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Physicochemical and Sensory Evaluation of Gummy Candies Fortified with Microcapsules of Guinea Pig (*Cavia porcellus*) Blood Erythrocytes and Tumbo (*Passiflora tarminiana*) Juice

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Abstract: Recently, interest in developing functional foods that promote health has grown significantly. This study aimed to evaluate the feasibility of microencapsulating guinea pig blood erythrocytes by vacuum drying and incorporating them into gummies fortified with tumbo juice. Physicochemical analysis (proximate analysis, iron content, color, pH, soluble solids, and particle size) and functional group analysis by Fourier transform infrared spectrophotometry were performed on three formulations of gummy candy with added encapsulated erythrocytes from guinea pig blood (EEGPB): F1 (4% EEGPB), F2 (5% EEGPB), and F3 (6% EEGPB). The results showed a significant decrease in the moisture content (52.02% in F1 to 43.27% in F3) and increases in protein (11.44% in F3) and iron (2.63 mg Fe/g in F3) contents when higher EEGPB levels were used. Sensory evaluation revealed that F3 was the most acceptable formulation in terms of taste, aroma, and texture, with no significant differences in color. FTIR analysis confirmed physical incorporation with no chemical interactions between ingredients. These results demonstrate that the encapsulation of erythrocytes by vacuum drying not only preserves the bioactive compounds but also improves the organoleptic properties of the gummies, making them an attractive product for consumers. In conclusion, this technique is effective for fortifying functional foods and has potential application in other food products. This approach represents a significant advance in the development of innovative functional foods.

Keywords: microencapsulated erythrocytes; iron fortification; sensory analysis; vacuum drying; gummy candy; functional confectionery

1. Introduction

In recent years, there has been growing interest in developing functional foods. This interest is driven by the consumer demand for products that provide essential nutrition, promote health, and help prevent chronic diseases [1]. Among these needs, iron deficiency stands out as a global problem affecting more than 1.62 billion people, leading to anemia and severe health impacts, particularly in vulnerable populations such as children and pregnant women [2,3]. In this context, blood erythrocytes from guinea pig (*Cavia porcellus*), a sustainable and culturally accepted resource in Andean regions, emerge as a rich source of heme iron, which is highly bioavailable and effective in addressing iron deficiencies [4,5]. When combined with high-Andean fruit juices such as tumbo (*Passiflora tarminiana*), which are known to be rich in bioactive compounds, they offer significant potential for food fortification [6]. Despite its potential, no detailed studies on the encapsulation of guinea pig blood erythrocytes exist, underscoring the need for further research.

Advanced food technologies such as microencapsulation have been developed to address these challenges. This technique protects sensitive bioactive compounds and improves their stability, bioavailability, and controlled release in food matrices, promoting sustainability and advancements in functional foods [7–10]. Vacuum drying, in particular, preserves the bioactivity of sensitive compounds while improving their stability and controlled release in the digestive tract [11]. This process also enhances the stability of guinea pig blood erythrocytes and masks undesirable characteristics such as flavor and odor, making them suitable for fortification [4]. Guinea pig farming is also sustainable and culturally accepted in Andean regions, further supporting its use in emerging food products [12]. However, further research is needed to understand its applications and overcome its challenges [4]. The technique is particularly effective in protecting bioactive compounds during storage and improving the properties of food products. This method has gained relevance in the food industry, mainly using animal by-products with high nutritional and functional potential [4,5,13]. Improving these by-products' stability, sensory properties, and bioavailability can play a key role in facilitating their market acceptance [14,15].

Gummy candies, recognized for their attractive texture and taste, are creative means of incorporating food formulations enriched with bioactive compounds [16–18]. Beyond their nutritional value, recent innovations, such as microencapsulation, have demonstrated their effectiveness in stabilizing and improving the bioavailability of sensitive compounds while maintaining their sensory characteristics, which are crucial for consumer acceptance. These formulations, aligned with current trends of sustainability and customization in the food market, make fortified gummy candies a promising vehicle for satisfying both nutritional needs and sensory preferences [19–21]. Microencapsulation mitigates issues related to undesirable flavors and odors, enhancing consumer acceptance and making such products more appealing. Moreover, fortified gummies are an attractive option for younger populations due to their texture, flavor, and convenience, bridging the gap between nutrition and sensory appeal [22]. Assessing customer preferences and acceptability is essential to market success, and sensory evaluation is vital. Through hedonic preference and acceptability testing, it is possible to identify significant differences between formulations and predict the actual usage of a product. Before applying statistical methods, the normality of the data is evaluated using tests such as Shapiro–Wilk or Kolmogorov–Smirnov. If the data do not meet the assumptions of normality, non-parametric methods, such as Friedman's tests, followed by Wilcoxon or Kruskal–Wallis, are used to ensure a reliable analysis. These methods ensure reliable insights into consumer preferences, aiding in developing successful functional foods [23,24].

In addition, encapsulation preserves compounds during storage and enhances the sensory characteristics of food products, making them more appealing to consumers. This technique also ensures compliance with food safety standards, such as those established by SENASA (Peru's National Agrarian Health Service), while promoting sustainable and advanced raw materials like guinea pig blood erythrocytes. This cutting-edge approach opens up new opportunities for developing functional foods that are both nutritious and sensorially pleasing [4,25,26]. This study aims to evaluate the feasibility of microencapsulating guinea pig blood erythrocytes through vacuum drying for their incorporation into fortified gummies, focusing on enhancing their nutritional properties and sensory attributes to increase consumer acceptance.

2. Materials and Methods

2.1. Materials

Guinea pig blood collected under innocuous conditions was kindly provided by the Municipal Camal of the district of San Jeronimo in Andahuaylas (Peru), authorized by the National Agricultural Health Service (SENASA). The other supplies used in the trials were of analytical grade. The Universidad Nacional José María Arguedas Ethics Committee approved animal use in this research study through Resolution N° 087-2023-CO-UNAJMA, issued on 6 March 2023.

2.2. Microencapsulation of Guinea Pig Blood Erythrocytes by Vacuum Drying

Guinea pig blood was collected using sodium citrate (Biolab, Buenos Aires, Argentina) as an anticoagulant (3 g/L). Then, the globular package was separated twice by centrifugation (Bioridge TDL–5M, Shanghai, China) at 3000 revolutions per minute for 10 min and washed with 0.9% (p/v) NaCl. The residue was dried in a vacuum oven VD56 (Binder, Tuttlingen, Germany) at 80 °C for 24 h. Finally, the material obtained was ground and stored in polyethylene bags until further use.

For encapsulation, an encapsulating solution was prepared with 5 g of tara gum and 95 g of maltodextrin (Regon, Lima, Perú), homogenized in an ultraturrax. Then, 10 g of this mixture was diluted in 100 mL of ultrapure water using a magnetic stirrer, and 20 g of diluted erythrocytes was added. The liquid with erythrocytes was carefully poured into Petri dishes and placed in a vacuum oven VD56 (Binder, Tuttlingen, Germany) at 80 °C for 24 h; the material obtained was ground and stored in polyethylene bags until further use.

2.3. Formulation and Processing of Enriched Gummies

Good-quality ripe tumbos were selected, washed, peeled, and liquefied for 10 s to avoid the bitter taste caused by the seeds, thus obtaining the tumbo juice used for each formulation of gummies made with different percentages of encapsulated erythrocytes (Table 1). In the obtained juices, 20 g of neutral gelatin, 20 g of sugar, and 31 g of glucose were diluted and pasteurized at 75 °C for 5 min. Subsequently, encapsulated erythrocytes were added to each mixture obtained at different concentrations: 6.92 g for F1 (4% EEGPB), 8.92 g for F2 (5% EEGPB), and 10.92 g for F3 (6% EEGPB). The resulting mixtures were quickly poured into 1 mL molds, cooled to 8 °C for 24 h, de-molded, and stored for further analysis.

Table 1. Formulations of gummy candy with added encapsulated erythrocytes from guinea pig blood.

Ingredients	F1 (4% EEGPB)	F2 (5% EEGPB)	F3 (6% EEGPB)
Tumbo juice (g)	102	100	98
Neutral gelatin (g)	20	20	20
Sugar (g)	20	20	20
Glucose (g)	31	31	31
Erythrocytes encapsulated (g)	6.92	8.92	10.92
Total	179.92	179.92	179.92

F1, F2, and F3 are the formulations of the gummy candy with added encapsulated erythrocytes from guinea pig blood.

2.4. Iron Content

A total of 200 mg of the encapsulated erythrocytes was weighed and digested with a mixture of HCl (Spectrum Chemical Mfg. Corp, Bathurst, NB, Canada) and HNO_3 (Spectrum Chemical Mfg. Corp, Bathurst, NB, Canada) in a microwave digester (SCP Science, Miniwave, QC, Canada). Iron was measured with an ICP-OES 9820 138 (Shimadzu, Kyoto, Japan) using a calibration curve from 0 to 50 mg/L and a wavelength of 239.56 nm; the same procedure was performed on the gummy candy with added encapsulated erythrocytes from guinea pig blood [4].

2.5. Particle Size

A Mastersizer 3000 ((Malvern Instruments, Worcestershire, UK) laser diffraction analyzer was used. Encapsulated erythrocyte samples were dissolved in isopropyl alcohol, sonicated for 60 s, and measured at 600 nm [5].

2.6. Analysis by Scanning Electron Microscopy (SEM)

The morphology of the encapsulated erythrocytes was evaluated with a Thermo Fisher Prism E scanning electron microscope (Waltham, MA, USA) at 25 kV and 1000× magnification. Surface chemical analysis was performed with the same equipment and energy-dispersive X-ray spectroscopy (EDS) [5].

2.7. Proximate Analysis

In the proximate analysis of the gummy candy with added encapsulated erythrocytes from guinea pig blood, AOAC (2012) standard methods were used for moisture (AOAC 925.10), protein (AOAC 2003.05), fat (AOAC, 923.03), fiber (AOAC 985.29), and ash (AOAC 960.52) determination, and carbohydrates were determined by difference [27].

2.8. Color Analysis

Color analysis was performed on the gummy candy with added encapsulated erythrocytes from guinea pig blood, and the CIE Lab scale and a Konica Minolta model CR-5 colorimeter (Tokyo, Japan) were used. On this scale, the following parameters were evaluated: L^* representing lightness (0 = black and 100 = white), chroma a^* ($+a$ = red, $-a$ = green), and chroma b^* ($+b$ = yellow, $-b$ = blue) [28].

2.9. pH

Ten grams of the gummy candy with added encapsulated erythrocytes from guinea pig blood was dissolved in 50 mL of distilled water at 45 °C. The pH of the solution was measured using a calibrated potentiometer Lab 885 (SI Analytics, Mainz, Germany) [29].

2.10. Soluble Solids

Small samples of the gummy candy with added encapsulated erythrocytes from guinea pig blood were placed on the prism of an refractometer (Isolab ABBE, Wertheim, Germany), and readings were taken [29].

2.11. Analysis by Fourier Transform Infrared Spectrophotometry (FTIR)

FTIR analysis was conducted to identify the functional groups present in the gummy candies. The ATR (attenuated total reflectance) module of the Nicolet IS50 FTIR spectrophotometer (Thermo Fisher, Waltham, MA, USA) was used. The instrument was set with a resolution of 8 cm^{-1} and performed 32 scans, utilizing advanced correction for the diamond crystal. The incidence angle was 45 degrees, and the refractive index was 1.50 [5]. The analysis focused on the mid-infrared range (4000–400 cm^{-1}), commonly used to identify functional groups in organic and food matrices. The gummy candies were analyzed directly without additional pre-treatment by applying uniform pressure to the ATR crystal [5].

2.12. Sensory Evaluation

Sensory evaluation was carried out two weeks after storing the gummies enriched with encapsulated guinea pig blood erythrocytes. Portions of 20 g were offered to 80 untrained panelists aged 16 to 22. Panelists were selected to ensure an equal gender distribution and focus on individuals with no previous experience with fortified gummies. The evaluation cards used randomly assigned three-digit codes to ensure unbiased evaluations. The evaluation environment was adequately lit, odor-free, and well-ventilated.

This study included two consumer-based tests:

1. An acceptability test which used a four-point hedonic scale (Poor = 1, Fair = 2, Good = 3, Excellent = 4) to evaluate color, aroma, taste, and texture.
2. A preference test in which participants selected their preferred sample from the coded options.

The sample size was determined using Cochran's formula for proportions, ensuring a 95% confidence level and a 10% margin of error. This calculation confirmed that 80 participants were a representative sample size. The study protocol was approved by the Ethics Committee of the Universidad Nacional José María Arguedas, and all participants signed an informed consent form [23,24].

2.13. Statistical Analysis

The physicochemical properties were analyzed using analysis of variance (ANOVA) and Tukey's multiple range test at 5% significance. Each test was performed with three repetitions to ensure reliable and statistically significant results. For sensory evaluation data, the Kolmogorov–Smirnov normality test was performed first, followed by the Friedman and Wilcoxon tests [23].

3. Results and Discussion

3.1. Characterization of Microcapsules

The iron content in guinea pig erythrocytes encapsulated by vacuum drying was 4.00 mg Fe/g, a value higher than that obtained in guinea pig erythrocytes encapsulated using the spray drying technique with tara gum and native potato starch matrices (3.30 mg Fe/g) [4] and also greater than the value reported for commercial bovine erythrocytes (2.49 mg Fe/g) [13]. Dried erythrocytes represent a safe and efficient source of heme iron (up to 99%), making their extraction from various animal sources and subsequent encapsulation through drying methods that enhance release and absorption highly recommended [30,31]. The superior performance of vacuum drying is attributed to its low temperature and pressure conditions, which better preserve heme iron by reducing thermal and oxidative damage [11]. In contrast, spray drying, which operates at higher temperatures, may lead to more significant nutrient losses due to degradation and oxidation, explaining the lower iron content obtained [32,33].

Figure 1a,b show red-colored powders with average particle sizes of 37.60 μm. Encapsulation was performed within a matrix, characteristic of the vacuum drying technique [11]. EDS analysis confirmed the presence of biopolymers (carbohydrates and proteins), the NaCl used to extract erythrocytes, and iron in the matrix [5]. Iron absorption mainly occurs in the duodenum, where heme iron plays a crucial role in enhancing the absorption of non-heme iron, the consumption of which is significantly lower in resource-poor countries [34]. The recommended daily intake of iron ranges between 10 and 15 mg, and processed erythrocytes represent a promising alternative for food fortification, such as gummy candies [35–37]. Microencapsulation is one of the most effective and recommended techniques for ensuring the controlled release of iron in these products [38–41].

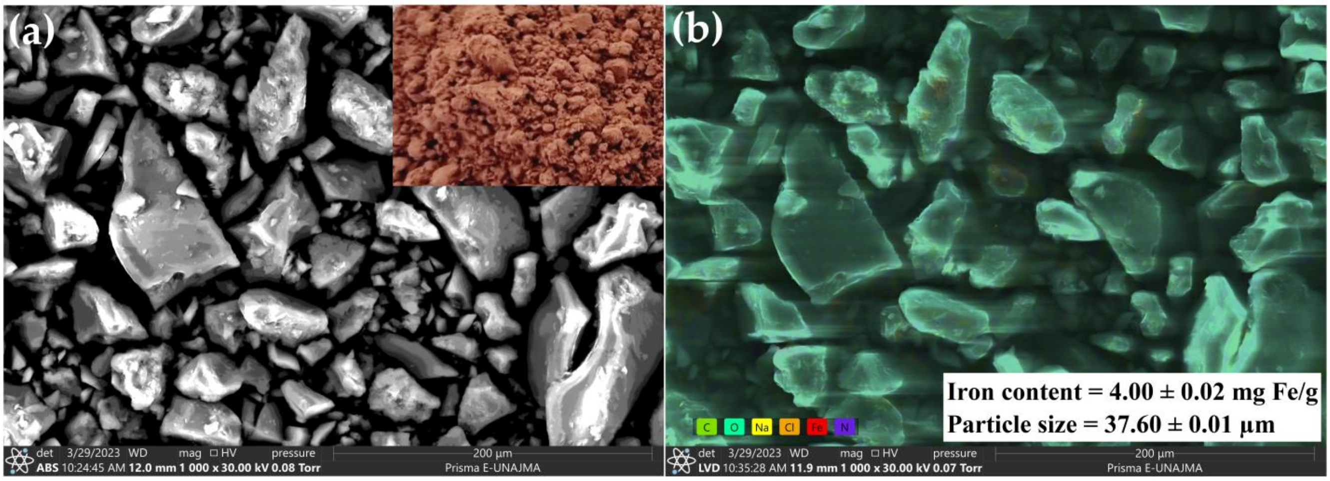

Figure 1. Characterization of the microcapsules: (**a**) morphology of powders obtained via SEM; (**b**) elemental analysis by SEM-EDS in terms of iron content and particle size.

3.2. Physicochemical and Sensorial Characterization of Gummy Candies

The results in Table 2 reveal significant changes in the proximate composition of gummy candy when higher concentrations of encapsulated erythrocytes were used. The moisture content decreases from 52.02 to 43.27%, which is expected due to the higher proportion of solids in the formulations. In contrast, protein content increases from 10.10 to 11.44%, reflecting the protein-rich nature of the erythrocytes. Ash, which represents the mineral content, increases from 0.68 to 3.14%, correlating with the increase in iron content (from 1.96 to 2.63 mg Fe/g), enhancing the gummies' nutritional value [4]. As moisture decreases, the carbohydrate content increases (from 37.11 to 42.06%).

Table 2. Results of the physicochemical analysis.

Properties	F1 (4% EEGPB)			F2 (5% EEGPB)			F3 (6% EEGPB)		
	$\bar{x}$	±	SD	$\bar{x}$	±	SD	$\bar{x}$	±	SD
Moisture (%)	52.02 ^{a}	±	0.27	48.45 ^{b}	±	0.57	43.27 ^{c}	±	0.54
Protein (%)	10.10 ^{a}	±	0.03	10.59 ^{b}	±	0.10	11.44 ^{c}	±	0.06
Fat (%)	0.05 ^{a}	±	0.01	0.05 ^{a}	±	0.01	0.07 ^{a}	±	0.01
Ash (%)	0.68 ^{a}	±	0.02	1.58 ^{b}	±	0.03	3.14 ^{c}	±	0.06
Fiber (%)	0.05 ^{a}	±	0.01	0.06 ^{a}	±	0.01	0.04 ^{a}	±	0.02
Carbohydrates (%)	37.11 ^{a}	±	0.35	39.28 ^{b}	±	0.45	42.06 ^{c}	±	0.55
Iron content (mg Fe/g)	1.96 ^{a}	±	0.01	2.47 ^{b}	±	0.04	2.63 ^{c}	±	0.03
L^*	22.47 ^{a}	±	0.42	20.93 ^{b}	±	0.10	19.90 ^{c}	±	0.14
a^*	1.27 ^{a}	±	0.04	1.28 ^{a}	±	0.07	1.30 ^{a}	±	0.11
b^*	0.59 ^{a}	±	0.08	0.42 ^{ab}	±	0.04	0.35 ^{b}	±	0.10
pH	3.96 ^{a}	±	0.01	3.98 ^{a}	±	0.01	4.01 ^{b}	±	0.01
Soluble solids (°Brix)	60.00 ^{a}	±	0.05	61.00 ^{b}	±	0.08	62.00 ^{c}	±	0.02

F1, F2, and F3 are the formulations of the gummy candies with added encapsulated erythrocytes from guinea pig blood. Different letters indicate significant differences per row evaluated at 5% significance.

Color parameters indicate a decrease in lightness (L^*) and the yellow component (b^*), while the red component (a^*) increases proportionally [19,42]. This change reflects the erythrocytes' visual impact on the gummies' hue (Figure 2). The pH experiences a slight increase from 3.96 to 4.01, suggesting a slight neutralization of the tumbo juice with the addition of encapsulated erythrocytes. Finally, soluble solids also increase slightly, reaching 62.00 °Brix in formulation F3 (6% EEGPB) [19,43].

Figure 2. Gummy candies with added encapsulated erythrocytes from guinea pig blood (F1, F2, and F3 are the formulations).

The results indicate that the gummies' soluble solid content is lower than the typical standard for gelatin products, which generally exceeds 70 °Brix, a key value to ensure the product's textural and microbiological stability [44–46]. This lower soluble solid content is mainly due to the lack of concentration and drying stages during processing, which prevents an increase in soluble solids, affecting the stability and final quality of the product. In addition, the high moisture content (~50%) exceeds the standard range of 15–30%, negatively impacting texture and increasing the gummies' susceptibility to microbial contamination [19,47]. Reducing moisture in gummy candies enhances their texture, making them firmer and palatable while extending their shelf life by limiting water activity, which is crucial for microbial growth. Lower humidity improves storage stability, reduces mold, and maintains sensory qualities, preventing stickiness, which is critical to consumer acceptance [19,48,49]. Adjusting formulations and incorporating drying processes are recommended to meet optimal quality and stability standards, ensuring product appeal and market success.

Figure 3 shows the FTIR spectra of the three formulations, evidencing similar strain bands and suggesting physical incorporation without chemical interactions. Peaks at 3378 cm^{-1} (hydroxyl group of water and polysaccharides), 1643 cm^{-1} (amide group of proteins), and 1546 cm^{-1} (phenols and flavonoids of tumbo juice) stand out. In addition, peaks between 703 and 1546 cm^{-1} correspond to sugar components, and at 1042 cm^{-1}, sucrose is detected, associated with the vibration of glycosidic bonds between fructose and glucose. The intensity of the FTIR peaks does not present significant variations due to the reduced amount of iron, which does not generate alterations in the functional groups [42,43].

FTIR analysis evidences the fact that incorporating encapsulated erythrocytes in gummy candy formulations does not significantly alter the structural characteristics of the matrix, which reinforces its viability for food applications [48,50]. The consistency of the strain bands, associated with hydroxyl groups, amides, phenols, flavonoids, and sugars, suggests that encapsulated erythrocytes interact compatibly with the original components [41,48]. This behavior is key to maintaining the functionality and chemical stability of the product, allowing the encapsulated iron to be incorporated without compromising the system's integrity [51]. In addition, these characteristics ensure that the gummy candies can serve as an efficient vehicle for delivering essential nutrients, such as iron, without negatively affecting sensory quality or consumer acceptance [41,45].

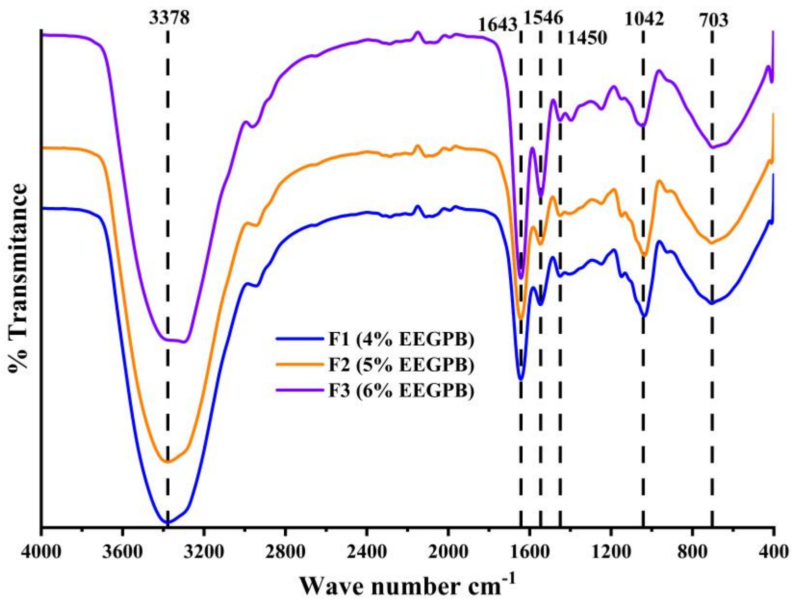

Figure 3. FTIR spectra of gummy candies with added encapsulated erythrocytes from guinea pig blood (F1, F2, and F3 are the formulations).

Figure 4a presents the acceptability test results for three formulations of gummy candies made with guinea pig blood. Formulation F3 (6% EEGPB) achieved the highest flavor, aroma, and texture acceptance, with no significant differences observed in color. The encapsulation process enhanced the sensory properties by masking off-flavors and improving taste and texture, leading to higher product acceptance [51,52]. Additionally, Figure 4b illustrates the preference test results, showing that F3 (6% EEGPB) was the preferred formulation, with 67% of panelists selecting it, followed by F2 (5% EEGPB) with 20% and F1 (4% EEGPB) with 13%. These findings confirm that higher EEGPB content correlates with greater consumer preference, likely due to improved sensory characteristics.

This technique effectively stabilized flavors and maintained sensory quality, which is crucial for consumer acceptance and market competitiveness [53–55]. Sensory evaluation emphasizes the importance of encapsulation in increasing the appeal of functional foods [51,56]. In the case of gummy candies with guinea pig blood, encapsulation masked undesirable flavors and incorporated iron-rich erythrocytes without compromising taste and texture. Moreover, as depicted in Figure 4c, the panel was equally distributed by gender (50% male and 50% female), ensuring a balanced representation in the sensory evaluation and eliminating potential biases related to gender preferences.

This process ensures that the nutritional benefits are effectively presented, boosting market acceptance. These results also suggest that encapsulation can be adapted to integrate other bioactive compounds into similar formulations, expanding the variety of fortified foods that meet specific nutritional needs [57,58].

The principal component analysis (PCA) in Figure 5 simplifies the interpretation of the physicochemical and sensory characteristics of gummy candy formulations enriched with encapsulated guinea pig blood erythrocytes. The first two principal components explained 100% of the variance; PC1 accounted for 82.96%, and PC2 for 17.04%. This distribution reflects a strong influence of the variables associated with PC1 in the differentiation of the formulations [59,60].

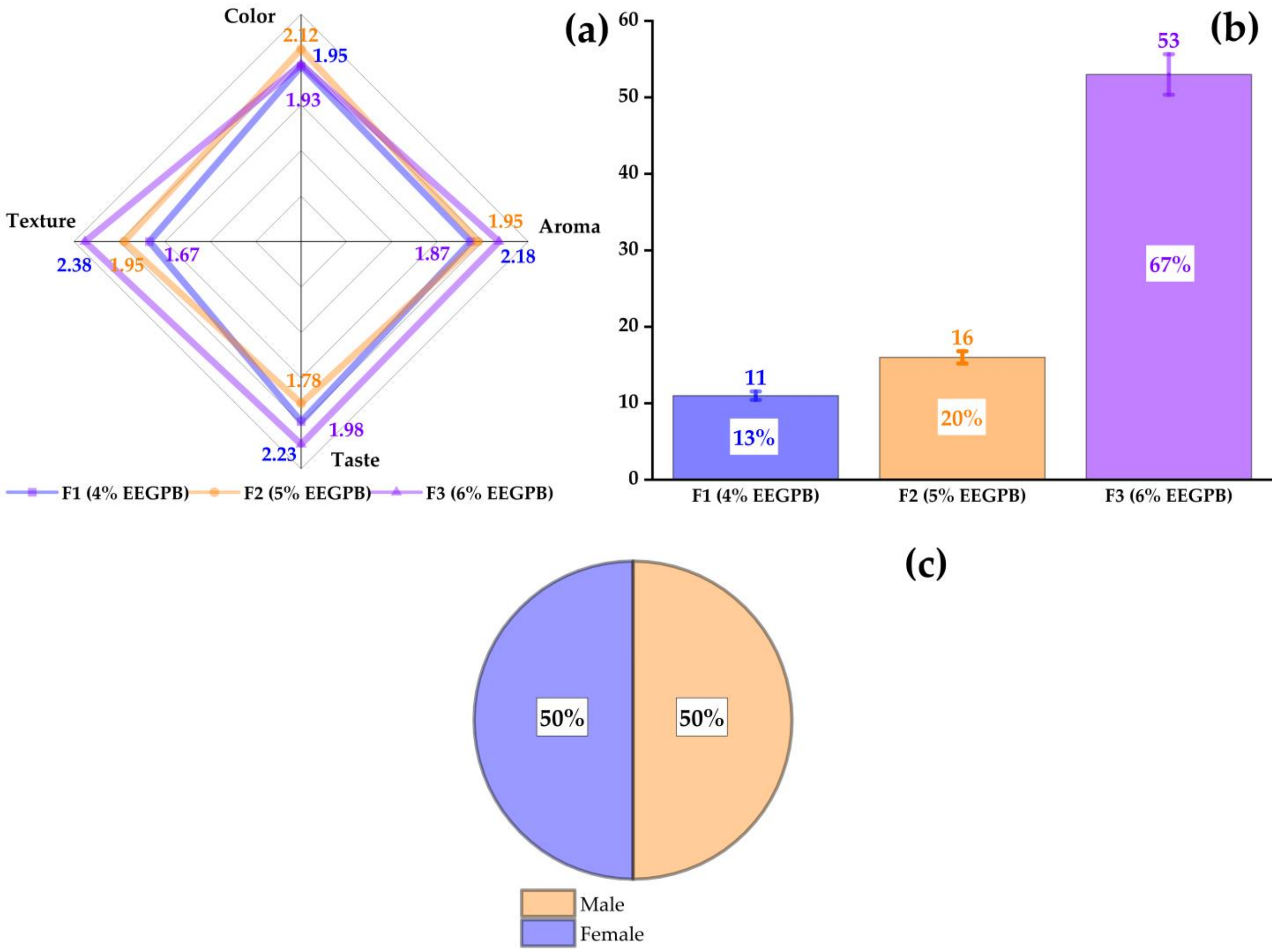

Figure 4. (**a**) Acceptability scores for color, aroma, taste, and texture; (**b**) preference test results (% of participants favoring each formulation); (**c**) gender distribution of the sensory panel.

PCA revealed that F3 clusters in the positive region of PC1 are associated with high soluble solids, carbohydrates, protein, iron, pH, and sensory attributes such as texture, aroma, and flavor. These results reinforce that this formulation has a superior profile in nutritional quality and sensory acceptability. On the other hand, F1 (4% EEGPB) is positioned in the negative region of PC1, standing out for its higher moisture content, lightness (L^*), and chroma b^*, which could be related to a softer texture and lower solid concentration.

F2 occupies an intermediate position in the graph, showing a balance between the characteristics of F1 and F3. It is moderately associated with variables such as color and fiber, suggesting that it presents a stable structural matrix and acceptable sensory attributes but without reaching the levels of nutrient concentration and sensory quality observed in F3. This balance makes it a viable alternative, especially for applications where a balanced formulation regarding nutritional and physicochemical properties is a priority. In addition, the analysis showed that moisture and lightness are negatively correlated with variables such as iron, soluble solids, and protein content, indicating that an increase in one of these physicochemical characteristics implies a decrease in the others. This negative correlation reflects the influence of EEGPB content on the balance between sensory and nutritional properties. Finally, the PCA identified F3 as the most suitable formulation, given its balance between physicochemical and sensory properties. This finding suggests that increased EEGPB concentration improves nutritional attributes and product acceptance.

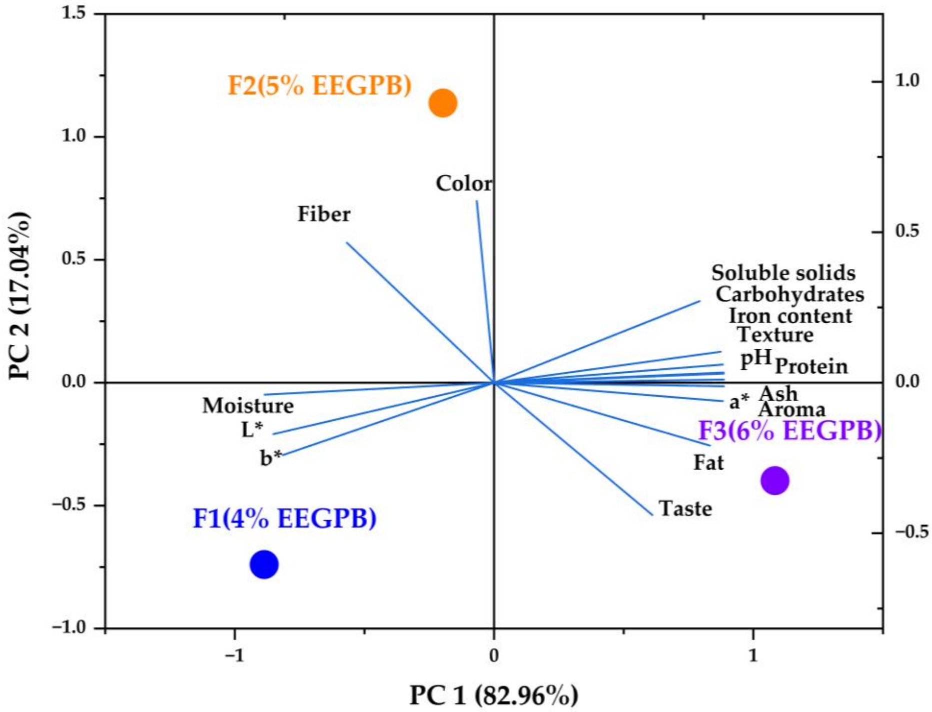

Figure 5. PCA (F1, F2, and F3 are the formulations).

According to the recommended daily iron intake, the dose for adults is 100–200 mg/day, while for children, it is approximately 3–6 mg/kg/day [61]. In one study, children ingested one gummy with heme iron (5 mg of elemental iron) each daily for 21 days. The results showed a significant increase in hemoglobin levels in all groups of participating children, and 93.9% of the children were no longer anemic at the end of treatment [62]. Thus, to meet their daily iron needs, a child would need between 6 and 7 gummies per day, depending on their weight and the specific doses of iron needed to meet their daily requirements.

4. Conclusions

This study confirmed that the microencapsulation of guinea pig blood erythrocytes by vacuum drying effectively improves the nutritional and sensory properties of gummies fortified with tumbo juice. The higher the concentration of encapsulated erythrocytes, the lower the moisture content and the higher the protein and iron content, validating its viability for fortifying functional foods. Formulation F3 (6% EEGPB) stood out for its acceptability in terms of taste, aroma, and texture, underlining the positive impact of encapsulation on organoleptic properties. FTIR analysis demonstrated the absence of chemical interactions, recommending further studies to evaluate its long-term stability.

While this work demonstrated the feasibility of incorporating encapsulated erythrocytes into gummy candies as an innovative strategy for food fortification, future studies could explore their stability during storage and iron bioavailability to further validate their nutritional impact. Although this study focused primarily on the sensory and nutritional evaluation of the product, future research will address additional aspects such as texture analysis, stability under industrial conditions, and optimization of formulations to improve shelf life. Sensory perception in more diverse demographic groups will also be explored to ensure that a product design is adaptable to different markets.

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