

1 **Impact of tamarind pulp powder enrichment on the functional properties and**
2 **physical/chemical composition of corn and soybean composite flours: towards agri-food**
3 **valorization.**
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7 Abstract

8 This study aimed to evaluate the impact of incorporating tamarind pulp powder (5%,
9 10%, 15%, 20%) on the physicochemical and functional properties of composite flours made
10 from sprouted corn and soybeans.

11 The analysis reveals that tamarind enrichment induces significant acidification,
12 lowering the pH from 4.36 to 3.28, while simultaneously increasing the fiber (14.50%) and
13 protein (16.73%) content. Functionally, the water absorption capacity (WAC) and emulsifying
14 activity (EA) are optimized, reaching 154.66% and 52.66%, respectively, for the 20%
15 tamarind formulation. Principal Component Analysis (PCA), validated by a permutation test
16 (1000 resamples), explains 86.22% of the total variance, confirming the robustness of the
17 model.

18 The 15% formulation (FC3) stands out as a major technological breakthrough, offering
19 an optimal balance between nutritional density and technological capabilities. These results
20 open up promising prospects for the formulation of stable and nutritious functional foods.

21
22 **Keywords:** Tamarindus indica, composite flour, functional properties, PCA, agri-food
23 valorization.
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28 **Introduction**

29 Diet plays a key role in the prevention of chronic diseases, particularly obesity and diabetes.
30 In this context, functional foods made from natural ingredients are attracting increasing
31 interest in nutrition and public health because they provide not only essential nutrients, but
32 also bioactive compounds that have shown beneficial effects on the prevention of chronic
33 diseases and the improvement of the nutritional quality of diets (**Arshad et al., 2025**).

34 Corn, soybeans, and tamarind possess interesting nutritional properties. As such, they
35 represent particularly valuable local resources. Corn, recognized as the most energy-rich

36 cereal (**Charcosset and Gallais, 2009**), is distinguished by its nutritional advantages (high
37 starch content, presence of protein and minerals) and its ease of cultivation, harvesting, and
38 storage (Nuss and Tanumihardjo, 2011). Soybeans, for their part, are a source of high-quality
39 protein and bioactive compounds, making them a choice ingredient for enriching food
40 formulations and providing techno-functional properties (**Schneider et al., 2015**). Finally,
41 tamarind, rich in polyphenols and minerals, offers antioxidant and hypoglycemic potential,
42 corroborated by various in vitro and in vivo studies (**Okello et al., 2017; Ahodegnon et al.,**
43 **2018; ANSM, 2019; Garba et al., 2020**). Furthermore, *Tamarindus indica* is widely used as a
44 food ingredient in several forms (**Bakayoko et al., 2024**).

45 Despite the individual potential of these ingredients, the combination of these resources in an
46 optimized food formulation remains understudied in the scientific literature (Abde-Aal, 2024).
47 It is with this in mind that this study aims to analyze, from a physicochemical and
48 biochemical perspective, a food formulated with corn, soy, and tamarind. The objective is to
49 determine its nutritional and functional potential, and thus propose an innovative food
50 solution adapted to the needs of populations seeking a healthy and balanced diet. We
51 hypothesized that progressively increasing the incorporation rate of tamarind powder would
52 simultaneously improve the nutritional and technological properties of the composite flours,
53 allowing for the identification of an optimal formulation that could be commercially viable in
54 the food industry.

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66 **MATERIALS AND METHODS**

67 **Raw materials**

68 The raw materials used in this study consist of corn kernels (*Zea mays*), soybean kernels
69 (*Glycine max*) and tamarind pulp (*Tamarindus indica* L.).

70 **Raw materials collection**

71 The corn, soybeans, and tamarind pulp were purchased in the Adjamé district, specifically at
72 the Gouro market in Adjamé (Abidjan, Ivory Coast). This market was chosen because it is
73 where all the food products harvested from other areas of Ivory Coast are available.

74 **Raw material transformation**

75 Soybeans and corn grains have been processed into flour (Kunimboa et al., 2015; Yaredi et
76 al., 2016). As for the tamarind pulps, they underwent several transformations before being
77 reduced to powder (Yao et al., 2025).

78
79 **Formulation of food supplements**

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81 For the methodology of the ternary mixture tests, five incorporation rates were used after a
82 sensory evaluation test: 5%, 10%, 15%, and 20%. The choice of these incorporation rates is
83 based on preliminary tests in which we used rates up to 33.33%.

84 Preliminary results showed that a high level of added tamarind powder resulted in a
85 very sour flour; therefore, we limited it to a maximum of 20%. The exact quantities of each
86 ingredient (corn, soy, bean, and tamarind) for the different formulations are listed in Table (I).

87 **Table I:** Proportion of raw materials in formulations

Formulations	Maize (g)	Soy(g)	Tamarind(g)	Total quantity(g)
FC1	65	30	5	100
FC2	60	30	10	100
FC3	55	30	15	100
FC4	50	35	15	100
FC5	50	30	20	100

88 FC : Composite flour

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90 **Physicochemical characterization of food supplements**

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92 For the characterization of the food supplements obtained, the physico-chemical and
93 biochemical parameters were evaluated.

94 The methods recommended by the Association of Official Analytical Chemists were used for
95 the determination of pH, titratable acidity, moisture, ash, fiber, protein, and total lipids
96 (AOAC, 1990). Three analytical replicates were performed for each sample.

97 The total carbohydrate content and energy value were determined by calculation (European
98 Parliament and Council, 2011).

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101 **Functional characterizations of food supplements**

102 For the determination of the Water Absorption Capacity (WAC), 1 g of formulated
103 flour was dispersed in 10 ml of distilled water. After stirring for 30 min using a KS10 shaker,

104 the mixture was centrifuged at 4500 rpm for 10 min and the wet pellet was weighed and then
105 dried at 105°C to constant weight (**Philips et al., 1988**).

106 For the determination of the Oil Absorption Capacity (OAC), 1 g of formulated flour
107 was dispersed in 7 ml of cottonseed oil. After stirring for 30 min using a KS10 stirrer, the
108 mixture was centrifuged at 4500 rpm for 10 min and the pellet was collected and weighed
109 (**Sosulski, 1962**).

110 The hydrophilic-lipophilic ratio (HLR) was calculated by dividing the water
111 absorption capacity by the oil absorption capacity (**Njintang et al., 2001**). Three tests were
112 performed on each sample.

113 For determining the emulsifying activity (EA) and stability of emulsions (SE), 1 g of
114 formulated flour was mixed with 3 ml of distilled water and 3 ml of cottonseed oil in a
115 graduated tube. The mixture was stirred for 10 min in a KS 10 shaker and then centrifuged at
116 2500 rpm for 5 min. The height of the emulsified layer and the total volume of the tube were
117 measured (**Neto et al., 2001**).

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119 **Statistical analyses**

120 The results were collected using Excel. Statistical tests were performed using R
121 software version 4.5.2. For variables following a normal distribution (the set of
122 physicochemical variables), parametric tests comparing means using analysis of variance
123 (ANOVA) were performed. A difference between two values was considered significant at p
124 < 0.05 . When a significant difference was observed, Tukey's HSD post-hoc test was
125 performed to determine the level at which the observed differences occurred.

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127 **Results and Discussion**

128 **Physicochemical composition of different food formulations**

129 The results relating to macronutrient content and deduced energy values obtained for
130 the five formulations are presented in Table II.

131 Statistical analysis of pH and titratable acidity showed significant differences at the
132 5% level between the pH and acidity of the formulated feeds. The pH of the formulated feeds
133 ranged from 3.28 ± 0.10 to 4.36 ± 0.46 . Formulation (FC5) had the lowest pH, while the
134 highest pH was recorded for flour FC1 (4.36 ± 0.46). However, all of these feeds were acidic.
135 The pH of these ternary formulations was influenced by the incorporation rate of tamarind
136 pulp. This decrease in pH could be explained by the high organic acid content of tamarind
137 pulp, particularly tartaric acid, which contributes to increased acidity (**Sudjaroen et al.,**

138 **2005**). Conversely, an increase in acidity was observed in the formulations enriched with
139 tamarind pulp. It ranges from $2.93 \pm 0.12\%$ (FC1) to $5.53 \pm 0.15\%$ (FC5). From a
140 physicochemical standpoint, the progressive decrease in pH, correlated with the increase in
141 titratable acidity, reflects the substantial contribution of tartaric acid and other organic acids
142 characteristic of tamarind. This acidification plays a key technological role by modifying the
143 net charge of soybean proteins, which directly influences their solubility and spatial
144 conformation (**Kinsella, 1979**). Indeed, the synergy between acidic components and protein
145 matrices is fundamental in dictating the rheological behavior of composite flour blends during
146 processing (**Kohajdova et al., 2013**).

147 In summary, the balance between the acidity provided by the tamarind and the protein
148 structure derived from the soy gives these flours optimal technological properties for a variety
149 of industrial applications.

150 Regarding the moisture content of our composite flours, it ranged from $4.97 \pm 0.21\%$
151 to $5.67 \pm 0.15\%$. Composite flour FC5 had the lowest value ($4.97 \pm 0.21\%$), while FC1 had
152 the highest ($5.67 \pm 0.15\%$). However, analysis of variance showed a significant difference at
153 the 5% level between the moisture content of the different composite flours FC1 and FC2
154 compared to composite flours FC3, FC4, and FC5. These values (4.97 ± 0.21 – $5.67 \pm 0.15\%$)
155 were lower than those found in flour enriched with *Rhynchophorus phoenicis* (palm worm)
156 (**Angaman et al., 2021**). This study demonstrated that the composite flours have very low
157 moisture contents. This low moisture content is due to the fact that these flours are produced
158 using a technological process in which corn and soybean grains are dried at 65°C for 72
159 hours. The FAO/WHO recommends a moisture level below 10% for preserving flour products
160 for reasonable periods (**FAO/WHO, 2006**). Indeed, with a moisture content below 10%, our
161 flours are well-suited to long-term storage. Furthermore, from a microbiological perspective,
162 these low moisture levels limit the growth of microorganisms, including molds (**Aryee et al.,**
163 **2006**).

164 Ash content ranged from 2.1 ± 0.10 to $3.33 \pm 0.15\%$. The highest levels were recorded
165 by FC5. These values are similar to those obtained in maize flours enriched with
166 safou (*Dacryodes edulis*) (**Sika et al., 2019**). The recommended ash content of nuts, seeds, and
167 tubers should be in the range of 1.5–2.5% to be suitable for animal feed (**Pearson, 1976**). The
168 ash content of the resulting composite flours falls within this range; therefore, they can be
169 recommended for animal feed. These values are higher than that found in millet porridges,
170 which was 1.35% (**Ponka, 2015**). The difference in ash content between flours FC1, FC2, and
171 FC3 compared to FC4 and FC5 is due to the incorporation rate of tamarind powder.

172 Specifically, FC4 and FC5 contain 15% and 20% tamarind pulp powder, respectively, while
173 FC1, FC2, and FC3 contain 5%, 10%, and 15% tamarind pulp powder, respectively.

174 Regarding fiber, the composite flours had contents ranging from $11.83 \pm 0.28\%$ to
175 $14.5 \pm 0.7\%$. The digestion of nutrients or food compounds (dry matter, organic matter,
176 energy) is influenced by the chemical and physical characteristics of the food (**Le Goff and**
177 **Noblet, 2001**). Indeed, fiber leads to increased fermentation, resulting in a rise in bacterial
178 mass and higher fecal excretion of nitrogenous matter and, to a lesser extent, fat (**Wilfart,**
179 **2006**). Furthermore, the high fiber content of these studied composite flours could aid
180 intestinal transit by promoting hydration and fecal bulk, promote weight loss, decrease fat
181 absorption, and reduce blood LDL cholesterol and triglycerides (**Kalaki, 2022**).

182 Total lipid analysis showed that the composite flours contained lipids ranging from
183 $2.13 \pm 0.15\%$ (FC5) to $3.9 \pm 0.26\%$ (FC1). The lipid content of our composite flours is below
184 the Codex Alimentarius standards (10–25%) (**Codex Alimentarius, 1991**). However, a low
185 fat content in a dry product would contribute to increasing the sample's shelf life, hence the
186 use of germination as an effective technological lever to improve the nutritional profile of
187 grains (**Bodroža-Solarov et al., 2021**).

188 This low lipid content in our composite flours ($2.13 \pm 0.15\%$ to $3.9 \pm 0.26\%$) could be
189 explained by the fact that the lipids would be consumed during germination to meet the
190 energy needs within the seed.

191 Protein analysis also showed that these formulations contained relatively high protein levels
192 ($14.38 \pm 0.01\%$ to $16.73 \pm 0.19\%$). This high protein content is likely due to the inclusion of soy
193 in the formulations.

194 The study showed that these formulations had moderate caloric values, with energy
195 values ranging from 320.27 ± 1 (FC5) to 341.1 ± 1.15 kcal/100 g dry matter (FC2). Indeed,
196 foods with an energy value between 150 and 400 kcal/100 g DM are considered moderate-
197 energy foods (**Ledikwe et al., 2006**).

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199 **Table II** :Physicochemical properties of food formulations
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Formulation	FC1	FC2	FC3	FC4	FC5	P-value Pr(>F)
pH	4.36±0.46a	3.57±0.06b	3.4±0.08b	3.38±0.01b	3.28±0.10b	0.000703***
At (%)	2.93±0.12d	3.6±0.10c	3.7±0.20c	4.9±0.10b	5.53±0.15a	3.48e-09 ***
Humidity (%)	5.67±0.15a	5.5±0.10a	5.16±0.15b	5.13±0.15b	4.97±0.21b	0.00158 **
Ash (%)	2.1±0.10c	2.1±0.10c	2.1±0.10c	2.4±0.20b	3.33±0.15a	2.12e-06 ***
Fiber (%)	12.63±0.55b	11.83±0.28c	13.83±0.15a	14.5±0.7a	14.3±0.2a	7.55e-05 ***
Lipid (%)	3.9±0.26a	3.76±0.15a	3.16±0.15b	2.3±0.10c	2.13±0.15c	3.68e-07 ***
Protein	15.28±0.16c	14.66±0.11d	14.38±0.01e	16.73±0.19a	15.84±0.06b	3.92e-09 ***
Total carbohydrates (%)	73.05±0.46b	73.98±0.4a	75.2±0.19b	73.44±0.98c	73.73±0.13c	0.000114 ***
TEV (kcal/100g dry matter)	388.42±1.91b	388.4±1.15a	386.76±1.15c	381.38±1d	377.45±1e	1.22e-07 ***

201 Mean ± standard deviation, n = 3; Means in the same row with different exponents are significantly different at P
 202 ≤ 0.05 according to Tukey's HSD test; **TEV**: Total energy value; **FC**: Composite flour; **At**: Titratable acidity
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205 **Functional parameter**

206 The results of the functional properties obtained from the different formulations FC1 to FC5)
 207 are presented in Table III.

208 The results show statistically significant differences between the formulations for all
 209 the parameters studied, showing that the relative proportions of the ingredients strongly
 210 influence the technological properties of the flours.

211 The Water Absorption Capacity (WAC) varies from 137.33±1.53% to 154.66±1.15%.
 212 The highest value is observed for formulation FC3, while the lowest is obtained for FC1.

213 The significant increase in Water Absorption Capacity (WAC) and Emulsifying Activity (EA)
 214 observed in mixtures enriched with tamarind pulp could be explained by the complex
 215 interactions between tamarind acid polysaccharides and soy protein isolates. Polysaccharides
 216 rich in hydroxyl groups promote hydrogen bonding with water, improving matrix hydration
 217 (**Qiu et al., 2024**).

218 Similar studies have shown that adding legume to composite flours improves the
 219 hydration capacity of food matrices (**Irondi et al., 2024**).

220 Furthermore, the oil absorption capacity (OAC) varies between 104.33 ± 1.5% and
 221 121.66 ± 1.15%, with a maximum value for FC1. This property depends on the availability of
 222 proteins capable of interacting with lipids via their hydrophobic sites. Proteins in soybeans are
 223 known to promote oil retention in food products, which contributes to improving the texture
 224 and flavor of formulations (**Qiu et al., 2024**). However, increasing the proportion of fiber
 225 from tamarind could also lead to a relative dilution of these proteins, explaining the AAC

226 variations observed between formulations.

227 The hydrophilic-lipophilic ratio (HLR) ranges from 1.13 ± 0.02 to 1.43 ± 0.03 , with the
228 highest values observed in FC3 and FC4. This parameter reflects the balance between
229 hydrophilic and lipophilic compounds in food matrices. The interactions between proteins,
230 starch, and fibers in composite flours strongly influence these functional properties and their
231 technological behavior in food systems (Milenković et al., 2019).

232 Overall, the combination of corn, soy, and tamarind improves the functional properties
233 of composite flours, including water absorption capacity, emulsifying activity, and emulsion
234 stability, suggesting their potential for use in the formulation of functional foods.

235 **Table III:** Functional properties of food formulations

Food	FC1	FC2	FC3	FC4	FC5	P-value Pr(>F)
WAC (%)	137.33±1.53d	140.33±1.15c	154.66±1.15a	148±1.00b	147±1.00b	5.17e-08 ***
OAC (%)	121.66 ±1.15a	104.33±1.5 3d	107.66±1.5 3bc	105.66±1.5 3cd	109.33±1.15b	2.08e-07 ***
RHL	1.13±0.02c	1.34±0.03b	1.43±0.03a	1.40±0.02a	1.34±0.00b	2.06e- 07***
EA (%)	45.31±1.16c	60.65±1.17a	61.25±2.33a	53.81±1.65b	61.90±0.82a	3.98e-07 ***
SE (%)	86.72±4.04b	77.85±1.49c	72.75±4.59c	94.73±2.49a	88.46±0.15b	3.42e-05 ***

236 Mean ± standard deviation, n = 3; Means in the same row with different exponents are significantly different at P
237 ≤ 0.05 according to Tukey's HSD test; FC: Composite flour
238 WAC: Water absorption capacity; OAC: Oil absorption capacity; HLR: Hydrophilic-lipophilic ratio; EA:
239 Emulsifying activity; SE: Emulsification stability

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243 **Principal Component analysis (PCA)**

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245 All the results from the PCA are presented in Table IV and Table V.

246 The robustness of our formulation classification model was confirmed by Principal
247 Component Analysis (PCA). This chemometric approach, explaining over 81.6% of the
248 variance, is recognized as a tool for dimensionality reduction and the extraction of relevant
249 information from complex data matrices such as those derived from food product
250 characterization (Brereton, 2009). This analysis accurately discriminated the specific impact
251 of tamarind incorporation on the overall physicochemical profile. This result is significantly
252 higher than the 70% threshold often recommended in the literature for reliable interpretation
253 of food matrices (Kohajdová et al., 2013). The analysis of the correlations between the
254 variables and the principal components reveals that axis 1 (PC1) simultaneously represents

255 the physico-chemical and functional composition of the formulated flours, while axis 2 (PC2)
 256 reflects only the functional capabilities of the different formulated flours.

257

258 **Table IV:** Eigenvalue matrix and percentage of variability expressed by principal components

Principal components	Eigen values	Percentage variance (%)	Cumulative percentage of variances (%)
Component 1	6.64	55.37	55.37
Component 2	3.73	31.15	86.52
Component 3	0.82	6.9	93.42
Component 4	0.78	6.58	100

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260

261 **Table V :** Correlation matrix between the variables studied and the principal components

Variables	Correlation coefficient with respect to PC1	p-value_PC1	Correlation coefficient with respect to PC2	p-value_PC2
Humidity	-0.89	8.82E-06***	-0.26	0.34399 ^{ns}
Ash	0.72	0.002205**	-0.19	0.493332 ^{ns}
Fibers	0.90	3.28E-06***	-0.10	0.710155 ^{ns}
Lipids	-0.95	5.04E-08***	0.06	0.832805 ^{ns}
Proteins	0.65	0.008693**	-0.65	0.008157**
Carbohydrates	-0.74	0.001686**	0.63	0.011606*
TEV	-0.96	8.3E-09***	0.16	0.554442 ^{ns}
WAC	0.65	0.008463**	0.57	0.025165*
OAC	-0.45	0.090724 ^{ns}	-0.68	0.004692**
HLR	0.61	0.015852*	0.73	0.002017**
EA	0.41	0.126187 ^{ns}	0.81	0.000211***
SE	0.44	0.099715 ^{ns}	-0.81	0.000238***

262

PC1: Main component 1; PC2: Main component 2; TEV: Total energy value; ns: Not significant

263

264 **PCA validation test using the permutation method**

265 The results of the PCA validation test are presented in Table VI.

266 It should be noted that the PCA was performed on a limited number of experimental
267 formulations. However, to validate the robustness of this structure and to rule out any
268 statistical artifacts, a permutation test (1000 resamples) was applied. This test confirms that
269 the observed separation between the control formulations and the enriched mixtures
270 (particularly FC3) is not due to chance, thus strengthening the reliability of the predictive
271 model. This rigor in the statistical processing of physicochemical data aligns with the
272 analytical standards recommended for the certification of the quality and authenticity of agri-
273 food products. The combined analysis of correlations and permutations thus leads to the
274 conclusion that the FC3 formulation (15% tamarind) constitutes a distinct technological pole,
275 optimizing both nutritional density and suitability for industrial processing.

276 **Table VI:** Correlation between the variables studied and the principal components

Main Components	Observed eigenvalues	Permutated average values	p-value
PC1	6.64	6.15±0.56	0.000** *
PC2	3.73	2.97±0.45	0.012*
PC3	0.82	0.83±0.26	1 ns
PC4	0.78	0.68±0.18	1 ns

277 ns: not significant

278 The results obtained from the PCA biplot between the physico-chemical and
279 functional parameters of the formulated foods are shown in Figure 5.

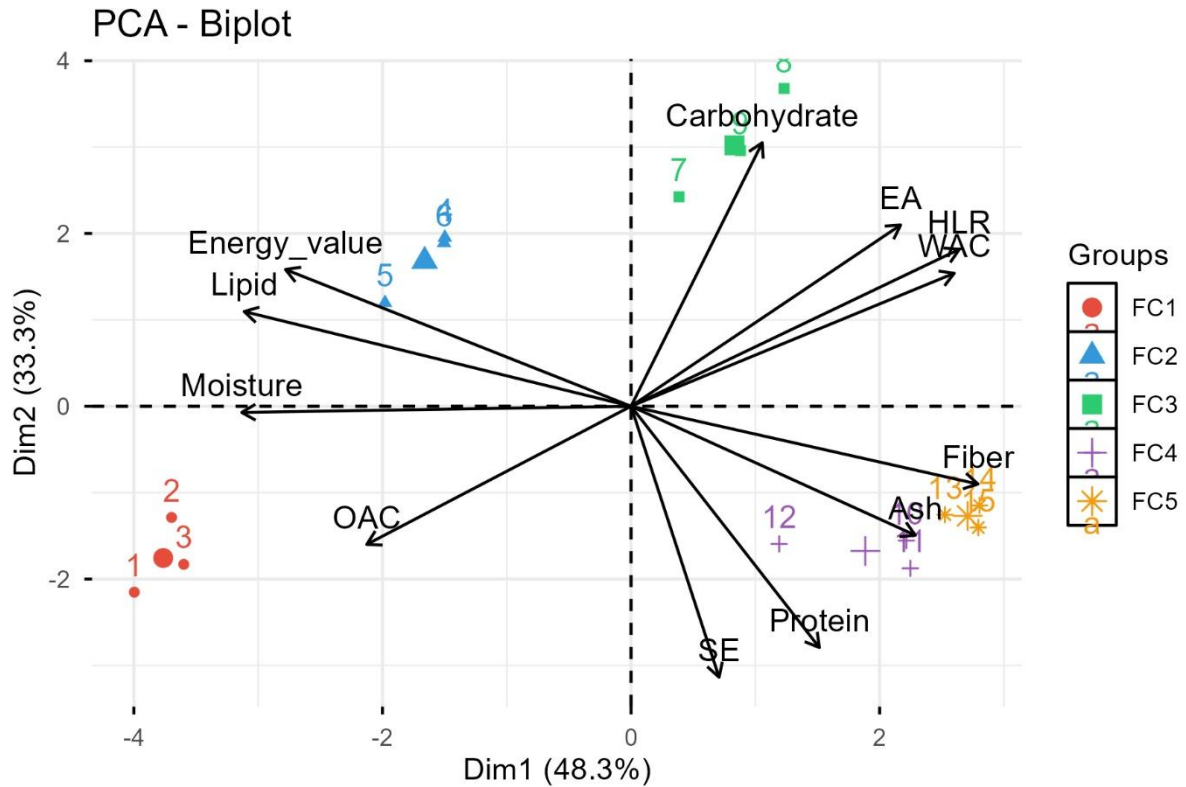
280 The use of multivariate analysis made it possible to effectively discriminate between
281 formulations, an approach widely validated in the characterization of food quality.
282 FC1 and FC2 flours have a high energy content, while FC3, FC4, and FC5 flours have a high
283 nutritional content in terms of protein and fiber. Flours formulated with a high protein and
284 fiber content are considered to have high nutritional value for good human health.

285 Samples FC4 and FC5 clustered opposite each other, correlated with protein and ash
286 content. This correlation is likely due to the milling method used in our study to reduce the
287 grains to a fine powder; this association is typical of flours produced by dry fractionation
288 processes, where the protein fractions carry with them the mineral salts located in the outer
289 layers of the grain.

290 The projection of FC3 shows that its functionality is not solely due to its protein
291 content, but likely to a synergy between its fibers and its protein structure. Hydrophilic
292 interactions via hydrogen bonds between the hydroxyl groups of polysaccharides and the side
293 chains of amino acids are the main determinants of WAC. From an industrial perspective, the

294 isolated position of FC3 suggests specific potential for applications in baking or fine meat
 295 processing, where water retention is critical for process yield and texture.

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298
 299 **Figure1:** Graphical representation of the PCA-Biplot analysis of physicochemical and
 300 functional parameters in formulated flours
 301

302 **Table IV :** Euclidean distance matrix between samples
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	FC1	FC2	FC3	FC4	FC5
FC1	0.00	25.01	30.92	23.76	25.55
FC2	25.01	0.00	15.86	21.36	17.76
FC3	30.92	15.86	0.00	25.01	20.05
FC4	23.76	21.36	25.01	0.00	11.68
FC5	25.55	17.76	20.05	11.68	0.00

304
 305 The Euclidean distance matrix calculated from the means of the three analytical replicates
 306 reveals varying dissimilarities between the samples studied. The minimum distance is
 307 observed between FC4 and FC5 (11.68), indicating strong physicochemical similarity, while
 308 FC1 exhibits the maximum distances with all the other samples (FC2, FC3, FC4, and FC5).

309 The cophenetic coefficient of 0.857 confirms the goodness of fit of the dendrogram derived
310 from Ward's method. D2 to the original distance matrix.

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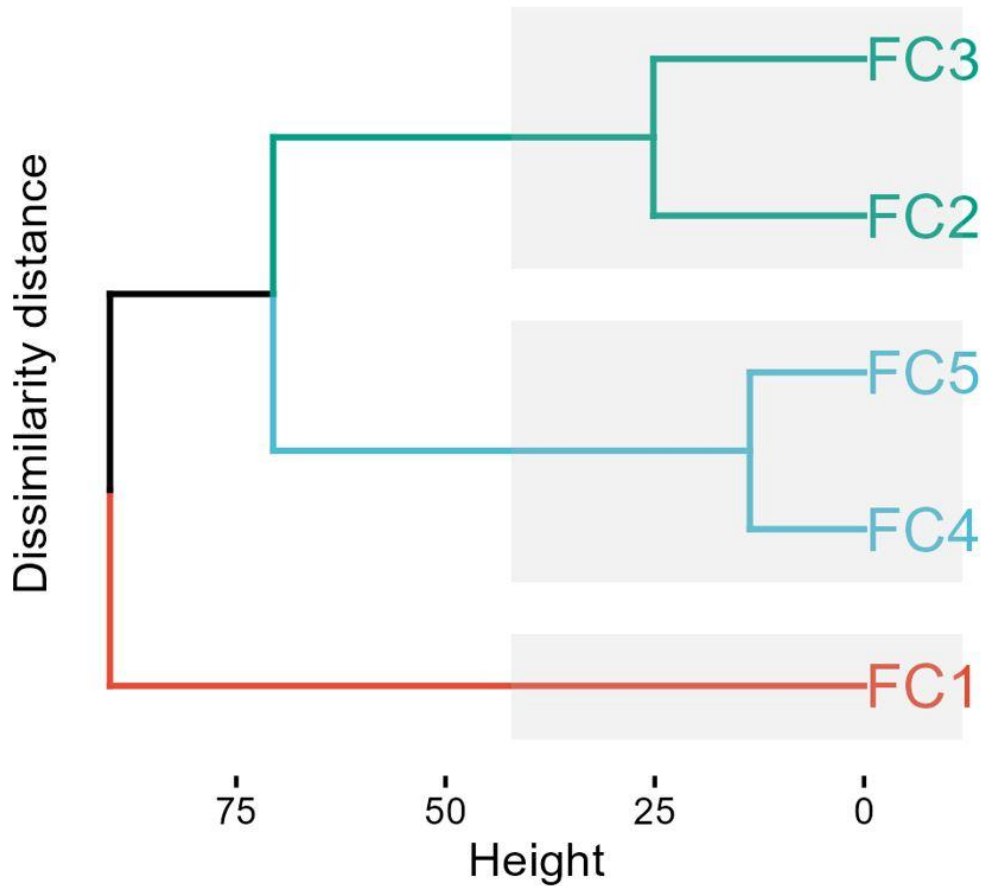


Figure 3 :HCA dendrogram of samples FC1 to FC5. Ward's method. D2, Euclidean distance. Cophenetic coefficient = 0.857

321 Hierarchical clustering based on twelve physicochemical parameters grouped the five samples
322 into three distinct clusters with a cophenetic coefficient of 0.875, indicating a faithful
323 representation of the Euclidean matrix. FC1 forms an isolated cluster due to its large distances
324 from the other samples, ranging from 23.77 to 30.92.

325 Samples FC2 and FC3 form a second cluster with an inter-sample distance of 15.86. The third
326 cluster comprises FC4 and FC5, which have the lowest inter-sample distance of 11.68. The
327 separation of FC1 can be attributed to its specific moisture, fiber, and protein content.

328 The proximity of FC4 and FC5 suggests a similar composition, corroborated by their small
329 Euclidean distance. This three-group structure is consistent with PCA, where Dim1 and Dim2
330 also separate FC1 from the other samples.

331

332 **Conclusion**

333 This study enabled us to develop composite flours enriched with tamarind pulp. The resulting
334 flours exhibit a good nutritional composition, rich in macromolecules necessary for a healthy
335 and balanced diet. Principal component analysis (PCA) revealed that the first two components
336 (PC1 and PC2) explain a significant portion of the variance in the data, with PC1 related to
337 macronutrient composition and PC2 to functional properties. These results provide a better
338 understanding of the relationships between different approaches for product optimization.

339
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