PHYSICOCHEMICAL CHARACTERIZATION OF MIXTURES OF CORN GRITS AND AMARANTH FLOUR EXPANDED BY EXTRUSION-COOKING

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ABSTRACT

The amaranth seed is more nutritionally rich than other cereal as corn grits, wheat, and rye. Amaranth can be presented in different formats, such as grains, flakes, seeds and flours. The flours can be used in cakes or pancakes preparation or to add to yogurt or milk, for example. Additionally, amaranth is a gluten-free pseudo cereal, rich in good quality proteins, fibers, vitamins, and minerals such as calcium and zinc, providing excellent health benefits when included in a healthy and balanced diet. This study aimed to evaluate the effects of amaranth flour incorporation (F: 20, 30, and 40%), extrusion temperature (T: 140, 160, and 180 °C), and processing moisture (M: 14, 16, and 18%) on the physicochemical properties and antioxidant activity of extrudates based on corn grits. AF showed higher values of free radical inhibition (ABTS = 18.11 μm Trolox mg^{-1} and DPPH = 4.19 μm Trolox mg^{-1} for $TEAC_0$, than CG 1.65 μm Trolox mg^{-1}, and DPPH = 0.23 μm Trolox mg^{-1}). Among the physicochemical properties studied, the results show possibilities of use for drinks, soups, and porridges, among other alternatives.

INTRODUCTION

Amaranth (*Amaranthus cruentus*) is a gluten-free pseudo cereal, rich in good quality proteins, fibers, vitamins, and minerals such as calcium and zinc, providing excellent health benefits when included in a healthy and balanced diet. Several studies have reported their properties regarding the health benefits, such as anti-inflammatory activity (SANDOVAL-SICAIROS *et al.*, 2021), anticancer, anticholesterol, antioxidant, and antimicrobial peptides (MOYER *et al.*, 2021). Amaranth has excellent potential to become a valued crop and is successively integrated into traditional farming systems and in different regions of the world. It is proclaimed as the future food, with a relevant role in human nutrition, for its ease of cultivation, possibilities for agricultural and commercial use, and for being a source of nutrients from both the grain and the vegetative parts. The high concentration of squalene in its composition, a substance only found in significant amounts in the liver oils of marine animals, is a unique characteristic of amaranth. Its natural properties include antioxidant action in the fight against free radicals. With a shape and consistency similar to oatmeal, amaranth can be consumed with fruit and yogurt for breakfast, and as an ingredient in bread, cakes, candies, soups, and smoothies, among other sweet and savory dishes. As a way to facilitate the preparation of this pseudocereal, extrusion cooking is used in combination with corn grits to produce nutritionally balanced products, as only a few studies have been reported on extrusion cooking of amaranth alone or in combination with other grains.

According to SAUNDERS e BECKER (1983), the limiting amino acid in amaranth is leucine, followed by threonine. This characteristic is not inconvenient, because leucine is present in excess in most cereals. This result was partially confirmed in studies carried out by CHÁVEZ-JAUREGUI (1999), CHÁVEZ-JÁUREGUI e AREAS (1998) where they showed that the *Amaranthus caudatus* species has leucine as a limiting amino acid.

A common factor among the three most studied species is the high lysine content and sulfur amino acids compared to the standard FAO/OMS/WHO (1985).

OBJECTIVE

The objective of this work was to process, by extrusion, mixtures of different proportions of corn grits with amaranth flour, followed by the corresponding physical-chemical characterization and application possibilities.

RESULTS AND DISCUSSION

It is well known that corn grits, originating from hard or semi-hard corn, is one of the ingredients that best behave in terms of expansion during extrusion. This ingredient forms a major part of the expanded products of various snacks and expanded breakfast cereals available on the market. On the other hand, amaranth is a pseudocereal, when extruded as a whole it expands at good levels, but not with the same results as corn grits. In addition to considering that it is integral, the composition, on average, of the amylose content of this pseudocereal can be between 4.5 to 7.5%. Expansion may have influences, based on studies already carried out, in which significant differences are shown between starches with proportionality equivalent to that of normal corn, and the so-called waxy ones. On the other hand, it is also known that they have a lower tendency to retrograde, which suggests that they would have better conditions to overcome the aging of the products produced. In this sense, these characteristics may influence the retrogradation properties, according to the degree of substitution. Higher percentages, as in formulations containing amaranth flour, would have lower degrees of retrogradation. Table 1 presents the different experimental results of the physical properties of the different trials. Apparent density (APD), expansion index (EI), water absorption (WAI) and solubility (WSI), paste viscosity (V_{inic}, V_{max}, and V_{end}), and color profile (L, b, and ΔE) of the extrudates. A certain degree of correlation is observed between these results, such as denser products, corresponding to treatments with higher moisture content, and lower temperature, therefore, they expand less. However, they may have a higher WAI and lower WSI. In the case of viscosity, the lowest value of V_{inic} at 25 ºC was reached at a temperature of 140 ºC, with 14% moisture and 40% amaranth in its formulation, reaching a value of 99 cP, and a V_{max} was at a temperature of 180 ºC, with 18% of moisture, and 20% of amaranth in its formulation, reaching a value of 826 cP.

The work by SIWATCH *et al.* (2019), presented similar viscosity values for AF. These results show that the extrusion process adopted in the different treatments significantly modified the structure of the starch granules. Because of the differences between the treatments, some can be directed to use in the formulation of drinks, others for the preparation of soups or porridges for instant preparation. The degree of contribution of micro and macronutrients from maize and amaranth will be related to the degree of replacement of AF in the CG. In this sense, due to the properties found regarding the functional properties, was consider, according to the results presented in the experimental design, there are tests that have high solubility properties, others, on the contrary, with good levels of water absorption, allowing the possibility of using in the preparation of drinks, porridges or instant soups, respectively.

Table 1. Results of the characterization of extrudates made with blends of whole meal amaranth flours (AF) and corn grits (CG).

Trial	Experimental design					Responses							
	T	M	F	APD	EI	WAI	WSI	V_{inic}	V_{max}	V_{end}	L	b	ΔE
	°C	%	%	g/cm^3		g/g	%	cP	cP	cP			
1	140	14	20	0.17	3.12	7.12	11.26	252	375	562	80.44	13.66	16.12
2	180	14	20	0.15	1.90	5.70	9.72	216	435	953	82.27	13.72	14.78
3	140	18	20	0.19	3.10	9.52	8.77	338	412	481	77.94	15.22	18.16
4	180	18	20	0.26	1.90	8.68	9.76	826	923	812	80.66	13.22	15.69
5	140	14	40	0.48	1.61	3.84	7.44	99	347	816	78.40	14.62	18.12
6	180	14	40	0.38	1.21	4.96	8.38	119	479	945	76.70	15.89	15.88
7	140	18	40	0.16	2.30	7.41	22.15	175	293	345	75.59	16.32	21.26
8	180	18	40	0.20	1.69	6.38	17.90	255	395	831	76.67	16.15	20.32
9	160	16	30	0.20	2.41	6.70	13.29	511	588	585	78.24	14.74	18.22
10	160	16	30	0.21	2.42	6.60	12.99	513	560	597	78.88	15.51	19.77
11	160	16	30	0.22	2.89	6.22	12.17	460	573	582	76.67	15.25	19.70
12	160	16	30	0.21	2.68	6.58	10.18	426	450	583	78.64	14.86	17.77
13	126.3	16	30	0.15	3.11	7.62	22.19	221	321	472	80.14	13.96	16.21
14	193.6	16	30	0.21	1.36	6.31	14.57	219	458	943	79.35	14.55	17.31
15	160	12.6	30	0.56	1.46	5.38	10.83	288	571	1095	77.49	15.70	19.24
16	160	19.3	30	0.23	1.99	8.90	10.98	354	515	472	76.85	15.66	19.73
17	160	16	13.1	0.19	2.62	7.25	12.94	606	708	946	82.79	12.79	13.69
18	160	16	46.8	0.70	1.30	5.91	11.90	122	451	948	74.10	16.42	22.40

T: processing temperature (°C); M: processing moisture of the mixture (%); F: amaranth flour incorporation (% amaranth in the mixture with corn grits); APD: apparent density (g/cm^3); IE: expansion index; WAI: water absorption index (g. gel/g dry matter); WSI: water solubility Index (%) ;V_{inic}: initial viscosity at 25°C (cP); V_{max}: maximum viscosity at 95 °C (cP); V_{end}: final viscosity at 50 °C (cP); L: brightness (white/black); a: chromaticity (green/red); b: chromaticity (blue/yellow); ΔE: total color difference. Central points of T9 to T14.

Table 2 presents the results of the proximal composition of amaranth flour (AF), and corn grits (CG) and of four treatments that were selected according to physical properties and possible applications. Regarding the AF, the high protein value that this flour has is verified. Several studies have shown similar results, both for protein and in the quality of the amino acids, it contains, which has attracted the attention of researchers around the world. (MENEGASSI *et al.*, 2011; RAMSOOKMOHAN *et al.*, 2020). According to ADERIBIGBE *et al.* (2022), the protein of *A. cruentus* species has a high content of sulfur-containing amino acids which include methionine, and cysteine, making it a good combination with cereals that can be used for the formulation of complementary food and expanded products, which after grinding and subsequent formulation with other flours, can form part of foods with important nutrition value.

Referring to the results of the antioxidant activity shown in Table 2, there are convergent reaction profiles. Higher values were estimated by extrapolation to zero sample concentration ($ABTS_0$) and this technique includes the largest portion of reactive substances compared to the other methods. The estimated TEAC (Trolox Equivalent Antioxidant Capacity) in the DPPH method was lower for the tested extracts, which was probably caused by incomplete involvement in the reaction of active compounds in other methods. In studies carried out by TANG *et al.* (2016), for amaranth, values of similar varieties were found from DPPH that were between 2.5 to 4.5 (μm Trolox mg^{-1}), for ORAC between 2.3 to 4.5 (μm Trolox mg^{-1}). According to Tang, et al. (2016), the average

DPPH, FRAP, and ORAC activities were 3.50 μmol of TE/g, 4.59 μmol of AAE.g^{-1}, and 4.43 μmol of TE.g^{-1} for amaranth seeds, respectively.

Table 2. Proximal composition and antioxidants of whole meal amaranth flours (AF), corn grits (CG), and mixed flours pre-cooked by extrusion.

Component	AF	CG	Flours selected from the best test			
			T1	T7	T13	T16
Protein (%, db)	17.51	8.81	10.38	12.41	10.99	11.76
Lipids (%, db)	4.54	0.52	0.46	0.77	0.64	0.65
Ash (%, db)	2.60	0.88	0.97	1.39	1.25	1.21
Total fiber (%, db)	10.38	0.72	1.65	1.46	1.79	1.25
Carbohydrates (%) *	65.99	88.05	86.54	83.97	85.33	85.13
Caloric value (kcal) **	370.72	397.02	391.80	392.45	391.00	393.41

	Amaranth flour blended with corn grits extruded antioxidant activity			
Component	AF (Raw)	AF (Extruded)	CG (Raw)	T7
ABTS (6 min) ***				
$TEAC_0$	18.11 ± 1.28	19.10 ± 1.15	1.65 ± 0.18	17.69 ± 1.13
$TEAC_{50}$	8.11 ± 1.73	7.19 ± 1.83	0.75 ± 0.18	9.69 ± 1.25
DPPH (24 h) ***				
$TEAC_0$	4.19 ± 0.23	4.36 ± 0.54	0.23 ± 0.18	2.87 ± 0.53
$TEAC_{50}$	3.59 ± 0.15	3.12 ± 0.23	0.19 ± 0.15	2.84 ± 1.23

db: dry basis; T1: trial 1 (T = 140 °C; U = 14% e F = 20:80); T7: trial 7 (T = 140 °C; U = 18% e F = 40:60); T13: trial 13 (T = 126.3 °C; U = 16% e F = 30:70); T16: trial 16 (T = 160 °C; U = 19.3% e F = 30:70). * Carbohydrates = 100 – (protein + lipids + ash + total fibers). ** Caloric value. kcal/100 g (without fiber). *** in μmol Trolox/kg (n = 4 - 5); $TEAC_0$: Trolox Equivalent Antioxidant Capacity. Extrapolated to zero sample concentration; $TEAC_{50}$: Trolox Equivalent Antioxidant Capacity interpolated to 50% inhibition (IC50 equivalent).

CONCLUSIONS

The extrusion process is an excellent tool to process amaranth and possible mixtures gluten-free, with cereals, such as corn grits, which resulted in an excellent combination, offering alternatives, according to the treatment with the moisture and process temperatures, in very soluble products, and others with good levels of water absorption for use in porridges or instant soups. Amaranth is rich in nutritional contents and bioactive compounds; it has huge relevance for domestic and industrial applications. It is a culture with great perspective for the countries of North America, Central America, and South America, obviously, from the lands of origin, all of Africa. Mainly to fight malnutrition. However, despite its millenary existence, its full potential has not yet been explored. There is a need for focused and continuous exercises in research and coordination of all parties as stakeholders for the implementation of the relevant actions.

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