.48	-0.51 ± 0.05

References

1. da Silva Simão R, de Moraes JO, Carciofi BAM, Laurindo JB. Recent Advances in the Production of Fruit Leathers. Food Engineering Reviews. 2020, **12**, 68–82.
2. Bandaru H, Bakshi M. Fruit Leather: Preparation, packaging and its effect on sensorial and physico-chemical properties: A review. Journal of Pharmacognosy and Phytochemistry. 2020, **9**, 1699–709.
3. Quintero Ruiz NA, Demarchi SM, Massolo JF, Rodoni LM, Giner SA. Evaluation of quality during storage of apple leather. LWT. 2012, **47**,485–92.
4. Naz R. Physical properties, sensory attributes and consumer preference of fruit leather. Pakistan Journal of Food Sciences. 2012, **22**, 188-90.
5. Man YBCHE, Jaswir I, Yusof S, Selamat J, Sugisawa H. Effect of Different Dryers and Drying Conditions on Acceptability and Physico-Chemical Characteristics of Durian Leather. Journal of Food Processing and Preservation. 1997, **21**, 425–41.
6. Valenzuela C, Aguilera JM. Effects of maltodextrin on hygroscopicity and crispness of apple leathers. Journal of Food Engineering. 2015, **144**, 1–9.
7. Gujral HS, Oberoi DPS, Singh R, Gera M. Moisture Diffusivity During Drying of Pineapple and Mango Leather as Affected by Sucrose, Pectin, and Maltodextrin. International Journal of Food Properties. 2013, **16**, 359–68.
8. Pegu K, Arya SS. Comparative assessment of maltodextrin and sugar addition on physical and nutritional attributes of Syzygium cumini L. Leather: an optimization study using mixture design. Journal of Food Measurement and Characterization. 2021,**15**, 3994–4005.
9. Tontul I, Topuz A. Production of pomegranate fruit leather (pestil) using different hydrocolloid mixtures: An optimization study by mixture design. Journal of Food Process Engineering. 2017, **41**, e12657.