Preliminary screening of dry- and wet-recovered starchy fractions from *Persea americana* and *Mangifera indica* seeds for bioplastic formulation

Evaluación preliminar de fracciones amiláceas secas y húmedas de semillas de *Persea americana* y *Mangifera indica* para bioplásticos

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ABSTRACT

In this study, we compared dry-recovered starch-rich flour and wet-recovered sedimented starchy fractions from *Persea americana* Mill. and *Mangifera indica* L. seeds as a preliminary screening step for bioplastic formulation. The 2 × 2 factorial design included three separately weighed process replicates per treatment; the records did not identify independent biological lots. Recovered fraction yield was calculated relative to the initial as-weighed seed mass, without moisture correction. Wet-recovered mango exhibited the highest yield (27.99 ± 0.01%), followed by dry-recovered mango (19.51 ± 0.01%), dry-recovered avocado (18.51 ± 0.01%) and wet-recovered avocado (11.99 ± 0.01%). Wet-recovered avocado recorded the highest moisture and ash content (21.13 ± 0.76% and 3.25 ± 0.05%). Factorial ANOVA identified seed, method and interaction effects for all responses. The exceptionally high yield fit (R^2 = 99.9998%; F = 1,294,604) arose from a residual mean square of 0.0001 and within-treatment SD of 0.01. The Brown-Forsythe test supported variance homogeneity, while the Shapiro-Wilk test indicated non-normal residuals for yield and moisture. Exact permutation tests confirmed overall treatment differences ($p \leq 0.000584$). Wet-recovered mango is a candidate for further characterization, but does not constitute evidence of film-forming or packaging performance.

Keywords: *avocado seed starchy fraction, mango seed starchy fraction, wet recovery, dry milling, preliminary screening, agro-industrial residue*

RESUMEN

Este estudio comparó una harina rica en almidón recuperada por vía seca y una fracción amilácea sedimentada recuperada por vía húmeda de semillas de *Persea americana* Mill. y *Mangifera indica* L. como evaluación preliminar para formular bioplásticos. El diseño factorial 2 × 2 incluyó tres réplicas de proceso pesadas por separado en cada tratamiento; los registros no identificaron lotes biológicos independientes. El rendimiento de la fracción recuperada se calculó respecto de la masa inicial de semilla pesada, sin corrección por humedad. El mango húmedo presentó el mayor rendimiento (27.99 ± 0.01 %), seguido por mango seco (19.51 ± 0.01 %), palta seca (18.51 ± 0.01 %) y palta húmeda (11.99 ± 0.01 %). La palta húmeda registró la mayor humedad y ceniza (21.13 ± 0.76 % y 3.25 ± 0.05 %). El ANOVA factorial identificó efectos de semilla, método e interacción en las tres respuestas. El ajuste extremo del rendimiento (R^2 = 99.9998 %; F = 1,294,604) se originó en un cuadrado medio residual de 0.0001 y una desviación estándar intratratamiento de 0.01. Brown-Forsythe respaldó la homogeneidad de varianzas, mientras Shapiro-Wilk indicó residuos no normales para rendimiento y humedad. Las pruebas exactas por permutación confirmaron diferencias globales entre tratamientos ($p \leq 0.000584$). El mango húmedo constituye un candidato para caracterización posterior, no evidencia de desempeño filmogénico o de empaque.

Palabras clave: *fracción amilácea de semilla de palta, fracción amilácea de semilla de mango, recuperación húmeda, molienda seca, evaluación preliminar, residuo agroindustrial*

1. Introduction

Plastic waste generation has outpaced recycling, increasing demand for renewable feedstocks that reduce dependence on fossil polymers. Global plastics use reached 460 Mt in 2019, while only 9% of plastic waste was recycled. Packaging remains a major use category (OECD, 2022; Pottinger *et al*., 2024). Mango and avocado processing produces seed residues at scales that justify recovery studies, as international trade in both fruits continues to grow (FAO, 2024). Converting these residues into characterized carbohydrate-rich fractions is relevant to circular material research, but the recovered product and its limits must be defined precisely (Manuel Hoyos Alayo, 2025; Hoyos-Alayo *et al*., 2026; Hoyos-Alayo, 2025a, 2025b; Hoyos-Alayo, 2026a, 2026b).

Avocado and mango seeds contain starch-bearing matrices, although reported recovery rates vary across different cultivar, pretreatment and extraction conditions. Wet-isolated avocado seed starch has been shown to yield around 19.5%, whereas mango kernel studies have reported recovery of between 42.1% and 62.1% under conventional or assisted extraction conditions (Martins *et al*., 2022; Akhter *et al*., 2024; Mieles-Gómez *et al*., 2025). Particle size, extraction time, temperature and solid-to-liquid ratio influence both recovery and purity (Choudhary *et al*., 2023). Direct comparison under one factorial design can therefore separate the effects of botanical source, recovery route and their interaction.

The two routes evaluated in this study do not produce equivalent materials. Wet processing separates a sedimented starch-enriched fraction after homogenization, filtration and settling. Dry processing produces a milled and sieved starch-rich flour that can retain fiber, protein, lipids, minerals and phenolic compounds. Studies comparing avocado flour with isolated starch and mango kernel flour with purified starch have shown that the degree of separation affects composition, structure and subsequent material behavior (De Dios-Avila *et al*., 2022; Gómez-Caturla *et al*., 2022). Accordingly, the term starch is reserved for literature where isolation or purity has been demonstrated, while the products addressed in this study are known as recovered starchy fractions.

Starch-based films require functional validation beyond recovery yield. Mechanical strength, elongation, thermal transitions, water-vapor permeability, solubility, opacity and disintegration are dependent upon on starch structure, plasticizer content and processing (Liu *et al*., 2020; Ballesteros-Mártinez *et al*., 2020; Muñoz-Gimena *et al*., 2024). Because this experiment did not produce films or measure their properties, it serves as a raw-material screening rather than as evidence of packaging performance.

Previous studies have tended to examine one seed source, one extraction route or a subsequent film formulation. Studies involving the controlled comparison of avocado and mango seed fractions under dry and wet routes remain limited. The working hypothesis for this study was that rates of recovered fraction yield, moisture and ash would be dependent upon the seed x method interaction, rather than on either factor alone.

Therefore, for this study we compared dry-recovered starch-rich flour and wet-recovered sedimented starchy fractions from *Persea americana* Mill. and *Mangifera indica* L. seeds within the framework of a 2 × 2 factorial design. The aim was to identify the treatment with the most favorable combination of recovery yield, moisture and ash, for further characterization and formulation trials. Our analysis did not assess starch purity, film-forming capacity or final bioplastic performance.

2. Materials and methods

2.1. Experimental design and analytical strategy

For our study, we employed a 2 × 2 factorial design with three process replicates per treatment combination. The archival worksheets record a separately weighed initial mass and a separate response for each run. They do not identify independent biological lots; the three observations are therefore classified as process or technical replicates from the sampled material, not as biological replicates. Inference is restricted to the evaluated material and runs. The fixed factors were seed type, *Persea americana* Mill. or *Mangifera indica* L., and recovery method, wet or dry. The model estimated both main effects and the seed x method interaction for recovered fraction yield, moisture and ash.

Proximate characterization was applied before recovery. One laboratory report was available for each composite flour sample. These values were descriptive and were not entered into the factorial ANOVA. The recovered products were evaluated by recovery yield, moisture and ash. These variables supported a preliminary process-screening decision and did not measure starch purity or film functionality. The factorial matrix is summarized in Table 1.

Table 1. Factorial matrix for recovery of starchy fractions from avocado and mango seeds

Treatment	Seed	Extraction method	Process replicates (n)	Response variables
T1	*Persea americana* Mill.	Wet	3	Recovered fraction yield, moisture, ash
T2	*Persea americana* Mill.	Dry	3	Recovered fraction yield, moisture, ash
T3	*Mangifera indica* L.	Wet	3	Recovered fraction yield, moisture, ash
T4	*Mangifera indica* L.	Dry	3	Recovered fraction yield, moisture, ash

Note. Each replicate was a separately weighed and processed run. The source records did not identify distinct biological lots.

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2.2. Raw material and pretreatment

Persea americana Mill. and *Mangifera indica* L. seeds were obtained in Motupe, Lambayeque, Peru, from mature fruits and agro-industrial residues. The archived collection records identify mature material but do not record cultivar, exact collection date, supplier-lot structure or the interval from collection to processing. Because no lot identifiers were available, each species was treated as one composite source batch. Commercial processing maturity and visual integrity guided selection; no cultivar-specific maturity index was recorded. Whole seeds without visible fungi, pests, decomposition, foreign material or excess adhered pulp were included.

For the study, 10 kg of avocado seeds and 10 kg of mango seeds were used. The seeds were washed first with potable water and then again with distilled water. Detachable external tegument was removed from both seed types before manual cutting into 1-2 cm fragments. The material assigned to dry milling was dried after cutting at 65°C for 24 hours, milled and sieved to ≤600 µm. The resulting flour moisture was 4.27 g 100 g^{-1} for mango and 6.42 g 100 g^{-1} for avocado. The flours were stored in labelled airtight containers under dry ambient laboratory conditions until analysis; storage duration was not recorded in the archived record.

2.3. Proximate characterization of seed flours

Proximate characterization was conducted once on each composite seed flour. The laboratory report included total energy, carbohydrates, total fat, moisture, protein and ash, using the FAO Food and Nutrition Paper Vol. 14/7 method. Moisture was determined by oven mass loss to constant weight, ash by incineration at 550°C, total fat by gravimetric extraction, protein by nitrogen determination and conversion, carbohydrates by difference and energy by Atwater factors. Because replicate-level analytical readings were not available, Table 2 reports descriptive values without standard deviations.

The proximate profile was used to describe the carbohydrate-rich source matrices and their moisture and mineral residue. Total carbohydrates were not interpreted as isolated starch content, because the analysis did not quantify starch, amylose or non-starch polysaccharides.

2.4. Recovery of starchy fractions by wet and dry methods

For wet recovery, each separately weighed seed portion was homogenized with distilled water until a freely flowing suspension formed. The archived record retains 2 minutes of blending but not total water volume, a fixed solid-to-liquid ratio, blender manufacturer, model or speed. The suspension was filtered through sterile gauze or fine mesh; filter aperture and layer count were not retained. The filtrate was left to settle for 2 hours under ambient laboratory conditions, after which the supernatant was decanted. The sediment was washed until visible soluble residue decreased, although wash-cycle count, wash volume and ambient temperature were not logged. No centrifugation was used. The sediment was dried at 65°C for 24 hours, pulverized and sieved to ≤600 µm. This product is known as the wet-recovered sedimented starchy fraction, rather than as purified starch.

For dry recovery, each separately weighed chopped seed portion was dried at 65°C for 24 hours, milled, pulverized and sieved to ≤600 µm. Because the fine product did not undergo fiber, protein, lipid or mineral separation, it cannot be described as purified or isolated starch, and should be known as the dry-recovered starch-rich flour fraction. The two routes were compared as process-recovery alternatives using a common as-weighed seed denominator.

2.5. Determination of recovered fraction yield, moisture and ash

The recovered fraction yield was calculated as the dry recovered mass divided by the initial as-weighed seed mass assigned to the run. The denominator was the seed mass before route-specific processing, on an as-is or wet-basis basis, and was not corrected for initial moisture. The same basis was applied to both routes. The result is therefore a process mass-recovery index, rather than a dry-basis starch-isolation yield.

$$Y_{RF}\,(\%)=(m_{RF,dry}\,/m_{initial,as\text{-}is})\times 100 \qquad (1)$$

where Y_{RF} is the recovered fraction yield, $m_{RF,dry}$ is the dry mass of the recovered product and $m_{initial,as\text{-}is}$ is the initial seed mass weighed before route-specific processing.

Moisture was calculated by Equation (2).

$$H(\%)=[(m_{initial}\text{-}m_{dry})/m_{initial}]\times 100 \qquad (2)$$

where H is moisture, $m_{initial}$ is the mass before drying and m_{dry} is the mass after drying to constant weight.

Ash content was calculated by Equation (3).

$$C_{ash}\,(\%)=(m_{ash}/m_{dry})\times 100 \qquad (3)$$

where C_{ash} is ash content, m_{ash} is the incinerated residue and m_{dry} is the dry sample mass before incineration.

2.6. Technical selection criterion for subsequent casting formulation

Three observed criteria were employed for the preliminary selection: higher recovered mass yield, controlled moisture and lower ash. This ranking was intended to identify a candidate for further compositional and film-forming tests, not to establish starch purity, mechanical performance, barrier behavior, biodegradability or environmental superiority.

2.7. Statistical treatment of data

Data were organized by treatment, process replicate and response. Descriptive statistics included mean, standard deviation, coefficient of variation and 95% confidence interval. A two-factor fixed-effects model with interaction was fitted to each response. Residual normality was assessed through the Shapiro-Wilk test, and variance homogeneity by the Brown-Forsythe version of Levene's test, centered on group medians. Normal Q-Q and residual-versus-fitted plots were inspected. Because each cell contained n = 3 and normality departures occurred, an exact four-treatment label-permutation test across all 369,600 allocations was added as an omnibus sensitivity analysis.

$$Y_{ijk}=\mu+S_i+M_j+(S\times M)_{ij}+\varepsilon_{ijk} \quad (4)$$

where Y_{ijk} is the response, μ is the grand mean, Si is the seed effect, M_j is the method effect, $(S \times M)_{ij}$ is the interaction and ε_{ijk} is the residual for process replicate k.

Factorial effects were evaluated at α = 0.05 (Hoyos-Alayo and Leiva-Piedra, 2026). Tukey's HSD test was used for treatment-level pairwise grouping after model fitting; its interpretation is conditional on the small within-cell sample and residual diagnostics. The original analyses were performed in Minitab 22.3.1, and the revised ANOVA, diagnostics and permutation tests were independently reproduced in Python 3.11 with SciPy 1.17. Raw values, residual tables and diagnostic plots are provided in Supplementary material S1.

2.8. Quality control and waste management

Each of the processes run used labelled material, a verified balance, and temperature control in the oven and muffle furnace. Samples were kept in closed containers before analysis, and crucibles were dried and cooled in a desiccator before weighing. Initial masses were archived to 0.01 g. The source worksheets contained a recovered-mass column with arithmetic precision beyond the reporting resolution; inferential analyses used the recorded percentage responses. Organic residues and laboratory waste were segregated according to composition.

3. Results

3.1. Proximate characterization of seed flours

The composite *Mangifera indica* L. and *Persea americana* Mill. seed flours exhibited carbohydrate-rich profiles. Avocado flour recorded 85.86 g 100 g^{-1} carbohydrates compared with 80.82 g 100 g^{-1} in mango. Mango flour had higher energy, fat and protein values, while avocado flour had higher moisture and ash values. These values came from one laboratory report per composite flour sample and are descriptive rather than replicated estimates. The proximate comparison is shown in Table 2 and Figure 1.

Table 2. Proximate composition of seed flours used for extraction of starchy fractions

Parameter	Unit	Mango flour	Avocado flour
Total energy	kcal 100 g^{-1}	401.09	374.17
Carbohydrates	g 100 g^{-1}	80.82	85.86
Total fat	g 100 g^{-1}	5.42	1.99
Moisture	g 100 g^{-1}	4.27	6.42
Protein	g 100 g^{-1}	7.26	3.20
Ash	g 100 g^{-1}	2.23	2.53

Note. Mango corresponds to laboratory sample S-3243 and avocado to S-3244. The values are single composite-sample determinations from the laboratory reports; replicate-level analytical readings and standard deviations were not available.

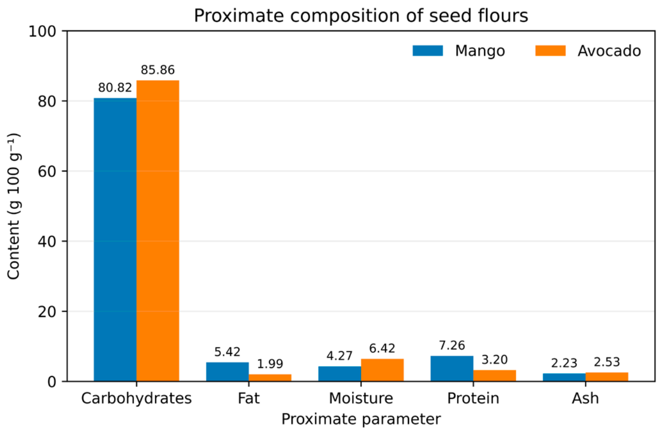

Figure 1. Comparison of carbohydrates, fat, moisture, protein and ash in seed flours.

3.2. Recovered fraction yield, moisture and ash

Levels of recovered fraction yield were dependent on the seed x method combination. Wet-recovered mango reached 27.99 ± 0.01%, followed by dry-recovered mango at 19.51 ± 0.01%, dry-recovered avocado at 18.51 ± 0.01% and wet-recovered avocado at 11.99 ± 0.01%. The crossed response anticipated the factorial interaction. All the treatment summaries are shown in Table 3, while Figures 2-4 show yield, moisture and ash.

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Table 3. Descriptive responses of the recovered starchy fractions by treatment.

Treatment	Seed	Method	n	Recovered fraction yield (%)	Moisture (%)	Ash (%)
Mango dry	Mango	Dry	3	19.51 ± 0.01	6.88 ± 0.78	2.56 ± 0.06
Mango wet	Mango	Wet	3	27.99 ± 0.01	12.07 ± 0.73	2.57 ± 0.03
Avocado dry	Avocado	Dry	3	18.51 ± 0.01	7.15 ± 0.75	2.95 ± 0.05
Avocado wet	Avocado	Wet	3	11.99 ± 0.01	21.13 ± 0.76	3.25 ± 0.05

Note. Values are mean ± standard deviation from three process replicates. They do not represent independent biological lots.

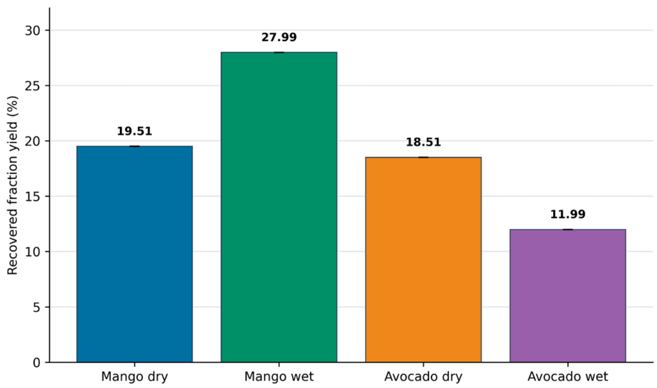

Figure 2. Recovered fraction yield by treatment

Note. Bars showing the mean and error lines represent the standard deviation, n = 3.

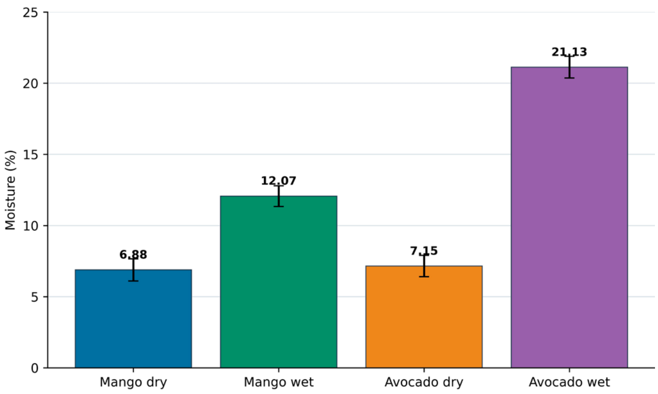

Figure 3. Moisture of recovered starchy fractions by treatment

Note. Bars showing the mean and error lines represent the standard deviation, n = 3.

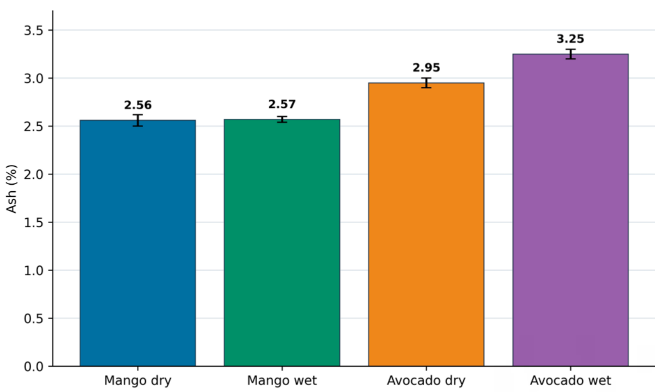

Figure 4. Ash content of recovered starchy fractions by treatment

Note. Bars showing the mean and error lines represent the standard deviation, n = 3.

3.3. Factorial effects on extraction responses

The factorial models effectively separated the four treatment means; however, model fit must be interpreted in light of the replication structure. The recovered fraction yield achieved an R^2 of 99.9998%, an adjusted R^2 of 99.9997%, and a predicted R^2 of 99.9995%. Its residual mean square was 0.0001, reflecting a consistent standard deviation (SD) of 0.01 percentage points across all treatments. Meanwhile, moisture and ash reached predicted R^2 values of 97.47% and 95.74%, respectively. Conventional factorial ANOVA revealed that the seed, method and their interaction terms were statistically significant for all responses (Tables 4 and 5).

Residual diagnostics did not support normality for recovered fraction yield (Shapiro-Wilk W = 0.811, p = 0.012) or moisture (W = 0.837, p = 0.026), while ash residuals showed no detected departure (W = 0.922, p = 0.299). Brown-Forsythe tests supported homogeneous variances for yield (p = 1.000), moisture (p = 0.9997) and ash (p = 0.853). Exact permutation tests confirmed overall differences among the four treatments for yield (p = 0.000065), moisture (p = 0.000455) and ash (p = 0.000584). These results support within-dataset separation but not population-level inference.

Table 4. Global fit of factorial models for the evaluated responses

Variable	S	R^2 (%)	Adj. R^2 (%)	Pred. R^2 (%)	Model F	Model p
Recovered fraction yield (%)	0.01000	99.9998	99.9997	99.9995	1294604.00	<0.001
Moisture (%)	0.75325	98.87	98.45	97.47	234.15	<0.001
Ash (%)	0.04882	98.11	97.40	95.74	138.27	<0.001

Table 5. Factorial effects of seed, method and seed x method interaction

Variable	Seed F	Seed p	Method F	Method p	Seed × method F	Interaction p
Recovered fraction yield (%)	2167500.00	<0.001	28812.00	<0.001	1687500.00	<0.001
Moisture (%)	114.90	<0.001	485.42	<0.001	102.13	<0.001
Ash (%)	358.04	<0.001	30.90	0.001	25.86	0.001

3.4. Multiple comparison of treatments

Tukey's HSD test separated all four treatments for recovered fraction yield. Dry mango and dry avocado shared a moisture group, while the two mango products shared an ash group. These pairwise groupings are reported as treatment-level screening results and should be read with the small n and residual-normality caveat. Table 6 shows the grouping letters. Figure 5 ranks the factorial effects.

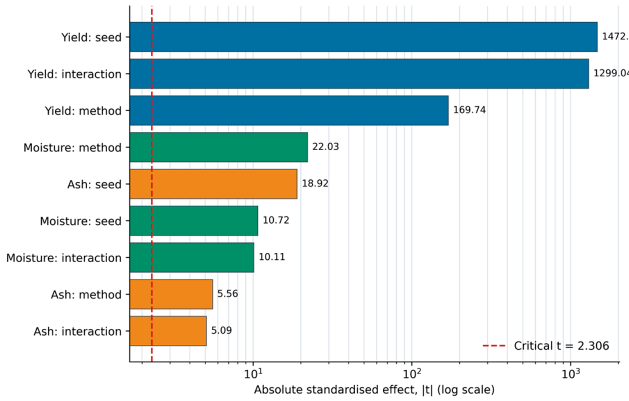

Figure 5. Hierarchy of absolute standardized factorial effects.

Note. Each bar is the absolute t statistic for an effect coefficient, calculated as the coefficient divided by its standard error. The red dashed line is the two-sided critical value $t_{0.975,8} = 2.306$. A logarithmic x-axis accommodates effects ranging from 5.09 to 1472.24; bars to the right of the line exceed the conventional $\alpha = 0.05$ threshold.

3.5. Preliminary technical selection of raw material and method

Wet-recovered mango exhibited the highest mass recovery and ash similar to dry-recovered mango, making it the primary candidate for compositional and film-forming tests within this dataset. Dry-recovered mango remains a key comparator when lower residual moisture and avoidance of wet processing are priorities. Note that this ranking does not establish starch purity or bioplastic performance.

3.6. Scope of the generated evidence

The evidence provides a preliminary comparison of recovery routes and products, not a characterization of films. It does not support claims regarding tensile strength, elongation, barrier behavior, thickness, thermal stability, biodegradation or packaging suitability. Furthermore, it does not establish that the wet route results in a lower environmental impact.

4. Discussion

The experiment compared two operationally distinct products: a wet-recovered sedimented starchy fraction and a dry-recovered starch-rich flour. Their yields quantified mass recovery on the same as-weighed seed basis, not isolated starch purity. Avocado flour contained more total carbohydrates than mango flour, 85.86 versus

Table 6. Treatment grouping by Tukey's HSD test at 95% for each response variable

Treatment	Recovered fraction yield (%)	Group	Moisture (%)	Group	Ash (%)	Group
Mango dry	19.51	B	6.88	C	2.56	C
Mango wet	27.99	A	12.07	B	2.57	C
Avocado dry	18.51	C	7.15	C	2.95	B
Avocado wet	11.99	D	21.13	A	3.25	A

Note. Different letters within a response denote Tukey-adjusted differences at $\alpha = 0.05$. Interpretation is conditional on n = 3 process replicates and the residual diagnostics reported above.

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80.82 g 100 g^{-1}, and yet wet mango produced the largest recovered fraction. This divergence indicates that recovery is dependent on matrix disruption, sedimentation and retention of non-starch solids, meaning that proximate carbohydrate content cannot be interpreted as recoverable starch.

The product distinction also affects later use. Dry milling retains more fiber, protein, lipids, minerals and phenolics, while wet settling removes part of those components. Avocado flour and isolated starch differ in structural, thermal and rheological properties, and mango kernel flour particle size changes film behavior (De Dios-Avila *et al*., 2022; Gómez-Caturla *et al*., 2022). Because starch content, amylose and purity were not measured as part of this study, lower ash cannot be treated as proof of starch purity; it serves only as a relative mineral-residue indicator.

Wet-recovered mango reached 27.99 ± 0.01%, 8.48 percentage points above dry-recovered mango. The value remained below reported mango starch recoveries of 42.05-62.11% obtained with controlled conventional, ultrasound or microwave procedures (Akhter *et al*., 2024; Mieles-Gómez *et al*., 2023, 2025). Choudhary *et al*. (2023) identified particle size, time, temperature and solid-to-liquid ratio as significant recovery drivers. Differences in those parameters, cultivar, separation efficiency and losses during filtration and washing provide direct explanations for the lower value in the present low-instrumentation route.

Wet-recovered avocado reached 11.99 ± 0.01%, while dry-recovered avocado reached 18.51 ± 0.01%. The latter is close to the 19.5% yield reported for isolated avocado seed starch (Martins *et al*., 2022), although the products are not compositionally equivalent. Wet recovery from avocado has supported later biofilm preparation, and combined extraction studies show that cultivar and processing influence granular and pasting behavior (Jiménez *et al*., 2022; Esquivel-Fajardo *et al*., 2022). Our results indicate poor mass retention under the recorded wet route, rather than low intrinsic suitability of avocado starch.

Moisture differentiated the dry and wet products. Dry mango and dry avocado contained 6.88 ± 0.78% and 7.15 ± 0.75%, while wet mango and wet avocado contained 12.07 ± 0.73% and 21.13 ± 0.76%. Moisture control matters in later gelatinization and plasticization because water and plasticizer levels modify mechanical, optical and barrier responses (Ballesteros-Mártinez *et al*., 2020). Wet products therefore require controlled drying before any film-forming comparison.

Ash differentiated the botanical sources more strongly than the routes within mango. Mango values were 2.56 ± 0.06% and 2.57 ± 0.03%, whereas avocado increased from 2.95 ± 0.05% in the dry fraction to 3.25 ± 0.05% in the wet fraction. Mineral residue can affect color, pasting and matrix continuity; however, the current ash measurement cannot identify mineral species or establish purity. Functional and interfacial behavior must be measured directly before linking ash to packaging performance (Godoy Zúniga *et al*., 2024; Grisales-Mejía *et al*., 2024).

The high F and R^2 values for recovered fraction yield arose from the combination of large treatment-mean differences and a residual mean square of 0.0001. Each cell contained the same within-treatment SD of 0.01 percentage points. Residual normality was not supported for yield or moisture, although Brown-Forsythe tests supported variance homogeneity. Exact permutation tests confirmed overall treatment differences for all responses. These diagnostics strengthen transparency, but $n = 3$ and process-level replication call for cautious interpretation and rule out inference across cultivars or biological lots.

Wet-recovered mango is therefore the primary candidate within this screening dataset, because it maximized recovery and retained ash similarly to dry mango. It should be noted that this ranking does not demonstrate superior film formation. Mango starch and flour films can show useful mechanical and disintegration responses under defined formulations (Admase *et al*., 2022; Gómez-Caturla *et al*., 2022), but the selected fraction still requires compositional, thermal, rheological and film tests. Dry-recovered mango remains a relevant comparator because it exhibited lower residual moisture and avoided wet separation.

Environmental superiority also remains untested. Bio-based origin does not establish lower impact where water demand, drying energy, additives, food-contact safety and end-of-life conditions have not been quantified (Shaikh *et al*., 2021; Wang *et al*., 2022). Future comparisons should record water and energy inputs and assess film disintegration or biodegradation under standardized conditions.

This study had four main limitations. Firstly, cultivar, exact collection date, supplier-lot structure and time to processing were not retained in the archived records. Secondly, the observations were process replicates within the sampled material, rather than independent biological lots. Thirdly, the wet-route record lacked total water volume, fixed solid-to-liquid ratio, blender specification, filter aperture, wash-cycle count and ambient temperature. Fourthly, the dataset lacked starch purity, amylose, morphology, FTIR, thermal transitions, pasting, rheology and film properties. These limitations confine the contribution of the study to preliminary within-dataset recovery screening.

5. Conclusions

Recovered product yield was dependent on the seed x method interaction. Under the tested conditions, wet-recovered mango exhibited the highest mass recovery (27.99 ± 0.01%), while wet-recovered avocado had the lowest (11.99 ± 0.01%). These values compare two operational products and do not quantify isolated starch purity.

Wet processing increased mango recovery by 43.46% relative to dry milling but reduced avocado recovery by 35.22%. Therefore, this route cannot be selected independently of the seed matrix.

Dry-recovered mango and avocado had the lower moisture, while wet-recovered avocado exhibited the highest moisture and ash. These measurements provide storage and mineral-residue screening criteria, rather than evidence of gelatinization, purity or film quality.

Wet-recovered mango is the primary candidate for the next characterization stage, because it maximized recovery within this dataset and had ash comparable to dry-recovered mango. It should be categorized as a candidate for subsequent bioplastic formulation, rather than as a validated packaging material.

Subsequent work will be required in order to quantify starch content, amylose, morphology, FTIR, thermal and rheological behavior, film thickness, tensile response, water-vapor permeability, solubility, opacity and standardized disintegration or biodegradation. Water demand and drying energy will also need to be measured, before assigning environmental superiority to either route.

Authors' contributions

María Anita Chapoñan Cajusol: conceptualization, methodology, investigation, data curation, formal analysis and writing (original draft).

Segundo Gabino Díaz Santisteban: methodology, investigation, data curation, validation and writing (original draft).

Walter Manuel Hoyos-Alayo: conceptualization, supervision, formal analysis, validation and writing (revision and editing).

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Conflicts of interest

The authors declare no conflicts of interest.

Artificial Intelligence use statement

During the revision process, the authors used ChatGPT (OpenAI) to support language editing, statistical cross-checking and document organization. The authors reviewed and edited all the content and assume full responsibility for the scientific accuracy and integrity of the manuscript.

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