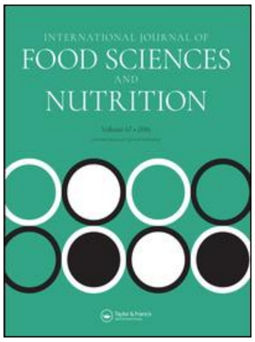

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RESEARCH ARTICLE

Losses of nutrients and anti-nutrients in red and white sorghum cultivars after decorticating in optimised conditions

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ABSTRACT

The aims were to optimise pearling process of red and white sorghum by assessing the effects of pearling time and grain moisture on endosperm yield and flour ash content and to assess nutrient and anti-nutrient losses produced by pearling different cultivars in optimised conditions. Both variables significantly affected both responses. Losses of ashes (58%), proteins (9.5%), lipids (54.5%), Na (37%), Mg (48.5%) and phenolic compounds (43%) were similar among red and white hybrids. However, losses of P (30% vs. 51%), phytic acid (47% vs. 66%), Fe (22% vs. 55%), Zn (32% vs. 62%), Ca (60% vs. 66%), K (46% vs. 61%) and Cu (51% vs. 71%) were lower for red than white sorghum due to different degree of extraction and distribution of components in the grain. Optimised pearling conditions were extrapolated to other hybrids, indicating these criteria could be applied at industrial level to obtain refined flours with proper quality and good endosperm yields.

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KEYWORDS
Sorghum; refined flours; decorticating; pearling; losses of nutrients

Introduction

Sorghum is a crop widely grown all over the world for food and feed. It is a key staple in many developing countries, particularly in the drier and more marginal areas of the semitropics (Stefoska-Needham et al. 2015). Sorghum has enormous potential as ingredient in the production of foods such as cookies, pasta, expanded products, snacks, sausages and beer (Taylor and Dewar 2001). In addition, the lack of gluten makes possible its use for foods for coeliac population (Ferreira et al. 2016). One option to include sorghum in foods is as refined, white and low ash content flours to replace other flours such as wheat (Mridula et al. 2007). In refined flour production, bran and germ can be removed by decortication process and discarded or used for animal feed (Lochte-Watson et al. 2000). However, after decortication healthy components of whole grains and anti-nutrients such as phytates are reduced (Moraes et al. 2015). The last ones are phosphate compounds, which can significantly influence functional and nutritional properties of foods (McKie and McCleary 2016). Phosphate groups of phytic acid (PA) serve as the main phosphorus store in mature seeds. In sorghum grains, PA is stored principally in the germ, also exists in the bran, and the endosperm content is minimal. Thus, removing pericarp results in 40 to 50% decrease of both, PA and total phosphorus (FAO 1995), which probably increase iron bioavailability because mainly divalent cations are complexed by PA, preventing their absorption (Hurrell and Egli 2010).

The aims were to optimise the decorticating process of red and white sorghum by assessing the effect of time and moisture grain on ash content and endosperm yield and to assess nutrient and anti-nutrient losses produced by decortication of different cultivars in optimised conditions.

Materials and methods

Raw material

Ten commercial hybrids were analysed: five were red sorghum (RS) hybrids (10SAR0010; PEX42353; PEX1282; PEX41027; 10SAR0025) and five white sorghum (WS) ones (Nidera A9941W; PAN8706W; NUSEED JOWAR FOOD 143; TOBIN TOB48W; PEX9261W). Sorghum hybrids were cleaned removing broken grains and foreign materials using a cereal cleaner-classifier Labofix (Brabender, Germany) on a pilot plant scale. Then, the samples were stored at 5 °C until analysis. All hybrids were evaluated through chlorine bleaching test (chlorine in alkaline medium)

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to determine grains with condensed tannins (SENASA 2011). The sample is considered without condensed tannins when the presence of obscured grains is less than 5% after bleaching. Moisture content of grains ranged 122–153 $g\,kg^{-1}$.

Study of sorghum decorticating process

Optimum pearling time (PT) and grain moisture content (MC) were determined using RS (10SAR0025) and WS (PEX9261W) hybrids and performing two experimental designs, one for each type of sorghum. Sorghum grains were decorticated by abrasion using a laboratory rice dehuller (Gallicet, Entre Rios, Argentina).

Experimental design

A factorial of three-level, two-factors, with three replicates in the central point design was used. The levels of factors were 4, 6 and 8 min for PT and 110, 135 and 160 $g\,kg^{-1}$ grain MC. These levels were selected by previous studies. Experiments were randomised. PT was measured with a stopwatch. Initial time was considered once 100 g sample was introduced through the feed hopper. The levels were defined in order to obtain ash content below 6.5 $g\,kg^{-1}$, as indicated by Argentinean legislation (AFC, art 663) for refined sorghum flour. The responses evaluated were ash content (AOAC 2000) and endosperm yield determined as: Endosperm yield (%) = decorticated grains weight $\times$ 100/whole grains weight.

Refined flour obtaining

After decorticating process, pearled grains were ground using a Ciclotex mill (UD Cyclone Sample Mill, UD Corp., Boulder, CO) with 1-mm mesh.

Analytical determinations

Refined flours were analysed regarding proximal composition according to AOAC (2000). Mineral content was determined after dry ashing. Fe, Zn, Ca, Cu and Mg were measured by Flame Atomic Absorption Spectroscopy and Na and K by flame photometry using an Atomic Absorption spectrophotometer Analyst 300 (Perkin Elmer). P and PA content were performed according to AOAC (2000). Phenolic compounds (PC) were extracted according to Qiu et al. (Qiu et al. 2010) and determined by the Folin–Ciocalteu method (Singleton et al. 1999).

Losses of nutrients and anti-nutrients. For each component (C_i), the losses were calculated as:

$$(C_{i\ whole\ grain\ flour\ content} - C_{i\ refined\ flour\ content}) \times 100/C_{i\ whole\ grain\ flour\ content}$$

where C_i was: ash, protein, ether extract, Fe, Zn, Ca, Cu, Mg, Na, K, P or PA.

Statistical analysis

All determinations were carried out in duplicate. Analysis of variance (ANOVA) followed by LSD test to compare means at 95% confidence and multifactor ANOVA to evaluate the effects of decorticating, colour grain and their interactions on each component content were performed using Statgraphics Plus 5.1 software (Manugistics Inc., Rockville, MD). Experimental designs and the optimisation of the responses were made using Design Expert 7.0.0 software (Stat-Ease, Inc., MN).

Results and discussion

Effects of sorghum grain moisture content and pearling time on endosperm yield and ash content of refined sorghum flours

The values of endosperm yield and ash content for different combinations of PT and grain MC are shown in Table 1. ANOVA for responses is shown in Table 2(A). The high values of the coefficient of determination (r^2) and the non-significant lack of fit suggest the models are suitable for data at 95.0% confidence level. For endosperm yield, a quadratic model was used, while for ash content, a linear model was fitted. It was found the two factors analysed (PT and grain MC) significantly affected both responses (endosperm yield and ash content) in their linear terms. In addition, the quadratic term of grain MC was significant for endosperm yield. The interaction terms were not significant for any of the two responses studied. The regression coefficients for the equation fitted to the data are given in Table 2(B). The response surfaces based on these functions for endosperm yield and ash content are shown in Figures 1(a–d), respectively.

Effect of pearling time and grain moisture on endosperm yield

Figures 1(a,b) (for RS and WS, respectively) show endosperm yield decreased with the increase of PT at all studied MC levels. At longer PT, higher amounts of pericarp, germ and some of endosperm were lost.

Regarding grain MC, a maximum endosperm yield near medium moisture level was observed, for both

Table 1. Endosperm yield and ash content of red and white sorghum refined flours after pearling at different pearling times and moisture contents of grains.

		Red sorghum (10SAR0025)		White sorghum (PEX9261W)	
PT (min)	MC (g kg^{-1})	Endosperm yield (%)[a]	Ash content[a] (gkg^{-1})	Endosperm yield (%)	Ash content[a] (gkg^{-1})
4	110	69.11	4.144 ± 0.085	75.83	9.104 ± 0.072
4	135	70.53	5.219 ± 0.049	80.97	9.825 ± 0.043
4	160	66.29	6.071 ± 0.048	79.89	10.32 ± 0.025
6	110	60.37	4.024 ± 0.161	69.18	7.667 ± 0.204
6	135	62.01	4.093 ± 0.021	75.44	8.191 ± 0.014
6	135	63.83	4.027 ± 0.054	74.28	8.142 ± 0.187
6	135	64.16	4.341 ± 0.120	76.56	8.117 ± 0.050
6	160	56.39	4.322 ± 0.101	75.88	8.159 ± 0.350
8	110	52.92	2.855 ± 0.156	60.37	5.336 ± 0.145
8	135	59.53	3.198 ± 0.088	67.39	6.030 ± 0.040
8	160	45.10	3.642 ± 0.046	63.38	6.688 ± 0.335

[a]Dry base. Mean ± SD. MC: moisture content; PT: pearling time.

Table 2. (A) Analysis of variance for the overall effects of pearling time and grain moisture content on endosperm yield and ash content and (B) Regression coefficients of polynomials for endosperm yield and ash content of red and white sorghum refined flours.

		Red sorghum (10SAR0025)		White sorghum (PEX9261W)	
		Endosperm yield (%)[b]	Ash content (g kg^{-1})[c]	Endosperm yield (%)[b]	Ash content (g kg^{-1})[c]
2.A	Degrees of freedom	*p* value			
A: PT (min)	1	**.0003**	**<.0001**	**<.0001**	**<.0001**
B: MC (gkg^{-1})	1	**.0438**	**.0041**	**.0089**	**.0004**
AA	1	.3130	–	.7146	–
AB	1	.5971	–	.0661	–
BB	1	**.0086**	–	**.0078**	–
Lack of fit	1	.1577	.2083	.3948	.9899
r^{2a}	–	.9090	.8765	.9588	.9795
2.B	–	Coefficients			
Intersection	–	63.70	4.21	75.72	8.01
A: PT (min)	–	−8.6	−.960	−7.59	−1.91
B: MC (gkg^{-1})	–	−2.24	.500	2.30	.510
AB	–	−1.25	–	−.26	–
A^2	–	.79	–	−1.99	–
B^2	–	−5.86	–	−3.64	–

[a]Adjusted for degrees of freedom.
[b]Quadratic model.
[c]Linear model.
MC: moisture content; PT: pearling time.

RS and WS. However, for WS, the lowest endosperm yield value corresponded to the maximum PT and the minimum grain MC, while for RS, the minimum endosperm yield was observed at the higher PT and MC. In this case, grain moisture contributes to the detachment of pericarp and part of endosperm, giving lower endosperm yield values. Yetneberk et al. (2005) observed decreasing sorghum grain moisture facilitated the removal of the pericarp, and the effect was more pronounced at higher seed oil content. However, low MC not only causes a change in endosperm losses by pearling, but also an increase in the amount of fines (particles smaller than 0.18 mm). Thus, it is necessary to determine the optimal grain MC for minimising fine particle production, increasing endosperm yield. On the other hand, endosperm yields were higher for WS (60.37–80.97%) than RS (45.10–70.53%), under the same conditions of grain MC and PT. This is probably because WS resulted less pearled, as evidenced by the highest values of ash content (Table 1). This also coincides with the results obtained by Buitimea-Cantúa et al. (2013), who found that WS was more resistant to decortication than RS.

Wills and Ali (1983) found different sorghum grain sizes have different behaviour during abrasion decortication. The larger the grain, the greater contact surface is generated, facilitating the pearling. However, RS and WS grain sizes were measured resulting average sizes of 3.77 and 3.81 mm/grain for RS and WS, respectively, with no statistically significant difference between them (p: .2108). Yetneberk et al. (2005) determined endosperm yield is directly related to grain hardness, and soft floury grains tend to disintegrate during pearling, reducing yield. In the present study, WS hybrid was harder than RS one (Llopart and Drago, 2016) requiring longer PT for reach desirable ash content.

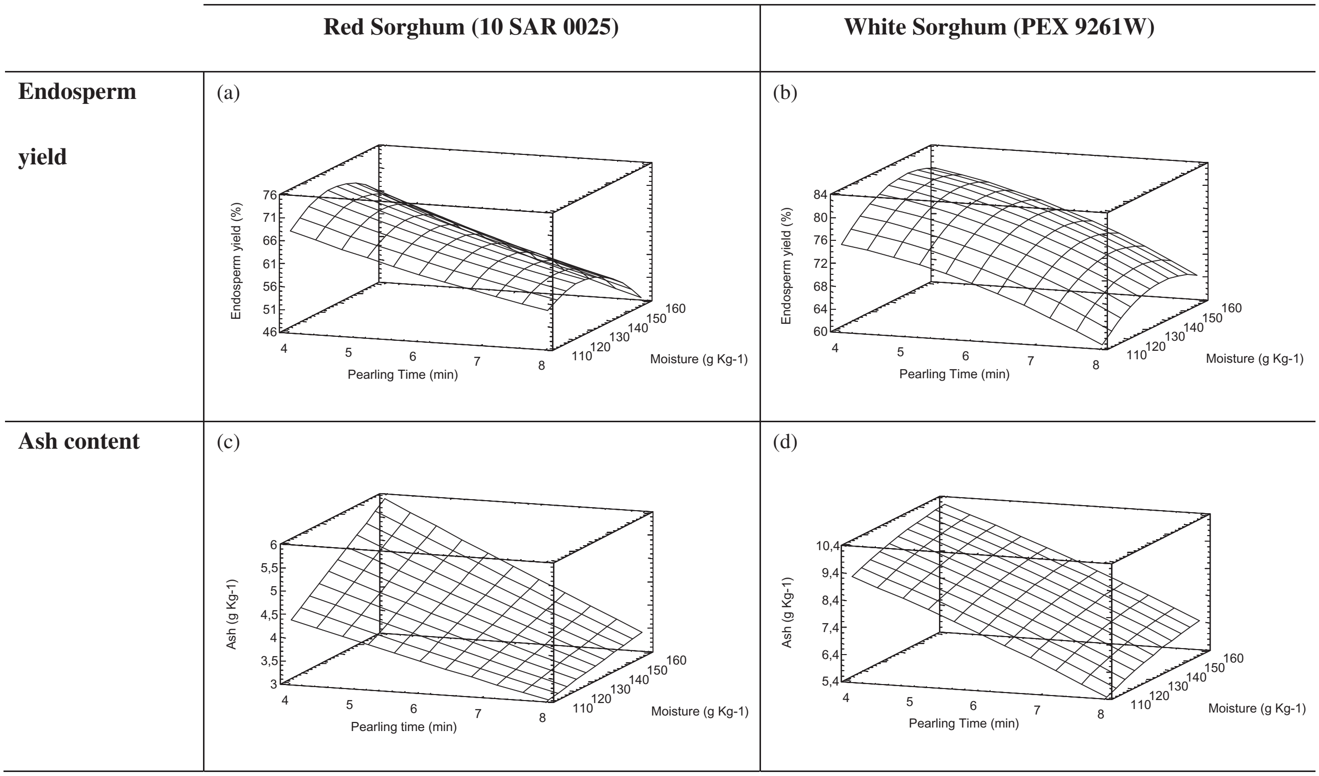

Figure 1. Response surfaces showing the effect of grain moisture and pearling time on endosperm yield of red sorghum (a) and white sorghum (b) and ash content of red sorghum (c) and white sorghum (d).

Effect of pearling time and grain moisture on ash content

Figure 1(c,d) (for RS and WS, respectively) shows ash content decreased with increasing PT, at all grain MC levels. Ash content is higher in grain pericarp and germ than endosperm (da Silva and Taylor 2004). Thus, the more intense pearling (higher PT), the lower ash content values in refined flours were found (Yetneberk et al. 2005). On the other hand, at lower grain MC, lower ash values were observed. Ash contents were higher in WS (5.33–10.32 $g\,kg^{-1}$) than RS (2.85–6.07 $g\,kg^{-1}$), indicating lower level of pearling, as was mentioned earlier.

Optimum levels of grain moisture and pearling time

Two aspects were taken into account for the optimisation of the responses. First, the ash content should be below 6.50 $g\,kg^{-1}$ for refined sorghum flour (AFC, art 663 bis), and secondly, endosperm yield should be maximised. For RS, the optimal values of the factors were: 4 min PT and 132.5 $g\,kg^{-1}$ grain MC, with high desirability (0.904). The following responses would be achieved in these conditions: ash content: 5.07 $g\,kg^{-1}$ and endosperm yield: 72.61%. On the other hand, for WS, the optimal values were: 7.5 min PT and 132.3 $g\,kg^{-1}$ grain MC, with a desirability of 0.258. This low value of desirability is because of at the selected optimal PT, a relatively low endosperm yield value (68.64%) would be obtained, but acceptable ash content (6.05 $g\,kg^{-1}$), which is the main requirement for sorghum refined flours. Note WS required almost twice longer PT than RS. As discussed above, this is probably related to grain hardness. Awika et al. (2005) also reported WS samples are harder and require more abrasive PT. The importance of this study is highlighted that grains of RS and WS have very different behaviours during decorticating, and MC is an important variable that can be managed to improve endosperm yield and make the process more efficient and profitable.

Composition of refined sorghum flours. Assessment of losses of nutrients and non-nutrients

Once the optimum levels of PT and grain MC for RS and WS were obtained, 10 hybrids were pearled under these conditions, and their composition and mineral content were evaluated (Table 3). Ash values for refined flours in all cases were lesser than 6.50 $g\,kg^{-1}$, which was one of the objectives. Furthermore, endosperm yields were between 74–80% and 68–70% for RS and WS, respectively. This means the optimal

Table 3. Proximate composition, phytic acid, phenolic compounds and mineral content of refined sorghum flours.

	Red sorghum					White sorghum				
	1010SAR0025	10SAR0010	PEX42353	PEX1282	PEX41027	PAN8706W	PEX9261W	NIDERAA9941W	TOB48W125	NUSJOWF143
Ash ($g\,kg^{-1}$)	5.13 ± 0.15	5.10 ± 0.10	5.59 ± 0.36	5.30 ± 0.31	5.34 ± 0.15	6.34 ± 0.2	6.13 ± 0.4	6.15 ± 0.1	6.19 ± 0.3	6.32 ± 0.1
Ether extract ($g\,kg^{-1}$)	9.27 ± 0.10	13.27 ± 0.24	15.21 ± 0.12	14.98 ± 0.32	9.49 ± 0.11	13.26 ± 0.23	16.12 ± 0.22	16.15 ± 0.32	12.95 ± 0.14	15.35 ± 0.27
Proteins ($g\,kg^{-1}$)	91.40 ± 0.83	105.30 ± 1.87	98.38 ± 2.76	99.26 ± 1.34	105.87 ± 1.34	97.04 ± 2.25	90.55 ± 1.05	100.15 ± 0.88	88.81 ± 0.37	96.82 ± 1.07
PA ($g\,kg^{-1}$)	4.39 ± 0.27	6.20 ± 0.35	7.54 ± 0.56	4.46 ± 0.29	6.98 ± 0.08	2.73 ± 0.15	2.71 ± 0.14	3.38 ± 0.25	4.15 ± 0.36	3.01 ± 0.15
PC ($g\,kg^{-1}$)	0.83 ± 0.02	0.76 ± 0.03	0.94 ± 0.04	0.73 ± 0.02	0.86 ± 0.00	0.69 ± 0.03	0.65 ± 0.03	0.62 ± 0.01	0.47 ± 0.02	0.41 ± 0.03
Fe ($mg\,kg^{-1}$)	16.39 ± 0.05	15.35 ± 0.25	18.01 ± 1.57	17.63 ± 0.44	18.25 ± 0.88	11.58 ± 0.87	14.99 ± 0.36	17.79 ± 0.02	7.59 ± 0.06	8.90 ± 0.03
Zn ($mg\,kg^{-1}$)	9.73 ± 0.74	9.25 ± 0.60	11.31 ± 0.85	11.45 ± 0.15	10.44 ± 0.88	6.87 ± 0.07	7.94 ± 0.71	9.46 ± 0.55	4.38 ± 0.03	5.71 ± 0.14
Ca ($mg\,kg^{-1}$)	55.81 ± 2.39	44.08 ± 0.73	43.80 ± 2.72	44.82 ± 1.49	43.81 ± 1.99	39.83 ± 1.14	36.79 ± 0.48	39.62 ± 2.75	54.67 ± 0.98	35.99 ± 1.12
Cu ($mg\,kg^{-1}$)	1.71 ± 0.06	1.74 ± 0.11	2.16 ± 0.17	2.09 ± 0.04	1.42 ± 0.07	0.80 ± 0.06	0.87 ± 0.06	1.13 ± 0.04	0.75 ± 0.05	0.69 ± 0.05
Mg ($mg\,kg^{-1}$)	793.39 ± 26.93	1250.58 ± 27.81	1429.75 ± 125.54	1391.15 ± 17.14	971.73 ± 80.02	831.97 ± 64.43	1160.24 ± 55.20	1134.84 ± 43.93	377.09 ± 5.32	457.52 ± 6.22
Na ($mg\,kg^{-1}$)	125.90 ± 7.59	125.28 ± 3.13	118.68 ± 8.64	78.27 ± 3.98	112.20 ± 7.67	140.02 ± 4.98	123.38 ± 8.25	100.76 ± 0.79	100.03 ± 1.07	103.00 ± 2.30
K ($mg\,kg^{-1}$)	2101.07 ± 124.99	1947.71 ± 35.69	2318.82 ± 183.41	2223.37 ± 178.03	1643.17 ± 49.39	1781.67 ± 21.78	2033.06 ± 98.04	1346.54 ± 25.71	1263.48 ± 3.49	959.56 ± 59.85
P ($mg\,kg^{-1}$)	1892.05 ± 66.37	3177.07 ± 185.59	3301.63 ± 71.71	3091.98 ± 60.43	1969.59 ± 134.45	1827.72 ± 99.63	2287.71 ± 9.21	1567.78 ± 6.05	935.28 ± 77.58	1158.83 ± 9.03

Dry base; Mean ± SD; GA: gallic acid; MC: moisture content; PA: phytic acid; PC: phenolic compounds; PT: pearling time.

Table 4. Composition of whole and refined sorghum flours according to grain colour.

Components	Colour	Whole flour	Refined flour
Ash (gkg^{-1})	R	13.71 ± 2.40[a]	5.27 ± 0.21[a]
	W	14.0 ± 2.091[a]	6.20 ± 0.22[b]
Protein (gkg^{-1})	R	111.07 ± 6.09[b]	99.98 ± 5.71[b]
	W	104.54 ± 5.48[a]	94.67 ± 4.62[a]
Fe ($mgkg^{-1}$)	R	21.97 ± 6.18[a]	17.12 ± 1.31[b]
	W	27.97 ± 13.02[b]	12.17 ± 4.00[a]
Zn ($mgkg^{-1}$)	R	15.42 ± 13.05[a]	10.44 ± 1.04[b]
	W	18.04 ± 12.39[b]	6.87 ± 1.87[a]
Ca ($mgkg^{-1}$)	R	114.09 ± 5.30[a]	45.68 ± 3.59[a]
	W	121.50 ± 19.71[a]	41.38 ± 7.26[a]
Cu ($mgkg^{-1}$)	R	3.75 ± 0.67[b]	1.83 ± 0.29[b]
	W	2.95 ± 0.38[a]	0.85 ± 0.16[a]
Mg ($mgkg^{-1}$)	R	1919.54 ± 232.83[a]	1167.32 ± 264.97[b]
	W	1896.19 ± 110.48[a]	792.33 ± 347.48[a]
Na ($mgkg^{-1}$)	R	159.00 ± 42.65 [a]	112.07 ± 19.20[a]
	W	225.94 ± 43.56[b]	113.44 ± 17.03[a]
K ($mgkg^{-1}$)	R	3856.59 ± 595.79[a]	2046.83 ± 267.99[b]
	W	3807.29 ± 515.36[a]	1476.86 ± 405.39[a]
P ($mgkg^{-1}$)	R	3817.85 ± 302.28[b]	2686.47 ± 660.21[b]
	W	3448.69 ± 414.50[a]	1555.43 ± 507.82[a]
PC (gkg^{-1})	R	1.40 ± 0.03[b]	0.82 ± 0.01[b]
	W	1.11 ± 0.07[a]	0.57 ± 0.00[a]
PA (gkg^{-1})	R	11.26 ± 8.50[b]	5.91 ± 1.38[b]
	W	9.45 ± 6.21[a]	3.20 ± 0.58[a]

Means ± SD; different letters in a column indicate significant differences ($p < .05$). PA: phytic acid; PC: phenolic compounds; R: red, W: white.

conditions of decorticating process defined through two selected sorghum hybrids (one red and one white) was successfully extrapolated to other hybrids of the same colour.

The multifactor ANOVA of the effects of grain state (whole/refined) and grain colour (red/white) on the content of some flour components showed they were affected by pearling. For selected sorghum samples, grain colour also had an effect on protein, Cu, Mg, Na, K, P, PC and PA ($p < .05$). In addition, it was observed an interaction of factors in the case of Fe (p: 0.00), Zn (p: 0.00), Mg (p: 0.01) and Na (p: 0.00).

Table 4 shows the average content of each component according to grain colour in whole and refined sorghum flours. All studied components were reduced after decorticating, mainly minerals. Rao and Deosthale (1980) reported that husking grains to remove seed pericarp resulted in a great reduction in mineral content. One-way ANOVA showed WS refined flours had higher ash content than RS, despite the longer PT applied to WS hybrids, probably due to the higher hardness of these grains, as discussed above. However, refined WS flours have lower contents of Fe, Zn, Cu, Mg, K and P than RS ones, indicating a different distribution of minerals in the germ, pericarp and endosperm, in the way the degree of extraction affected final content of each mineral. Hubbard et al. (1950) reported minerals in sorghum grains are distributed unevenly and is more

Table 5. Percentage of nutrient and non-nutrient losses produced by pearling sorghum hybrids.

	Percentage of losses												
Hybrids	Ash	Ether extract	Proteins	Fe	Zn	Ca	Cu	Mg	Na	K	P	PC	PA
10SAR0025	66.9	67.0	9.7	24.5	38.9	51.9	57.2	55.8	37.6	40.7	45.8	36.6	58.1
10SAR0010	57.4	56.1	11.0	22.4	26.1	63.8	38.5	23.1	34.0	35.1	25.5	61.1	50.6
PEX42353	49.6	50.0	10.3	19.0	22.2	60.1	54.2	34.4	15.6	49.2	15.8	39.1	31.2
PEX1282	65.5	49.4	11.6	19.7	31.2	60.5	47.0	36.3	10.6	49.7	19.5	34.0	60.6
PEX41027	64.0	70.7	7.3	23.5	40.4	62.7	56.1	46.4	36.0	56.2	44.7	20.0	36.2
Range RS	**49.6–66.9**	**49.4–70.7**	**7.3–11.6**	**19.0–24.5**	**22.2–40.4**	**51.9–63.8**	**47.0–57.2**	**23.1–55.8**	**10.6–37.6**	**35.1–56.2**	**15.8–45.8**	**20.0–61.1**	**31.2–60.6**
PAN8706W	64.3	57.8	12.1	48.3	61.2	64.0	76.9	60.2	26.2	58.0	54.2	35.9	70.2
PEX9261W	59.1	51.0	8.7	42.0	51.6	66.6	70.1	38.5	25.6	47.8	43.8	39.9	68.8
NIDERA A9941W	53.7	46.2	6.0	38.1	57.4	72.8	65.0	39.7	59.9	54.4	47.9	42.5	64.5
TOB48W125	51.3	51.5	9.1	76.6	73.4	61.7	69.1	79.6	58.5	70.8	70.5	60.8	59.2
NUS JOW F 143	45.1	44.7	11.1	70.6	67.1	63.5	74.3	74.2	63.4	73.4	63.6	61.1	68.8
Range WS	**45.1–64.3**	**44.7–57.8**	**6.0–12.1**	**38.1–76.6**	**51.6–73.4**	**61.7–72.8**	**65.0–76.9**	**38.5–79.6**	**25.6–63.4**	**47.8–73.4**	**43.8–70.5**	**35.9–61.1**	**59.2–70.2**

PA: phytic acid; PC: phenolic compounds; RS: red sorghum; WS: white sorghum.

concentrated in germ and pericarp. Pedersen and Eggum (1983) have shown increasing extraction rates of sorghum grains resulted in flours with a progressive reduction in minerals like P, Fe, Zn and Cu.

Table 5 shows the percentage of losses produced by decorticating sorghum grains. Ashes and lipids were the macro-components reduced in a greater extent, since decorticating mainly eliminate germ and pericarp. Lipid losses ranged 44.7–70.7%. Taking into account, sorghum oil is susceptible to oxidation because polyunsaturated fatty acids are found in high proportion (>84%) (Hadbaoui et al. 2010), the lower lipid content in refined flours reduces the susceptibility to oxidation, improving product shelf life.

Rao and Deosthale (1980) reported a similar decrease in mineral content for six dehulled sorghum hybrids. For whole grain sorghum, PA was around 10 $g\,kg^{-1}$ (Table 4). The relationship P_{PA}/P_{Total} was 86.5% and 90.2%, for RS and WS, respectively. Also, Doherty et al. (1982) reported that more than 85% of *P* of whole grain sorghum was as PA. After pearling, PA was reduced by 31–70% and the mentioned relationship was almost halved, due to the loss of PA. Although PA is the grain *P* store, it is responsible for the poor utilisation of *P* present in cereals (McKie and McCleary 2016). Even though enzymatic activity of acid phosphatases can potentially release phosphates from inosytol, for most cereals marginal values of intrinsic activity of phytases are reported, with consequent low bioavailability of *P*, divalent cations and protein digestibility (Lopez et al. 2002). Thus, PA reduction could potentially improve mineral bioavailability.

Regarding the content of PC, the results reported by researchers were highly variable because they depend on the extraction and determination methods, in addition to the sorghum hybrid analysed (Wu et al. 2017). Although there was a decrease of phenolics in refined flours, the content remained substantial (Table 3). Pontieri et al. (2016) found a direct relation between sorghum PC with antioxidant activity, which is associated with beneficial health effects related with antioxidant effects.

Conclusions

Pearling time and grain moisture were factors significantly affected ash content and endosperm yield, in the production of refined sorghum flours. Although there are different designs of industrial dehulling devices requiring others pearling times, grain moisture seems to be a critical factor to obtain a good endosperm yield when producing refined flours. On the other hand, WS required twice as much of pearling time than RS to achieve the desired ash level, since different endosperm hardness.

The optimisation of pearling process applied to two sorghum hybrids was extrapolated to other hybrids of the same colour, indicating these criteria could be applied at industrial level to obtain refined flours with proper quality and good yields, contributing to make the process economically feasible.

Although argentine legislation was followed to obtain refined sorghum flours, other criteria for ash levels can be applied for the optimisation of the pearling process. Refined flours have lower nutrient and anti-nutrient contents than the corresponding whole flour. The reduction of phytates would improve nutritional quality of sorghum flours making refined flours a good vehicle for mineral fortification. Losses of Fe, Zn, Ca, Na, K, Ca, Mg, PA and PC were higher in WS compared to RS hybrids. Nutrient levels in refined flours will depend on the hybrid and its colour, and the extraction rate, since each particular component is differently distributed in the grain and is present in different levels.

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