Valorization of prickly pear seeds in the formulation of biscuits: modelling of consumer acceptability by regression analysis and artificial neural networks

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Introduction

The prickly pear (Opuntia spp.) grows spontaneously and in recent years, intensive prickly pear plantations have emerged. Indeed, several companies have emerged that specialize in the trade of products from the prickly pear selling mainly jam from the fruit, dried flowers, cladodes powder and seeds oil. Prickly pear is gaining more and more interest and several scientific studies attempt to enhance the fruit, the skin, the cladodes, the flowers and the seeds. Fruit and vegetable wastes represent good source of dietary fibre due to high dietary fibre content, being inexpensive, and having high water binding capacity and relatively low enzyme digestibility. When comparing seeds, juice, pulp and cladode, from the same plant, the seeds are the best source of micro and macroelements, nutritional compounds and fibers.
The seeds of *Opuntia ficus indica* variety particularly, present high levels of proteins. An antioxidant effect for two protein fractions extracted from the PPS press cake (albumin and glutelin) was reported. PPS are a waste that can be valorized in food products

The increased interest of consumers for healthy food encourages the development of enriched food supplemented with natural products having beneficial effect for health. Cereals represent a principal source of nutrients for human diet providing essential macronutrients (carbohydrates, proteins, minerals, fat, vitamins) and micronutrients. Indeed in 2020 the quantity of consumed cereals was estimated about 2744.4 million tons (FAO, 2020)*. Baked cereal products and particularly biscuits are widely consumed due to their long shelf life offering the possibility to be stored for long periods, in addition that they serve as staple food that can be declined in different forms, tastes and textures.

This study aims to explore the ability of prickly pear seeds (PPS) to partially replace wheat flour in the biscuit formulations at different percentages. The incorporation of PPS (considered as a waste) into biscuit diminishes the fiber intake deficiency and considerably increases the level of proteins and polyphenol contents.
The overall acceptability of the biscuit was evaluated by panelists. A mathematical model was used to analyze the biscuit acceptability by multiple linear regression analysis (MLR) and artificial neural networks (ANN).

*FAO .2020. FAO Cereal Supply and Demand Brief.http://www.fao.org/worldfoodsituation/csdb/en/ Assessed in 03/12/2020

Methodology

1- **Biscuits preparation**:

The biscuit samples were prepared at the laboratory scale with: wheat flour (100 g), crystal sugar (25 g), shortening (30 g), glucose (1g), salt (1g), sodium bicarbonate (1g) and tap water (20 g).
The biscuits were prepared with different levels of prickly pear seeds (PPS) and Wheat Flour (WF):
Control 0 : 100 (PPS :WF), 5 : 95 (PPS :WF), 10 : 95 (PPS :WF), 15 : 85 (PPS :WF) and 20 : 80 (PPS :WF).

2- **Physico chemical analyses of biscuits**:

- Crude composition: the formulated biscuit samples were analyzed for their proximate composition (moisture, ash, protein, fiber and fat) using the AOAC procedures (AOAC, 1995). Soluble sugars were determined according to the method of Dubois et al. (1956).
- Mineral composition: samples were ignited and incinerated in a muffle furnace at 550 ° C for 8h according to the method of AOAC (AOAC, 1995). The ashes were dissolved in HNO3 and the mineral constituents (Ca, Fe, P, and Mg) and (Fe, Cu, Zn, Mg and Ca) were determined for biscuit samples by using an atomic absorption spectrophotometer (Hitachi Z-6100, Japan).
- Color measurements: The color of biscuits was measured with the Chroma Meter CR 300 (Minolta, Japan). Measurements were performed directly on biscuit and the L*, a* and b* values were determined. A glass plate was placed over the light port of the apparatus and was standardized using black and white reference. The L*, a* and b* values indicate lightness (0 = dark, 100 = white), redness (+60 = red, −60 = green), and yellowness (+60 = yellow, −60 = blue), respectively.

3- **Sensory analysis:**

The formulated biscuits were subjected to sensory evaluation. An initiated jury (familiar with sensory analysis) of 30 people (12 men and 18 women aged from 19 to 50) is recruited, judges are healthy and non-smoking. This jury has evaluated samples at an hedonic angle. The visual appearance (color), the taste, aroma, chewiness, crispiness and the overall acceptability of the product.
The sensory analysis was performed at room temperature, on discontinuous scales graduated from 1 to 9 (9 = extremely like; 1 = extremely dislike). During the session, each judge received 5 biscuits corresponding to the control and the 4 formulated biscuits with PPS supplementation at 5, 10, 15 and 20 %. The samples with random three digital codes were presented in white plates. Panelists were instructed to cleanse the palate with water between each sample.
The obtained results were analyzed by multiple linear regression and artificial neural network to explore the importance given by consumers to the percentage of seeds added and the different attributes: color, aroma, chewiness, crispiness and taste on overall acceptability of biscuits.

4- **Mathematical models**:

- Principal component analysis: PCA was used to analyze responses of consumers by extracting the important information from the data and express it as a set of new orthogonal variables (principal components). The PCA of sensory attributes was realized using Origin Pro 9.1. The Pearson correlation coefficients (which is a statistical method for quantifying the association between two variables) were used to calculate the correlations between variables.

Multiple linear regression:
The MLR was used in order to estimate the variable effects involved in the model. Overall acceptability was the response variable and the six sensory attributes were predictor variables. The success of MLR was measured by evaluating the determination coefficient R^2, the residual standard error (RSE) for the regression and the result of the student's t test results for the individual variables

Artificial neural networks:
ANN are a powerful analytical tool offering the advantage to present diverse network topology, fast and flexible learning algorithm leading to more sophisticated applications in food science particularly in sensory analysis. To modulate ANN, Neutral Network module of STATISTICA 8.0 was used. In the network, there were six inputs (the color, the percentage of seeds, the aroma, the chewiness, the crispiness and the taste) and one output (overall acceptability). In order to measure the performance of ANN model, the coefficient of determination (R^2) was calculated.

Results

Photos of the formulated biscuits

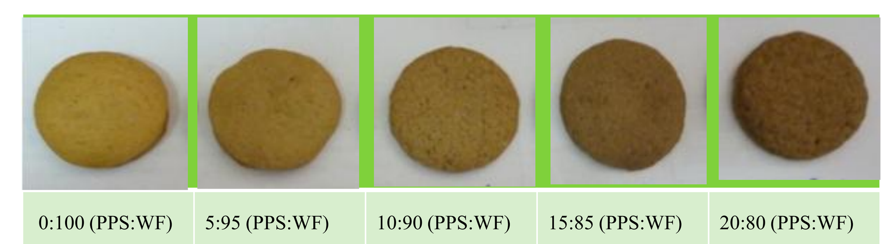

Table 1: Physical, chemical, and minerals parameters of biscuits with different levels of prickly pear seeds (PPS)

Properties	PPS content (g/100 g) used in the formulation of biscuit samples				
	0	5	10	15	20
Diameter D (mm)	45.12 ± 0.20 (a)	45.04 ± 0.30 (a)	43.92 ± 0.50 (ab)	42.88 ± 0.30 (c)	41.36 ± 0.60 (bc)
Thickness T (mm)	19.50 ± 0.05 (a)	19.30 ± 0.05 (b)	19.20 ± 0.08 (c)	19.90 ± 0.04 (d)	19.80 ± 0.06 (e)
Spread ratio (D/T)	2.31 ± 0.00 (a)	2.33 ± 0.01 (a)	2.29 ± 0.02 (a)	2.15 ± 0.01 (b)	2.09 ± 0.02 (b)
Weight (g)	5.40 ± 0.21 (a)	5.50 ± 0.23 (b)	5.60 ± 0.15 (bc)	5.80±0.24 (cde)	5.80 ± 0.16 (ef)
ΔE*	----	10.26±3.43(a)	14.56±1.81(b)	18.14±1.08(c)	22.75±3.69 (d)
Moisture (g/100 g)	6.29 ± 0.12 (a)	6.96 ± 0.13 (b)	7.22 ± 0.23 (c)	6.52 ± 0.04 (d)	7.05 ± 0.20 (bd)
Fat (g/100 g)	16.97 ± 0.45 (a)	17.3 ± 0.77 (a)	17.95 ± 0.18 (a)	18.79 ± 0.47 (ab)	19.60 ± 0.28 (c)
Protein (g/100 g)	7.48 ± 0.15 (a)	7.29 ± 0.13 (b)	7.57 ± 0.11 (a)	7.93 ± 0.17 (ac)	8.57 ± 0.12 (c)
Soluble sugar (g/100 g)	9.50 ± 0.57 (a)	9.70 ± 0.48 (a)	10.8 ± 0.55 (ab)	11.10 ± 0.47 (bcd)	12.20 ± 0.44 (bef)
Polyphenolics (mg GAE/100g)	127 ± 2.08 (a)	135 ± 1.35 (b)	170 ± 1.95 (c)	174 ± 0.07 (d)	185 ± 4.76 (cde)
Water activity	0.19 ± 0.00 (a)	0.23 ± 0.00 (b)	0.25 ± 0.00 (c)	0.21 ± 0.00 (d)	0.24 ± 0.00 (e)
Fe (mg/100 g)	1.51 ± 0.06 (a)	1.64 ± 0.02 (b)	1.86 ± 0.07 (bc)	1.89 ± 0.10 (bc)	1.90 ± 0.13 (bc)
Cu (mg/100 g)	0.84 ± 0.03 (a)	0.78 ± 0.02 (b)	0.80 ± 0.03 (b)	1.18 ± 0.05 (c)	1.27 ± 0.03 (c)
Zn (mg/100 g)	1.25 ± 0.06 (a)	1.10 ± 0.10 (b)	1.06 ± 0.12 (b)	1.14 ± 0.09 (ab)	1.01 ± 0.04 (b)
Mg (mg/100 g)	50.01 ± 1.32 (a)	60.44 ± 1.70 (b)	64.97 ± 2.53 (b)	82.90 ± 1.51 (c)	86.50 ± 3.10 (c)
Ca (mg/100 g)	47.06 ± 3.00 (a)	51.98 ± 3.93 (a)	72.21 ± 4.37 (b)	88.20 ± 4.06 (b)	97.22 ± 4.74 (c)

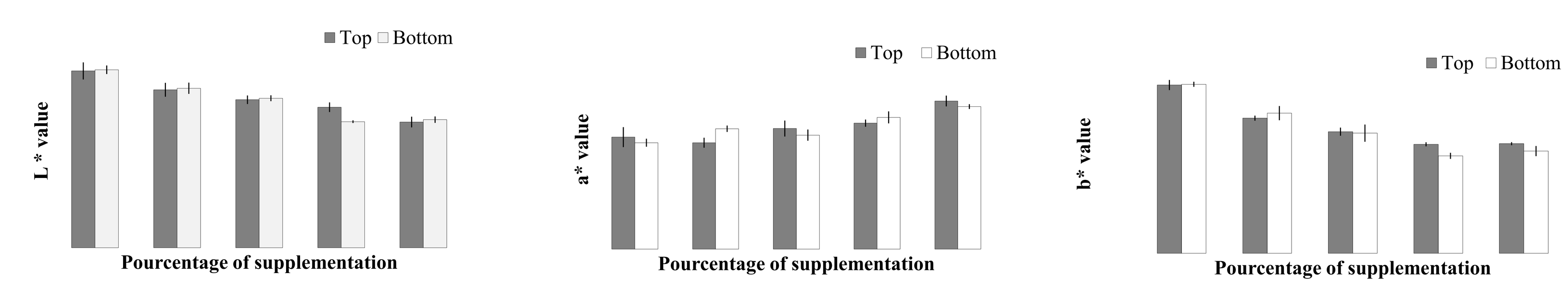

Figure 2 : Evolution of L*, a*, and b* values of biscuits formulated with different levels of prickly pear seeds at top and bottom.

Table 2 : Sensory characteristics of biscuits of biscuits formulated with different levels of prickly pear seeds (PPS).

Sensory attributes	PPS content (%) used in the formulation of biscuit samples				
	0	5	10	15	20
Color	6.42 ± 0.81 (a)	6.48 ± 0.38 (a)	5.29 ± 0.58 (a)	5.55 ± 0.76 (ab)	5.06 ± 0.84 (ac)
Crispiness	5.81 ± 0.21 (a)	6.00 ± 0.98 (a)	5.52 ± 0.96 (a)	5.94 ± 0.67 (a)	6.32 ± 0.74 (a)
Aroma	5.45 ± 0.22 (a)	5.35 ± 0.43 (ab)	4.74 ± 0.44 (cd)	5.23 ± 0.50 (ad)	5.55 ± 0.48 (ade)
Chewiness	6.29 ± 0.70 (a)	6.39 ± 0.80 (a)	5.52 ± 0.03 (ab)	6.55 ± 0.93 (a)	5.87 ± 0.02 (ac)
Taste	5.94 ± 0.08 (a)	5.84 ± 0.40 (a)	5.83 ± 0.42 (ab)	6.52 ± 0.52 (ac)	6.68 ± 0.41 (a)
Overall acceptability	6.31 ± 0.65 (a)	4.03 ± 0.58 (bc)	5.19 ± 0.78 (de)	6.71 ± 0.55 (ace)	6.23 ± 0.83 (ace)

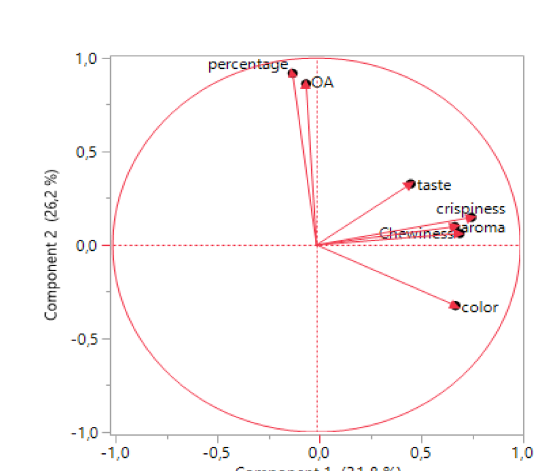

Figure1: Circle of correlations based on sensory parameters and percentage of seed incorporation

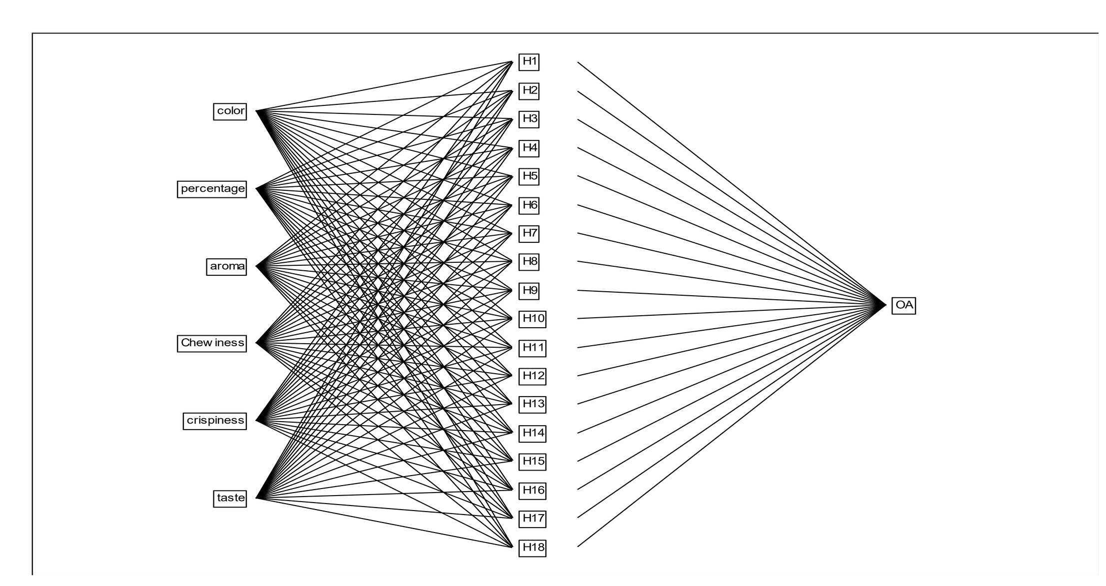

Figure 2 : Graphical representation of the artificial neutral network of the overall acceptability (OA) with respect to color, percentage of seed incorporation, aroma, chewiness, crispiness and taste

Conclusion

The results of this research suggest that replacing wheat flour with PPS led to a notable increase in the protein and polyphenol levels within the biscuits. Alterations in color and sensory characteristics were also detected. Furthermore, the diameter and spread ratio decreased, while the thickness increased as the proportion of PPS in the biscuits was raised. Biscuits of acceptable quality were produced when wheat flour was substituted with 15% PPS.

Future research could investigate how replacing wheat with 15% PPS affects biscuit shelf life. The phenolic compounds in PPS might extend shelf life due to their antioxidant properties, but this requires verification.

The artificial neural network (ANN) technique predicted overall acceptability more accurately (R^2=99.16%) than multiple linear regression (MLR) (R^2=67%) based on mathematical analysis. These statistical methods could be used to improve product processes by predicting consumer preferences.

Therefore, a part from their nutritional value, PPS can be used for technological purposes as food additive.

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