EFFECT OF HEAT TREATMENT AND MILLING ON THE SEED, FLOUR, RHEOLOGY AND BAKING QUALITY OF SOME AMARANTH ECOTYPES[1]

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SUMMARY

Forty-five harvests corresponding to the two predominating domestic species of amaranth in Mexico were studied. The proximate analysis revealed some statistically significant diffrences throughout three years of observation.

The Ca, P and Fe content did not vary greatly in 15 samples. No chemical differences were either manifested in the Mercado and Aztec types of *A. hypochondriacus*, nor in the Mexican type of *A. cruentus*. The latter exhibits a higher grain yield and a shorter life cycle; however, its baking quality is apparently inferior to that of the Mercado type of *A. hypochondriacus*.

The heat treatment of the seeds (toasting, popping and cooking) affected protein and lysine contents as does in cereals and leguminous seeds although toasting in particular improves its sensory characteristics without altering digestibility and PER. Popping only improves PER. Heating at 90 or 170°C for three to five minutes, at the usual seed's moisture rate of 6 to 15o/o, does not affect protein content and does so only slightly in the case of the fatty acids content. Amylographic and farinographic values of the starchy fractions indicate similarities to *C. quinoa* and differences with respect to wheat. In the case of "amaranth milk", viscosity and gelatinization temperature produced satisfactory values.

The extension of amaranth cultivation in the country is hereby suggested in view of the seed's nutritional quality, and considering the behavior of whole amaranth flour and its fractions.

Manuscrito modificado recibido: 8—5—85.

1 Financial support for this research was kindly provided by the U. S. National Academy of Sciences/National Research Council, through a grant-in-aid from the U.S. Agency for International Development.

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3 CONACYT-Mexico scholarship, 1982-83.

INTRODUCTION

The extraordinary alimentary quality of the *Amaranthus* genus has been discussed in two seminars held in Pennsylvania, both under the auspices of the Rodale Research Center (RRC) (1, 2), as well as in recent studies (3-5). This grain once constituted one of the most important nutritional sources among the Aztecs (6). Nowadays, however, only about 300 hectares are cultivated in Mexico, with two domestic species prevailing: *A. cruentus* and *A. hypochondriacus*. *A. hybridus*, better known by the varnacular name of "quintonil", is also grown, although in a lesser proportion, and it is used for soup and pottage preparation. The distinctive characteristic of these species lies in their high tolerance to arid conditions in which cereals usually render low productions. Although 90-day selections are now available, their biological cycle generally oscillates between 130 and 156 days.

The present paper deals with the observations that were carried out between 1980 and 1982 in field harvesting; it is concerned with the main characteristics of the seeds of these two predominant species. Further on, this paper will also deal with the effect of heat treatment on seeds, as has been done by other researchers (7-9).

The derived estimations, compared to the improved varieties developed by the Rodale Research Center (RRC) in Kutztown, Pennsylvania, shall be dealt with in another paper.

MATERIALS AND METHODS

Crops

A. hypochondriacus and *A. cruentus*, the two main species of seeds which predominate in Mexico, were harvested. Unfortunately, both of them are commonly found intermingled between themselves and *A. hybridus*. Harvesting was subjected to quick selection tests, mainly based on the grain's yield of more than 1,000 kg/hectare in rain-fed conditions, on its 130 to 156-day vegetative cycle, and its white or yellow seed with a minimal 13o/o protein content.

The initial 21 harvests which corresponded to the 1980 cycle were sown in May and reaped in either October or November, originating from the States of Puebla, Morelos, Oaxaca and Mexico. Twenty-four more lines were harvested in these same areas during the 1981-1982 cycle, undergoing, along with the former, chemical analyses and statistical evaluation of results. Species were identified according to Sauer's (10) and Feine's (11) keys.

Seeds

Farmers had exposed the seeds to sunlight for some hours and then stocked them at room temperature without any preservation problems. According to the employed quantity, the seeds were cleaned either mechanically, by the McGill rice cyclone, or manually. Some of the samples were ground in a CeCoCo mill in order to obtain whole flours for bread-baking tests and for the preparation of "amaranth milk" (a 10 g suspension of a mixture of amaranth flour and powdered milk in 100 ml of water). The amyloprotein fraction of the seed (perisperm) was also separated by a Strong-Scott pearler according to the method suggested by Betschardt *et al.* (8), as was the fraction with the highest concentration of protein (testa plus embryo). These fractions were also separated in a Raymond Laboratory Separator, Model 10, with a 5 to 25 kg/hr capacity and 6 to 12 reel whizzers.

The seeds' characteristics of *A. cruentus* and *A. hypochondriacus* were then compared by means of the RRC's established criteria. A Bartlett-Snow Pacific calcinator, type Pilot Plant Work K-4830 and operated at 90 and 120°C for 5 and 10 minutes was employed for toasting the seeds, while the popping procedure required the use of a device designed by the RRC, which operates at 150 to 200°C during 15 seconds.

Selections 3, 7, 8, 9 and 12 of *A. cruentus* were employed for these tests and for chemical composition studies. Lysine was appraised through the method of Tsai, Hansel and Nelson (12), and tryptophan by that of Knox *et al.* (13). Particularly in the case of harvest 12 of *A. cruentus*, the combined effects of moisture, temperature and time were studied as well as the heat treatment of the seed with respect to digestibility, and protein efficiency ratio (PER) by means of 55 g Sprague-Dawley rats, following the usual AOAC methods (14).

Analysis

The proximate analysis of all samples was performed employing the AOAC methods (14). Protein values are expressed as N x 6.25, and carbohydrates by difference, on proximate analyses values. Duplicate samples were used in all determinations and results expressed in mean values on a moisture-free basis, unless otherwise indicated.

When needed, statistically significant differences were applied by the Duncan's multiple range test (15). Viscosity of "amaranth milk", prepared with whole amaranth flour, was determined by means of a Brookfield synchroelectric viscosimeter, type RVT. The perisperm's starchy fraction's viscosity and the gelatinization temperature were both determined using a Brabender OHC Duisburg viscoamylograph; they were then compared to wheat and *Chenopodium quinoa* starch. The rheological properties were appraised in a Brabender farinograph. Calcium and iron determinations required AOAC methods (14), while phosphorus was established following the Fiske and Subbarow procedure (16). The measurement of fatty acids was carried out with a Perkin-Elmer Sigma 115 gas chromatograph (Perkin-Elmer, Handbook on Standard Conditions, 1973), by extracting samples with 2:1 chloroform-methanol and employing diethyl-glycol-succinate columns at 5% as well as a flame detector; temperatures reached 220°C in both the detector and ingestor and 180°C in the column. Bread-baking tests were carried out according to the AACC's methods (17).

Water absorption capacity was estimated in the isolated starchy fractions by applying the Medcalf and Gilles' procedure (18); Leach, McCowen and Scherch (19), were referred to for determining the swelling power and solubility, and Schoch and Maywald (20) for the gelatinization temperatures. Previous to analytical determinations, all samples were milled in an Alpine pin mill.

RESULTS AND DISCUSSION

Table 1 shows the presence of a certain variation in the results of both proximate and statistical analyses of crops harvested in 1980 and 1981. Protein values varied from 12.93 to 17.35o/o; fat, from 3.35 to 9.11o/o; raw fiber, from 3.91 to 9.22o/o and ash, from 1.09 to 4.99o/o whereas moisture just varied a little. The statistical analysis revealed significant differences as to protein content between the 1980 and 1981 crops. Fatty contents, on the other hand, were only significant in two of the samples, whereas raw fiber, ash and carbohydrate values underwent the most significant variations in 1981; moisture values were constant throughout both years. These facts cannot as yet be satisfactorily explained. The specific differentiation indicated the prevalence of *A. cruentus* with a 130-150-day cycle. Nevertheless, some selected 1982 samples corresponded to *A. hypochondriacus* with a maturation cycle of 120 days, equivalent to RRC 1122-1124 codes, as opposed to those from 1980 and 1981, belonging to the same species but with a longer than 150-day cycle.

Fifteen lines obtained from those stocked in 1980 for two years were taken for calcium, phosphorus and iron analyses (Table 2). No significant statistical differences were observed in any of the three minerals. By the end of 1981, RRC sent 100 g samples of both *A. hypochondriacus* (Mercado and Aztec types) and *A. cruentus* (Mexican type) with which chemical and taxonomic analyses were established with respect to the results presented in Table 3. The correspondence of domestic crops with Kauffman's (5) previous data may be observed. The following tests employed lines 3 (*A. hypochondriacus,* Mercado type) and 9 and 12 (*A. cruentus,* Mexican type) as the most adequate selections.

Table 4 contemplates some of the seeds' characteristics corresponding to two types of *A. hypochondriacus* and to two of *A. cruentus*. Their only difference lies in grain yield and a little in protein content.

The ample genetic variation which has been observed in the case of amaranth was also present in the proximate analysis, although within the usual limits (Table 1). Grain yield compared satisfactorily to that of cereals' average in Mexico.

Heat Treatment

As happens with other seeds (8, 21, 22), when amaranth seeds are subjected to heat treatment (toasting, popping and cooking), a reduction in quality may be appreciated or else, on the other hand, an improvement in nutritional value occurs (Table 5). Protein and lysine were affected to a certain degree while this did not turn out to be true for the remaining chemical components.

Even at temperature from 90 to 170oC, toasting seemingly benefits the protein content, with cooking behaving in a similar way. The combination of factors such as temperature, moisture and time (Table 6) makes it possible to foretell the materials' behavior during the different

TABLE 1

PROXIMATE ANALYSIS OF AUTOCTONOUS AMARANTH SPECIES

Samples*	Protein o/o	Fiber o/o	Fat o/o	Ash o/o	Carbohydrates, o/o	Moisture o/o
1	13.43 BA	8.24 A	3.88 B	4.30 A	70.15 A	Dry basis
2	12.93 B	9.14 A	4.64 B	4.80 A	68.49 A	Dry basis
3	14.57 B	8.22 A	4.65 B	3.48 A	69.08 A	Dry basis
4	13.28 BA	8.61 A	3.61 B	4.04 A	70.46 A	Dry basis
5	17.07 A	8.34 A	3.35 B	4.50 A	66.74 A	Dry basis
6	12.99 B	9.22 A	3.88 B	3.54 A	70.37 A	Dry basis
7	15.03 BA	8.39 A	3.64 B	4.64 A	68.30 A	Dry basis
8	16.25 BA	8.42 A	3.74 B	4.37 A	67.22 A	Dry basis
9	14.45 BA	8.14 A	4.82 B	4.21 A	68.38 A	Dry basis
10	14.90 BA	9.05 A	4.10 B	3.58 A	68.37 A	Dry basis
11	13.41 BA	7.74 BA	5.14 B	3.35 A	70.36 A	Dry basis
12	15.04 BA	8.13 A	5.79 B	4.12 A	66.92 A	Dry basis
13	13.86 BA	8.50 A	3.73 B	4.35 A	69.56 A	Dry basis
14	12.95 B	9.10 A	4.22 B	3.90 A	69.83 A	Dry basis
15	16.80 BA	8.25 A	4.67 B	3.73 A	66.55 A	Dry basis
16	13.39 BA	8.63 A	4.86 B	4.11 A	69.01 A	Dry basis
17	14.96 BA	8.63 A	4.35 B	4.65 A	67.41 A	Dry basis
18	14.72 BA	8.07 A	6.40 B	3.64 A	67.17 A	Dry basis
19	15.99 BA	8.38 A	4.30 B	3.97 A	67.36 A	Dry basis
20	13.03 B	4.99 B	6.27 B	3.25 A	72.46 A	Dry basis
21	15.11 BA	6.88 BA	6.80 B	4.99 A	66.52 A	Dry basis
22	15.43 BA	6.20 BA	9.11 A	2.50 BA	56.30 ED	10.46 B
23	14.31 BA	5.10 A	8.20 BA	2.14 BA	59.58 ED	10.27 B
24	17.05 BA	5.22 BA	7.11 BAC	2.10 BA	61.12 BC	7.40 B
25	15.81 BA	4.90 BA	5.20 BDC	2.48 BA	64.36 BAC	7.25 B
26	15.47 BA	7.10 A	4.32 BDC	2.40 BA	60.74 DC	9.97 B
27	14.90 BA	3.91 BA	5.00 BDC	3.00 BA	63.09 BAC	10.10 B
28	15.20 BA	5.80 BA	4.22 BDC	2.47 BA	64.60 BAC	7.71 B
29	15.91 BA	4.62 BA	4.65 BDC	3.80 A	64.92 BAC	6.10 B
30	14.75 BA	6.12 BA	3.82 DC	2.05 BA	63.91 BAC	9.35 B
31	14.45 BA	5.80 BA	4.23 BDC	1.09 B	65.18 BAC	8.30 B
32	17.35 A	4.95 BA	5.12 BDC	2.16 BA	63.21 BAC	7.21 B
33	16.80 BA	4.78 BA	4.73 BDC	3.14 BA	62.95 BC	7.60 B
34	15.31 BA	4.70 BA	5.00 BDC	2.10 BA	64.49 BAC	8.40 B
35	13.91 A	4.00 BA	3.98 DC	1.97 BA	68.42 BA	7.72 B
36	16.70 BA	4.80 BA	3.90 DC	2.18 BA	64.12 BAC	8.30 B
37	14.92 BA	5.10 BA	4.88 BDC	3.02 BA	62.28 BDC	9.80 B
38	15.90 BA	4.90 BA	5.40 BDAC	2.70 BA	61.80 DC	9.80 B
39	15.82 BA	5.80 BA	4.12 BDC	2.16 BA	63.20 BAC	8.90 B
40	14.85 BA	4.81 BA	4.61 BDC	3.00 BA	65.67 BAC	7.06 B
41	14.60 BA	4.29 BA	2.18 D	2.10 BA	69.58 A	7.30 B
42	14.70 BA	4.18 BA	4.26 BDC	2.19 BA	66.27 BAC	7.35 B
43	15.84 BA	5.70 BA	4.18 BDC	2.16 BA	64.47 BAC	7.65 B
44	16.73 BA	6.20 BA	4.40 BDC	2.19 BA	62.78 BC	7.70 B
45	15.88 BA	4.27 BA	4.09 BDC	2.28 BA	65.52 BAC	7.96 B

* Samples 1-21 are 1980 cultivars, while the rest are 1981 crops.

Duncan's test. Means with the same letter are not significantly different: $p > 0.005$.

TABLE 2

CONTENTS OF CALCIUM, PHOSPHORUS AND IRON OF SEEDS

Samples*	Calcium	Phosphorus	Iron
1	2.47 A	8.81 A	2.7 A
2	2.54 A	8.71 A	2.9 A
3	2.51 A	8.28 A	2.6 A
4	2.53 A	8.80 A	2.7 A
5	2.48 A	9.10 A	2.6 A
6	2.49 A	7.99 A	2.7 A
7	2.61 A	9.01 A	2.8 A
8	2.18 A	9.30 A	2.6 A
9	2.50 A	9.50 A	2.7 A
10	2.41 A	8.60 A	2.6 A
11	2.66 A	8.40 A	2.4 A
12	2.15 A	9.10 A	2.6 A
13	2.50 A	8.70 A	2.3 A
14	2.70 A	8.60 A	2.8 A
15	2.51 A	9.10 A	2.7 A

* Those numbered 1 to 5 = *A. hypochondriacus; 6 to 15 = A. cruentus.* Duncan's multiple range test, $p < 0.005$.
Means with the same letter are not significantly different.

procedural phases which are followed in the preparation of several products; protein underwent changes according to the treatments applied. Samples with 10o/o moisture did not exhibit variations in protein content when exposed to temperatures of 90 to 170oC during a 3-5 minute lapse. A higher moisture rate, however, does provoke changes in protein at 150-200oC during a 3-5 minute lapse.

The *A. cruentus* species with a 5.7o/o of raw fat contains an excellent proportion of oils of the highest nutritional value, oleic and linoleic, as well as a satisfactory proportion of linoleic and palmitic acids (23, 24). Cooking *A cruentus* seeds at 90oC for 5 minutes diminished fatty acids C 18:2 and C 18:3 in the studied samples (Table 7). Toasting and popping did not seriously affect the fatty composition of *A. hypochondriacus* while cooking, only in a small proportion. As previously indicated (7, 8), apparent digestibility and the PER value of selected *A. cruentus* flour were improved by the popping process, whereas toasting did not exactly alter that value, nor *in vivo* digestibility (Table 8). Baker's quality of *A. cruentus* flour was not affected in the toasted seed, while it was so in the popped one (Table 9).

TABLE 3

CORRELATIONS BETWEEN THE GERM PLASM BANK (RRC) AND THE 45 COLLECTIONS

Collections	Suppliers*	Origin	Type	Species	RRC (29)
1 to 5	LF/GN	Tulyehualco**	Mercado	*A. hypochondriacus*	412-414 (1022-1025)
6 to 15	LF/GN	Huazulco, Morelos	Mexican grain	*A. cruentus*	415-443
16 to 24	LF	San Simón, Puebla	Aztec	*A. hypochondriacus*	465-479
24 to 30	H.H.094	Oaxaca	Aztec	*A. hypochondriacus*	635
	H.H.093	Oaxaca	Aztec	*A. hypochondriacus*	641
	H.H.102	Oaxaca	Aztec	*A. hypochondriacus*	644
	LF/CSK124	Oaxaca	Aztec	*A. hypochondriacus*	723
	LF/CSK129-1	Puebla	Mercado	*A. hypochondriacus*	732
	LF/CSK129-8	Puebla	Mercado	*A. hypochondriacus*	739
31 to 45	LF/CSK	Tulyehualco**	Aztec and Mercado	*A. hypochondriacus*	745-759

* LF, Laurie Feine; GN, Gary Nabhan; HH, Holly Hauptly; CSK, Charles S. Kauffman.
** State of Mexico.

TABLE 4

SOME CHARACTERISTICS OF SEEDS FROM THE TWO AMARANTH SPECIES

Characteristics*	*A. hypochondriacus*		*A. cruentus*	
	Mercado type	Spike type	Aztec type	Mexican type
Size, mm	0.9	0.8	0.8	0.9
Weight of 100 seeds, g	0.06	0.06	0.05	0.06
Color	White or tan	White or yellow	White or tan	White, tan or yellow
Maximum yield kg/ha rain-fed	1,220	978	1,420	1,650
Protein, g/o/o	15.3	15.8	16.1	16.1

* Mean of three samples with two determinations each.

TABLE 5

EFFECT OF THERMAL TREATMENT OF SEEDS ON CHEMICAL COMPOSITION (*A. cruentus*)*

Seed treatment	Moisture o/o	Protein o/o	Crude fiber o/o	Fat o/o	Ash o/o	Lysine g/16 g N	Tryptophan g/16 g N
None	8.9	15.7	3.6	4.3	3.4	5.18	1.12
Toasted at 90oC	5.1	16.9	3.3	4.5	3.8	5.10	1.13
Popped at 170oC	4.2	17.1	3.1	5.0	4.1	4.80	1.12
Cooked for 3 min	4.0	14.7	3.2	4.6	3.7	4.41	1.10

* Mean values of three samples.

Experiments performed by Betschart *et al.* (8) suggest that the improvement in protein quality is derived from the increase of its unfolding, with available amino acid liberation.

Since lysine is one of the most important amino acids in the protein metabolism, and at the same time, one of the most sensitive to heat, a loss can be observed, similar to that described by several researchers, as far as the popped seed is concerned when appraising lysine both before

TABLE 6

EFFECT OF TEMPERATURE, TIME AND MOISTURE ON THE
A. cruentus SEEDS
(Expressed on a dry basis)

Time (min)	Temperature (°C)	Protein (o/o)
Sample with 6 to 10o/o moisture		
1	90	17.7
5	90	17.3
1	120	17.1
5	120	16.9
1	150	17.7
5	150	17.2
1	170	17.9
5	170	17.9
Sample with 15o/o moisture		
3	180	15.1
3	200	15.4
5	150	15.6
5	180	15.6
5	200	15.5
Sample with 20o/o moisture		
3	200	14.6
5	150	14.9
5	180	15.3
5	200	15.7
Raw seeds	—	16.4

and after the seeds' thermic treatment. This information is also confirmed with 318 and 333 mg/g N for raw seed values by Betschart *et al.* (8) in his recent work. This last estimation closely resembles the 340 value for the ideal protein in terms of total lysine as proposed by FAO/WHO.

Fraction Separation

Protein, as well as the remaining components studied, underwent limited variation according to the fractions which were separated by means of a pearler or Raymond separator (Table 10) of flours, cor-

TABLE 7

EFFECT OF THERMAL TREATMENT ON THE FATTY ACIDS FROM TWO *AMARANTHUS* SPECIES
(Expressed in percentage)

Seeds	C 16:0	C 18:0	C 18:1	C 18:2	C 18:3
A. hypochondriacus Mercado type					
Raw	18.9	2.85	37.1	33.5	7.1
Toasted, 90°C	18.9	2.82	34.5	32.8	7.1
Toasted, 120°C	18.4	3.80	34.0	31.9	6.4
Popped, 180°C	18.9	3.32	34.7	30.7	5.8
Cooked, 93°C, 5 min	18.8	4.20	38.0	31.8	6.8
A. cruentus, Mexican type					
Raw	18.1	4.60	26.7	39.3	3.6
Cooked	18.7	2.90	37.1	33.5	5.7

TABLE 8

EFFECT OF THERMAL TREATMENT ON PROTEIN EFFICIENCY RATIO AND APPARENT DIGESTIBILITY OF THE *A. cruentus* FLOUR

Flours of seeds	Digestibility %	PER	Bestchart *et al.* (8) Real	Bestchart *et al.* (8) Adjusted
Raw	80	1.70	1.99	1.51
Toasted	90	1.80	1.87	1.42
Popped	92	2.10	2.29	1.73
Casein	95	2.50	2.40	1.82

TABLE 9

INFLUENCE OF HEAT TREATMENT ON THE BREAD-BAKING QUALITY OF WHEAT AND AMARANTH FLOUR BLENDS

Wheat and amaranth	Seed treatment	Bread		Cookies	
		Volume cc	Quality score	Spread factor W/Tx10	Qualification 100 maximum score
90:10	Raw	690	95	95	90
	Toasted	780	95	98	95
	Popped	730	50	50	50
95:5	Raw	720	95	95	90
	Toasted	790	95	95	95
	Popped	775	15	40	45
100:0	Raw	750	100	100	100
	Toasted	760	100	98	100
	Popped	610	40	25	30

TABLE 10

VARIATIONS IN PROXIMATE ANALYSIS (%) OF CLASSIFIED AMARANTH FLOUR FRACTIONS

Samples[1]	Protein	Fat	Fiber	Ash	Yield (%)
Pearler[2]					
Fraction 1-P	36-40.3	9.1-16.6	7.5-13.2	4.8-9.8	69-72
Fraction 2-P	6.5-9.1	2.2-4.9	6.9-3.2	1.1-1.4	22-28
Amaranth whole flour	15-16.3	5.3-6.8	2.5-3.8	1.8-2.9	85-99
Miag mill + Raymond[3]					
Fraction 1-R	29.6-38.3	6.9-15.8	6.9-15.6	4.3-9.1	30-35
Fraction 2-R	7.0-9.1	2.4-5.1	1.4-4.1	1.2-3.0	62-68

[1] Variations in four trials. [2] Pearler after five passes. [3] Miag mill, one pass and Raymond separator, one pass.

responding to *A. cruentus* 12. Both fraction 1 from the pearler (testa + embryo) and the first one from Raymond reached the highest protein content while carbohydrates were concentrated in the pearler's fraction 2 and Raymond's 2 as starch, according to usual microscopic and coloring tests.

Starchy fractions subjected to farinographic (Figure 1) and amylographic studies (Table 11) exhibited the results shown in the same Table, compared to similar wheat and quinoa *(Chenopodium quinoa)* fractions, the

TABLE 11

AMILOGRAPH DATA OF AMARANTH STARCHY FRACTIONS AND WHOLE FLOUR

Determinations*	Pearler (Fraction 2-P)	Raymond (Fraction 2-R)	Wheat starch	Amaranth whole flour	*Ch. quinoa* starch
Viscosity U.B.					
Peak	590 (350)	815 (700)	330	650	560
90°C	501 (280)	617 (530)	280	540	510
90°C 30'	450 (290)	609 (480)	320	520	580
35°C	240 (260)	270 (280)	490	200	300
Gelatinization Temperature					
Initial	60 (63)	62 (64)	53	62	58.5
Mid point	62 (65)	64 (66)	56	66	65.0
Final	66 (67)	68 (70)	56	70	69.0

* Figures in brackets correspond to different samples.

latter, a South American species whose chemical and nutritional characteristics highly resemble those of amaranth (9). As may be appreciated, both *A. cruentus* and *C. quinoa* show similar rheological characteristics, while at the same time, they are different from those of wheat. Water-binding capacity, swelling power and solubility were also shared by these fractions and *C. quinoa* while once again exhibiting differences with wheat starch (Table 12). Even if the starchy fraction did not undergo purification, its characteristics may be compared to those indicated by other researchers (24-26).

On the other hand, the heat treatment's effect on viscosity and gelatinization temperature in "amaranth milk", which was prepared for this case, is shown in Table 13. Toasted seeds of sample 3, corresponding to *A. hypochondriacus,* and sample 12 of *A. cruentus,* exhibited the highest viscosity rate, followed by those subjected to 5-minute boiling. Gelatinization temperatures of the toasted seeds' milk remained within the amylographic values: 60-62°C at the beginning and 68-70°C at the end. In the case of *Ch. quinoa,* the obtained data were similar to those indicated by Briceño and Scarpati (26).

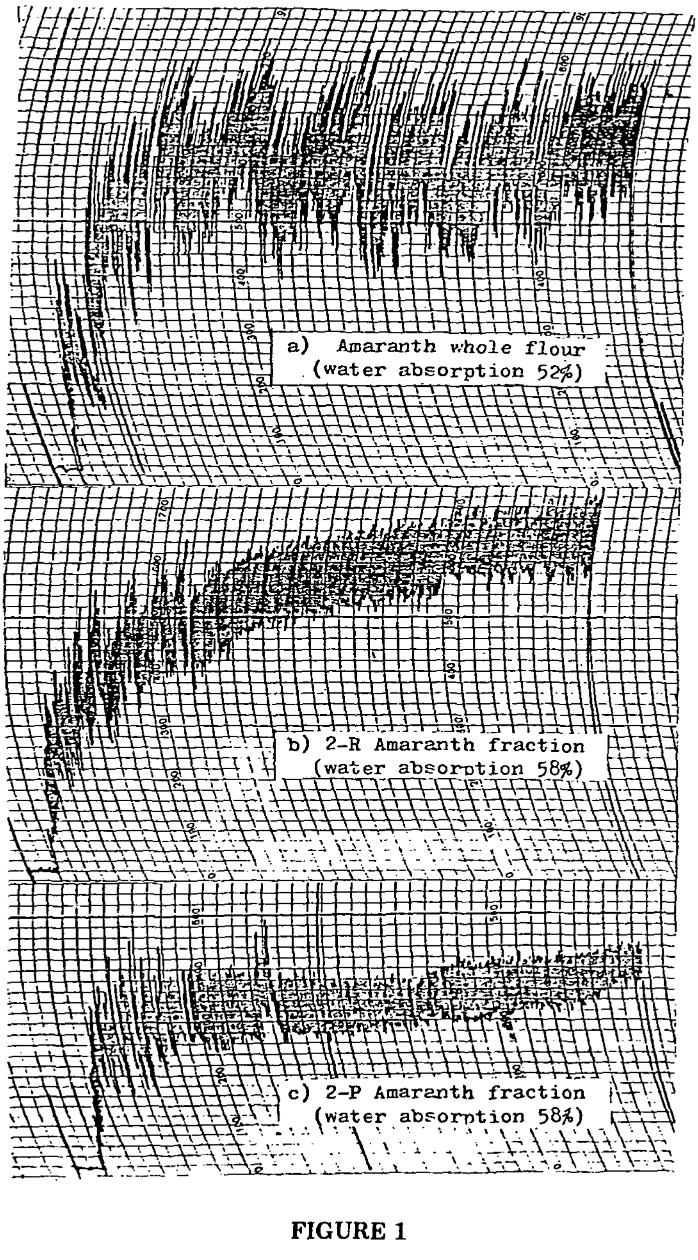

FIGURE 1

Farinographs of amaranth whole flour and starchy fractions

With regard to "amaranth milk", variable changes were appreciated during heating at 90 to 95°C for five minutes, provoking a bigger grain swelling power with a refringency loss. "Amaranth milks" were considered satisfactory due to their high viscosity.

TABLE 12

SWELLING POWER, SOLUBILITY AND WATER-BINDING CAPACITY OF THE AMARANTH STARCHY FRACTIONS

Sample	Temperature °C	Swelling power	Solubility %	Water binding capacity %
Fraction 2-P) (Starchy perisperm)	20	2.2	10.2	118.0
	60	2.4	14.7	—
	90	2.9	36.3	—
Fraction 2-R (Raymond separator)	20	—	—	120.0
	60	1.7	15.0	—
	90	3.2	34.4	—
Wheat starch	20	—	—	72.0
	60	4.8	2.1	—
	90	10.2	8.3	—
Ch. quinoa starch	20	5.8	4.3	103.4
	60	5.3	4.8	—
	90	6.1	6.1	—

TABLE 13

INFLUENCE OF THE THERMAL TREATMENT OF SEEDS ON VISCOSITY AND GELATINIZATION TEMPERATURE OF AMARANTH MILK

Amaranth milk samples	Seed treatment	Viscosity (cps)			Gelatinization °C	
		27°C	35°C	70°C	Initial	Maximum
3	Raw	500	600	450	52	64
12	Raw	600	1,200	1,200	40	58
3	Toasted 90°C	1,300	1,350	1,400	60	68
12	Toasted 90°C	1,400	1,400	860	62	70
3	Popped 170°C	860	830	650	65	72
12	Popped 170°C	600	520	450	58	70
3	Cooked 5'	960	980	1,200	50	60
12	Cooked 5'	1,350	1,200	1,400	54	66

Table 14 compares the distinctive characteristics of the two domestic Mexican species. It also indicates that there are no actual differences in protein content, whereas this is not true for the grain's yield.

TABLE 14

SUMMARY OF DATA ON AMARANTH AUTOCTONOUS SPECIES AND FLOUR FRACTIONS*

Data	*A. cruentus* (Mexican type)	*A. hypochondriacus* (Mercado type)
Seed	White, yellow or cream.	White to golden.
	1,500–2,500 kg/ha grain yield.	Less than 2,500 kg/ha.
	Fair popping.	Very good popping.
	Very good flour but grayish sometimes, with a strong flavor.	Very good flour, white, usually with mild flavor.
	Toasting advisable for bread-baking.	Usually, toasting is not necessary for bread-baking.
	Digestibility, 92o/o *in vivo*.	Digestibility, 90-92o/o.
	Baking quality, 95 score.	Baking quality, 98.
	13-16o/o protein content	13-17 o/o protein content.
Rheology	High viscosity of starchy fractions and high water-binding capacity and swelling.	Medium viscosity of starchy fractions and high water-binding capacity and swelling.
	Gelatinization temperature, 68oC-75oC.	Gelatinization temperature, 70oC–80oC.
	Higher solubility than wheat starchy fractions	Higher solubility than wheat starch.
	Peak viscosity, 650–700 U.B.	Peak viscosity, 600–900 U.B.
	Mixing time, 2.2 min	Mixing time about the same.
Plant	Not bushy at low densities.	Very bushy at low density.
	Less lodging.	More lodging.
	Soft panicles.	Hard panicles.
	Life cycle, 90 to 130 days.	Life cycle usually longer.
	Suitable for dry conditions.	Very suitable for dry conditions.
	More susceptible to Lygus.	More resistant to Lygus.

* Rain-fed conditions; no fertilization or inadequate; low density population; no frosting; hand cropping; rain precipitation 300–700 mm/year.

The present paper's global results, as well as those obtained by researchers who have studied the amaranth (3, 5, 27-29), confirm the high quality of the seed and recommend its ample use within alimentary technology.

RESUMEN

EFECTO DEL TRATAMIENTO TERMICO Y DE MOLIENDA EN LA SEMILLA, HARINA, REOLOGIA Y CALIDAD DE PANIFICACION DE ALGUNOS ECOTIPOS DE AMARANTO

Se estudiaron 45 cosechas de dos especies autóctonas de amaranto, predominantes en México. En algunos casos, el análisis proximal reveló diferencias estadísticamente significativas a través de los tres años de observación.

El contenido de Ca, P y Fe no varió del todo en 15 muestras. Tampoco se constataron diferencias químicas en los tipos Mercado y Azteca de *A. hypochondriacus* ni en el tipo mexicano de *A. cruentus*. Este último acusa mayor rendimiento de grano y un ciclo vital más corto, pero para propósitos de panificación, es inferior al *A. hypochondriacus*, tipo Mercado, en cuanto a calidad.

El tratamiento térmico de las semillas (tostado, reventado y cocción) afectó el contenido de proteína y lisina, al igual de lo que ocurre en cereales y leguminosas, pero el tostado en particular, mejora sus características organolépticas sin alterar su digestibilidad ni el PER. El reventado sólo mejora el PER. El calentamiento a 90 ó 170°C durante tres a cinco minutos a la humedad usual de 6 a 15%, no afecta el contenido proteínico y solo ligeramente el de ácidos grasos. Los valores amilográficos y farinográficos de las fracciones amiláceas indican similaridades con la *C. quinoa*, y diferencias con respecto al trigo. En el caso de la "leche de amaranto", la viscosidad y la temperatura de gelatinización rindieron cifras satisfactorias.

En vista de la calidad nutricional de la semilla, y dado el comportamiento de la harina integral y sus fracciones, se sugiere ampliar el cultivo de amaranto en el país.

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