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The Impact of Optimizing the Detoxification of Argane (*Argania spinosa*) Press Cake on Nutritional Quality and Saponin Levels

Research Article

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ABSTRACT

The use of *Argania spinosa* press cake for livestock feed is limited due to the presence of saponins, which give it a very bitter flavor and make it unpalatable to livestock. The present study aims to evaluate whether a detoxification method reduces saponin levels of press cake and how that affects its nutrient contents. The response surface methodology was used in this study involved grinding the argane press cake and subjecting it to soaking and boiling in three media: distilled water, sodium bicarbonate solution at different concentrations (0.02, 1.01, and 2%), and citric acid solution at various concentration (0.10, 1.05, and 2%); the respective ratios of argane press cake to the soaking and boiling media were fixed at 1:5, 1:12.5 and 1:20 (w/v, g/mL); the respective soaking times chosen were 1, 24, and 48 h; the boiling temperatures selected were 40, 80, and 120 ˚C, respectively; and the boiling times were, respectively, 10, 25, and 40 min. Experiments showed that soaking in acidic and alkaline media more effectively reduced saponin with averages 93% and 86% respectively, than soaking in distilled water (36%), while we observed significant average reductions amongst boiling solutions. The nutritional contents of argane press cake treated by different treatments decreased slightly than untreated; the crude protein of argane press cake non-detoxified was 48% compared to the detoxified that ranged between 40 to 47%. Therefore, decreasing the levels of saponins will make argane press cake more appetizing for livestock and might ameliorate protein malnutrition, a major animal feed problem in Morocco.

KEY WORDS argane press cake, citric acid, detoxification method, distilled water, saponins, sodium bicarbonate.

INTRODUCTION

In Morocco, ruminant livestock is considered a major socioeconomic sector, mostly in rural economic activities (Purser, 1981; Nardone *et al*. 2004). However, due to irregular climatic conditions, ruminants in Morocco's arid and semi-arid areas suffer from acute feed problems (Bendaou and Ait Omar, 2013). The major feed problems of ruminant livestock include unbalanced animal feeds as well as the high cost and unavailability of the conventional protein resources (El Maadoudi and El Housni, 2013a; Mouhaddach *et al*. 2016). For these reasons, there is great interest in finding and improving alternative feed resources to ensure the economic viability of livestock production. Moreover, Morocco has available a wide range of agricultural and agro-industrial by-products in considerable quantities, but they are underexploited (Susmel, 2001). Among unconventional feed resources, the argane tree (*Argania*

spinosa) offers important by-products and is one of the few alternative resources for animal feed (Bendaou *et al*. 2011), its leaves are used as hanging forage for goats and sheep, and the pulp of its fruit is consumed fresh or after drying, and this forage is completed by using the energetic leftovers (i.e., press-cake) obtained after argane oil preparation (Ouammou, 2012).

Argane press cake (APC), the by-product remaining after extraction of argane oil (Charrouf and Guillaume, 2002), was exclusively recycled as livestock feed (Charrouf, 1998).

The average amount of argane press cake produced during the argane oil production process was 2% (Zouhair *et al*. 2018). Its chemical composition attests to APC as an excellent nutrient source of crude protein (41.02%) (Igmoullan, 1999), fiber (17.6%), carbohydrates (9%) and crude lipids (18.9%) (Charrouf and Guillaume, 1999).

Therefore, APC could be a strategic resource to fill the gap in the feed rations of Moroccan livestock (El Maadoudi and El Housni, 2013b). However, its use has been limited, largely due to the presence of some antinutritional compounds, including saponins (4%) (Charrouf *et al*. 1992), which give it a very bitter or astringent flavor (Tarade *et al*. 2006).

That makes the APC unpalatable to the livestock and impairs both their digestion of protein and uptake of vitamins and minerals during the intestinal transit (Francis *et al*. 2002).

In addition, high doses of saponins alter the quality of the goats' milk, giving it an unpleasant taste and leading to severe diarrhea in young ruminants (El Hadi, 2012).

To improve the quality of APC, which is rich in protein, and to make it more appetizing for goat livestock, it must be detoxified to decrease or remove antinutritional factors such as saponins.

The methods employed in this work were soaking and boiling in different media (neutral, acid, basic pH) to evaluate the solubilization of the saponins in distilled water, sodium bicarbonate ($NaHCO_3$) and citric acid ($C_6H_8O_7$) to choose the optimum conditions.

Information on the nutritional quality and antinutritional factors of APC is available. However, information regarding the effect of processing methods on the antinutritional factors and development the quality of APC appears to be lacking. No work has yet been done on the effect of APC on saponin levels.

Therefore, the present study uses the response surface methodology to evaluate the optimal processing method for reducing saponins in APC and to assess their impact on the nutrient contents of detoxified APC.

MATERIALS AND METHODS

Argane press cake

APC collected from the Essaouira region (Southwestern Morocco) were ground to pass a 1 mm sieve screen using a laboratory mill MF 10 basic IKA WERKE, stored in air-tight plastic containers, and kept in a refrigerator at 4 ˚C before applying various treatments.

Processing methods

The processing methods used to optimize the reduction or elimination of APC saponin content were soaking and boiling separately. In the soaking process, different APC samples were soaked in three separated media: distilled water, citric acid, and sodium bicarbonate solutions, using different concentrations, volumes, and soaking times. The boiling process was used different boiling media at different concentrations, volumes, and boiling times to reduce APC saponins.

The initial saponin content in untreated APC was used as a control to compare with the treated samples. The experiments were studied following the central composite design (CCD) (Prakash Maran *et al*. 2016).

Soaking treatment

In the first treatment, APC was soaked in distilled water at different press cake-to-water ratios (1:5, 1:12.5 and 1:20; w/v, g/mL) with different soaking times (1, 24 and 48 hours) at room temperature. Noted that the ratios of the press cake to soaking water were chosen to cover completely the press cake by water therefore to avoid the possible problem of germination caused by the soaking water. Following CCD, 12 points were obtained within the experimental domain of soaking in distilled water (Table 1).

Afterward, the water was removed completely by filtration, and the press cakes were dried at 40 ˚C in a hot air oven. In the second treatment, one gram of APC was treated with different concentrations of sodium bicarbonate solution (0.02, 1.01, and 2%) at different volumes (5, 12.5, and 20 mL) and for different time periods (1 to 48 hours) at room temperature (Table 2). The residuals were then rinsed with distilled water to remove bitterness, and the samples were dried in a hot air oven at 40 ˚C. In the third treatment, the APC were treated with different concentrations of citric acid solution (0.10, 1.05, 2%) at different ratios 1:5, 1:12.5 and 1:20 (w/v; g/mL) and over times ranging from 1 to 48 hours at room temperature (Table 2).

After soaking, the residues were rinsed with distilled water to remove the saponins, which combined with citric acid, then dried by hot air oven at 40 ˚C.

Table 1 Central Composite design to optimize the conditions of the detoxification of argane press cake by soaking in cold distilled water*

Exp N°	Volume	Time
	mL	h
1	5.00	1
2	5.00	48
3	20.0	1
4	20.00	48
5	12.50	1
6	12.50	48
7	5.00	24
8	20.00	24
9	12.50	24
10	12.50	24
11	12.50	24
12	12.50	24

* A randomized, two-factor, three-level central composite design was carried out with three replicates of each point.

Table 2 Central composite design to optimize the conditions of the detoxification of argane press cake by soaking in sodium bicarbonate and citric acid solutions*

Exp N°	Concentration of $NaHCO_3$	Concentration of $C_6H_8O_7$	Volume	Time
	%	%	mL	h
1	0.02	0.10	5.00	24
2	0.02	0.10	20.00	24
3	2.00	2.00	5.00	24
4	2.00	2.00	20.00	24
5	1.01	1.05	5.00	1
6	1.01	1.05	20.00	1
7	1.01	1.05	5.00	48
8	1.01	1.05	20.00	48
9	0.02	0.10	12.50	1
10	2.00	2.00	12.50	1
11	0.02	0.10	12.50	48
12	2.00	2.00	12.50	48
13	1.01	1.05	12.50	24
14	1.01	1.05	12.50	24
15	1.01	1.05	12.50	24
16	1.01	1.05	12.50	24

* A randomized, two-factor, three-level central composite design was carried out with three replicates of each point.

All samples were stored in airtight plastic containers at room temperature while awaiting further analyses.

Heat treatment

Three boiling media; distilled water, sodium bicarbonate solution (0.02, 1.01, and 2%), and citric acid solution (0.10, 1.05, 2%) were chosen for evaluation using reflux mounting, to determine how well different boiling media worked to eliminate the antinutrient saponin contents of APC under different boiling temperatures and for various lengths of time. The ratios of APC to boiling media were fixed at 1:5, 1:12.5 and 1:20 (w/v); the boiling temperatures selected were (40, 80, and 120 ˚C); and the boiling times used were 10, 25 and 40 minutes (Tables 3 and 4). The boiling media were removed by filtration, and then the residual press cakes were rinsed with distilled water and dried at 40 ˚C in a hot air oven. The powdered samples were stored in air-tight plastic containers at 25 ˚C until further use.

Determination of saponins from APC

Extraction of saponins

Saponin extraction was done according to the method of Charrouf (1991) with slight modification. Essentially, 1g of milled APC was extracted with 20 mL of 80% aqueous ethanol and shaken on a rocker arm for 24 hours at room temperature, followed by centrifugation at 3000 rpm for 10 minutes. Then the supernatant was collected and filtered. Afterwards, the ethanol was evaporated to dryness. The residual was dissolved in a minimum of distilled water. It was then transferred into a 250 mL separatory funnel for decantation and, after adding 20 mL of diethyl ether, it was shaken vigorously.

Table 3 Central composite design to optimize the conditions of the detoxification of argane press cake by boiling in distilled water*

Exp N°	Volume	Temperature	Time
	mL	°C	Min
1	5.00	40.00	25.00
2	20.00	40.00	25.00
3	5.00	120.00	25.00
4	20.00	120.00	25.00
5	5.00	80.00	10.00
6	20.00	80.00	10.00
7	5.00	80.00	40.00
8	20.00	80.00	40.00
9	12.50	40.00	10.00
10	12.50	120.00	10.00
11	12.50	40.00	40.00
12	12.50	120.00	40.00
13	12.50	80.00	25.00
14	12.50	80.00	25.00
15	12.50	80.00	25.00
16	12.50	80.00	25.00

* A randomized, two-factor, three-level central composite design was carried out with three replicates of each point.

Table 4 Central composite design, to optimize the conditions of the detoxification of argane press cake by boiling in sodium bicarbonate and citric acid solutions*

Exp N°	Volume	Concentration of $NaHCO_3$	Concentration of $C_6H_8O_7$	Temperatures	Times
	mL	%	%	°C	Min
1	5.00	0.02	0.10	40.00	10.00
2	20.00	0.02	2.00	40.00	10.00
3	5.00	2.00	0.10	40.00	10.00
4	20.00	2.00	2.00	40.00	10.00
5	5.00	0.02	0.10	120.00	10.00
6	20.00	0.02	2.00	120.00	10.00
7	5.00	2.00	0.10	120.00	10.00
8	20.00	2.00	2.00	120.00	10.00
9	5.00	0.02	0.10	40.00	40.00
10	20.00	0.02	2.00	40.00	40.00
11	5.00	2.00	0.10	40.00	40.00
12	20.00	2.00	2.00	40.00	40.00
13	5.00	0.02	0.10	120.00	40.00
14	20.00	0.02	2.00	120.00	40.00
15	5.00	2.00	0.10	120.00	40.00
16	20.00	2.00	2.00	120.00	40.00
17	5.00	1.01	0.10	80.00	25.00
18	20.00	1.01	2.00	80.00	25.00
19	12.50	0.02	1.05	80.00	25.00
20	12.50	2.00	1.05	80.00	25.00
21	12.50	1.01	1.05	40.00	25.00
22	12.50	1.01	1.05	120.00	25.00
23	12.50	1.01	1.05	80.00	10.00
24	12.50	1.01	1.05	80.00	40.00
25	12.50	1.01	1.05	80.00	25.00
26	12.50	1.01	1.05	80.00	25.00
27	12.50	1.01	1.05	80.00	25.00

* A randomized, two-factor, three-level central composite design was carried out with three replicates of each point.

The aqueous layer was recovered, while the ether layer was discarded (twice). The sample was reextracted with 15 mL of n-Butanol (twice).

Then the solvent was removed by rotary evaporation at 40 °C. Finally, the dry residue constituting a mixture of saponins was recovered in MeOH-water (80/20, v/v).

Standard curve for saponins

The total saponin contents of APC were estimated by the method of Hiai *et al.* (1976), expressed as diosgenin equivalents. The test was performed in triplicate, and the standard curve was (Figure 1) obtained with the regression equation y= 3.389 × -0.020 (R^2=0.99).

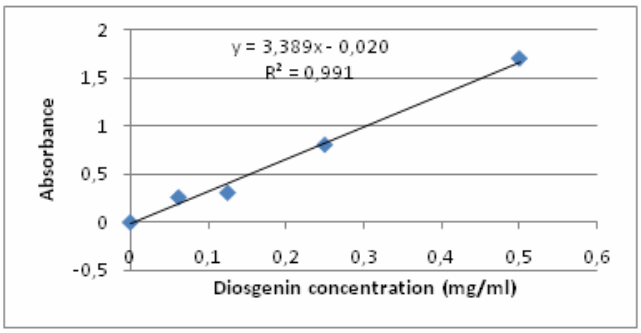

Figure 1 Calibration curve of standard diosgenin for determination of saponins content

Determination of nutritional composition of APC

The methods recommended by the Association of Official Analytical Chemicals (AOAC, 2000) were used to determine dry matter, ash, crude protein, crude fat and crude fiber.

Statistical analysis

The optimization of the detoxification of APC was carried out using the statistics of the response surface methodology, such as analysis of variance and polynomial modeling using the NEMRODW software (2006). The effect of detoxification on the nutrient composition of APC was determined by ANOVA using the SAS (2006).

Results are shown as mean ± standard deviation, and differences among means were evaluated using Duncan's new multiple range test. The significance level was set at below 0.05.

RESULTS AND DISCUSSION

Saponins are glycosidic compounds consisting of a steroid (C27) or triterpenoid (C30) aglycon 'sapogenin' bonded to one or more carbohydrates (Schwarz, 1993). APC is known for containing triterpenoid sapogenins (Guillaume and Charrouf, 2005).

In the present study, the initial saponin contents of the untreated APC was 4.56 mg/g of DM. In fact, saponins are harmless at 1% and irritating at 5% (Fenwick and Oakenfull, 1983); at 1.5%, these may also damage the mucosa of the digestive tract (Ndouyang *et al.* 2009a). Moreover, saponins can reduce protein digestibility by forming sparingly digestible saponin-protein complexes (Potter *et al.* 1993).

Soaking treatment

The three-dimensional response surface and contour plots obtained in the composite central design (shown in Figure 2) were applied to visualize the influence of process variables on the response. These have proven very helpful for assessing the relationship between independent variables and the response.

The optimum conditions for reducing the saponins proved to be the ratio of raw material to water ranging from 1:5 to 1:10 g/mL and soaking times ranging from 1 to 2 hours at room temperature.

Under these conditions, the saponin levels in the soaked APC reduced significantly (P<0.01) to 2.90 mg/g of DM as compared to untreated APC (4.56 mg/g of DM). Therefore, the decreased saponin content with an increasing volume of water could be explained by the saponins being water soluble (Shi *et al.* 2009) and being amphiphilic molecules. Furthermore, the decrease in saponin levels during soaking may be attributed to the breakdown of oligosaccharides, by a simple diffusion mechanism into the soaking medium (Shimelis and Rakshit, 2007).

However, increasing soaking times to 48 hours did not appear to influence saponin leaching. These results agree with those reported for *Jatropha curcas* seeds (Abou-Arab and Abu-Salem, 2010) and *Tacca leontopetaloides* (Ndouyang *et al.* 2015).

Optimizing the effect of soaking in sodium bicarbonate solution on APC saponin levels is shown in Figure 3. The loss of saponins increased (0.80 mg/g of DM against 4.56 mg/g of DM for the control untreated) under the influence of the concentration gradient from 0.02% to 1.10% for 12 to 24 hours at ratios 1:5 to 1:20 g/mL at room temperature. The decrease in saponin levels during soaking in sodium bicarbonate solution may be due to solubilization of those compounds in alkaline solution (Ndouyang *et al.* 2015).

Soaking in sodium bicarbonate solution was significant (P<0.01) to the elimination of APC saponins.

The effects of soaking in citric acid solution on APC saponin levels are presented in Figure 4. The optimum conditions for decreasing saponin content occurred when APC was soaked in 2% citric acid for 24 hours at a ratio of 1:20 g/mL.

APC saponin levels decreased significantly (P<0.01) after treatment from 4.56 mg/g of DM to 0.50 mg/g of DM. Greater solubilization of saponins occurred in acidic (89%) and basic (82%) media than in water (36%). This result is similar to the findings of Ndouyang *et al.* (2009b) using the plant *Tacca leontopetaloides*.

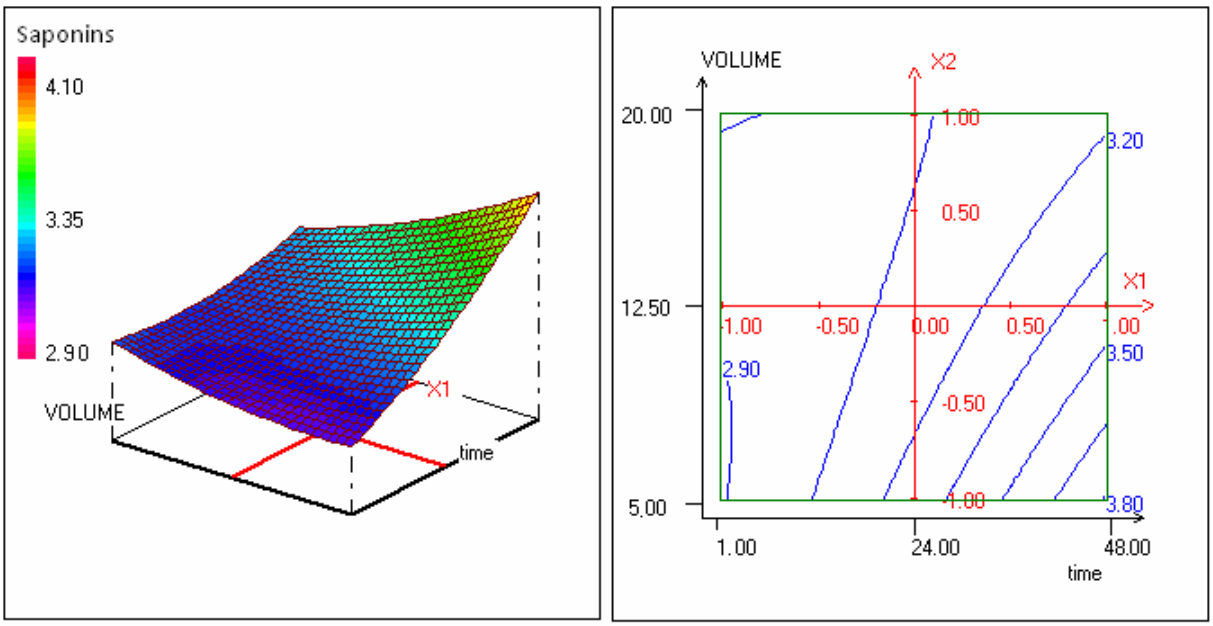

Figure 2 Response surface and contour plots showing the effect of soaking in distilled water on the levels of saponins of Argane press cake

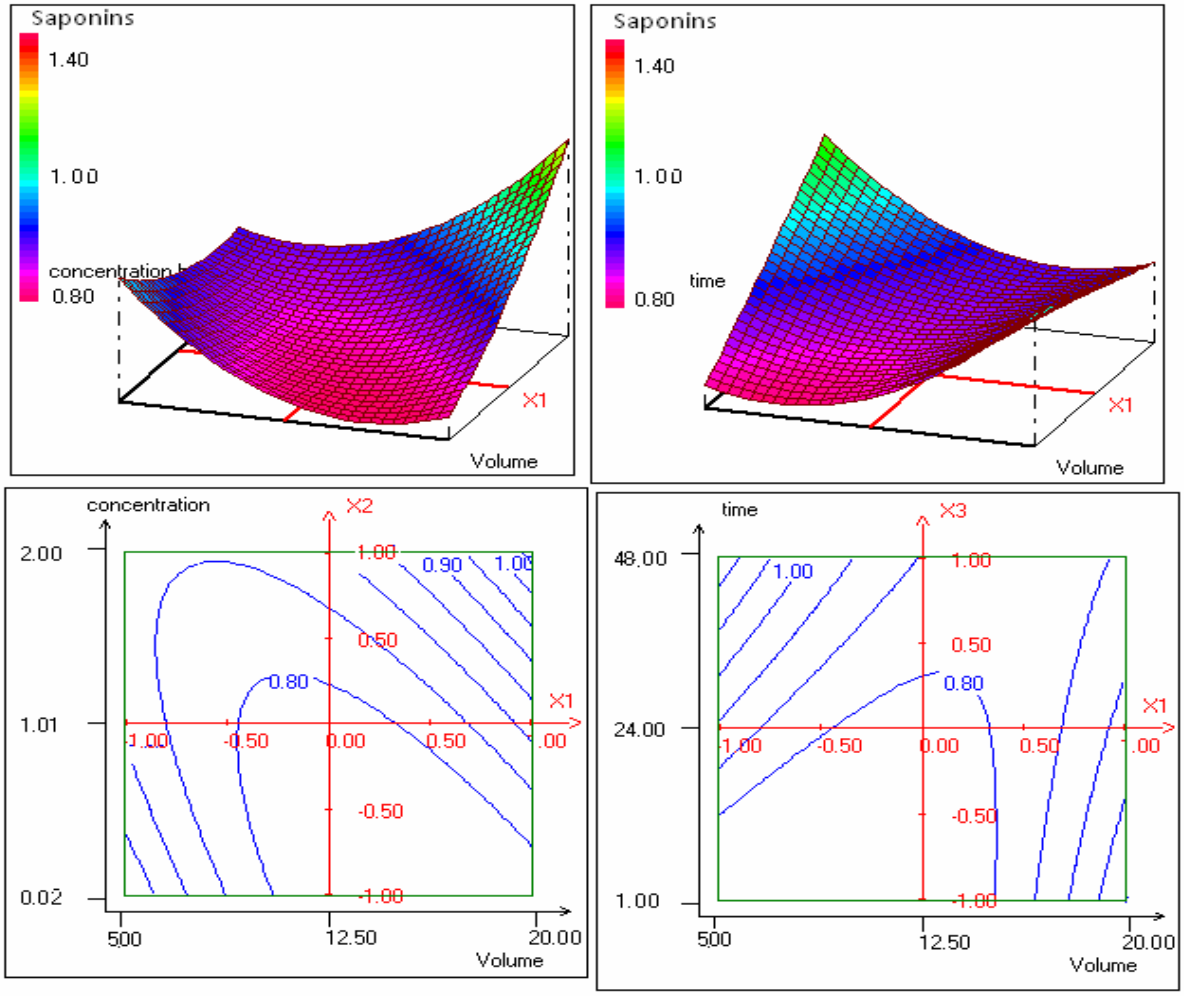

Figure 3 Response surface and contour plots showing the effect of process variables on the levels of saponins from argane press cake

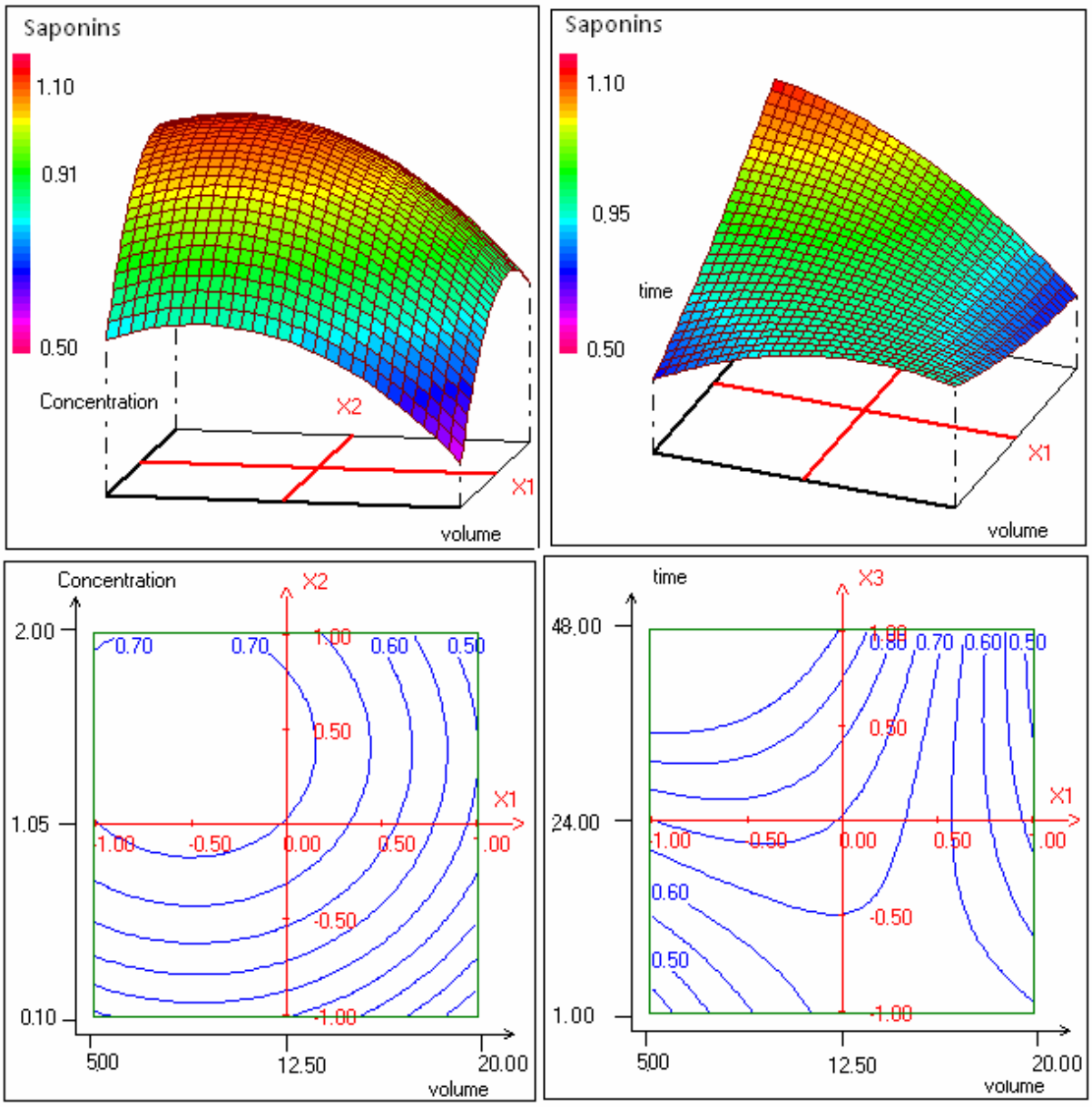

Figure 4 Response surface and contour plots showing the effect of soaking in citric acid on the levels of saponins from argane press cake

The degradation of saponin in citric acid did follow the second order polynomial with a correlation coefficient (R2=0.920). The polynomial model derived from the data obtained using the central composite design for total saponin content is presented in equation (1):

Saponin content (mg/g of DM)= 0.697 - 0.107 × X1 + 0.110 × X2 + 0.112 × X3 - 0.105 × (X1×X1) – 0.131 × (X2×X2) + 0.035 × (X3×X3) – 0.012 × (X1×X2) – 0.201 × (X1×X3) + 0.128 × (X2×X3)

Where:
X1, X2, and X3: respectively, volume, concentration, and time of soaking.

Heat treatment

The results showing how boiling in distilled water affects APC saponin levels are shown in Figure 5.

Boiling the APC in distilled water at the ratio of 1:12.5 g/mL for 25 minutes at 80 ˚C significantly (P<0.01) reduce the saponin content from 4.56 mg/g of DM to 0.4 mg/g of DM.

The data from the present study revealed that boiling in distilled water is more effective (91%) than soaking in cooled water (36%) for decreasing saponin levels. These results agree with those for *Tacca leontopetaloides* (Ndouyang *et al.* 2015).

According to Figure 6, the optimal conditions for boiling APC in the sodium bicarbonate solution were as follows: a

1.01% concentration of sodium bicarbonate solution,a boiling time of 25 minutes, an APC to sodium bicarbonate solution ratio ranging from 1:6 to 1:20 g/mL, and a boiling temperature at 60 ˚C. Under these optimum conditions, the level of saponins was reduced to 0.6 mg/g of DM. The loss in APC saponins (86%) during boiling was higher than soaked whole and kernel of *Jatroph acurcas* seeds in 0.07% sodium bicarbonate (2%) followed by autoclaving at 121 ˚C for 25 minutes (Abou-Arab and Abu-Salem, 2010). That might be due to the concentration of sodium bicarbonate solution used by Abou-Arab and Abu-Salem (2010), or to the high energy level produced by the combination of high temperature and high pressure in the autoclave. The optimization of boiling APC in the citric acid solution (Figure 7) showed that using a 1.05% concentration of citric acid at a ratio of up to 1:12.5 g/mL and boiling for 25 minutes at 100 ˚C significantly reduced saponin levels.

The lowest saponin content during boiling in citric acid solution was 0.2 mg/g of DM. Boiling in citric acid reduced saponins by up to 95%.

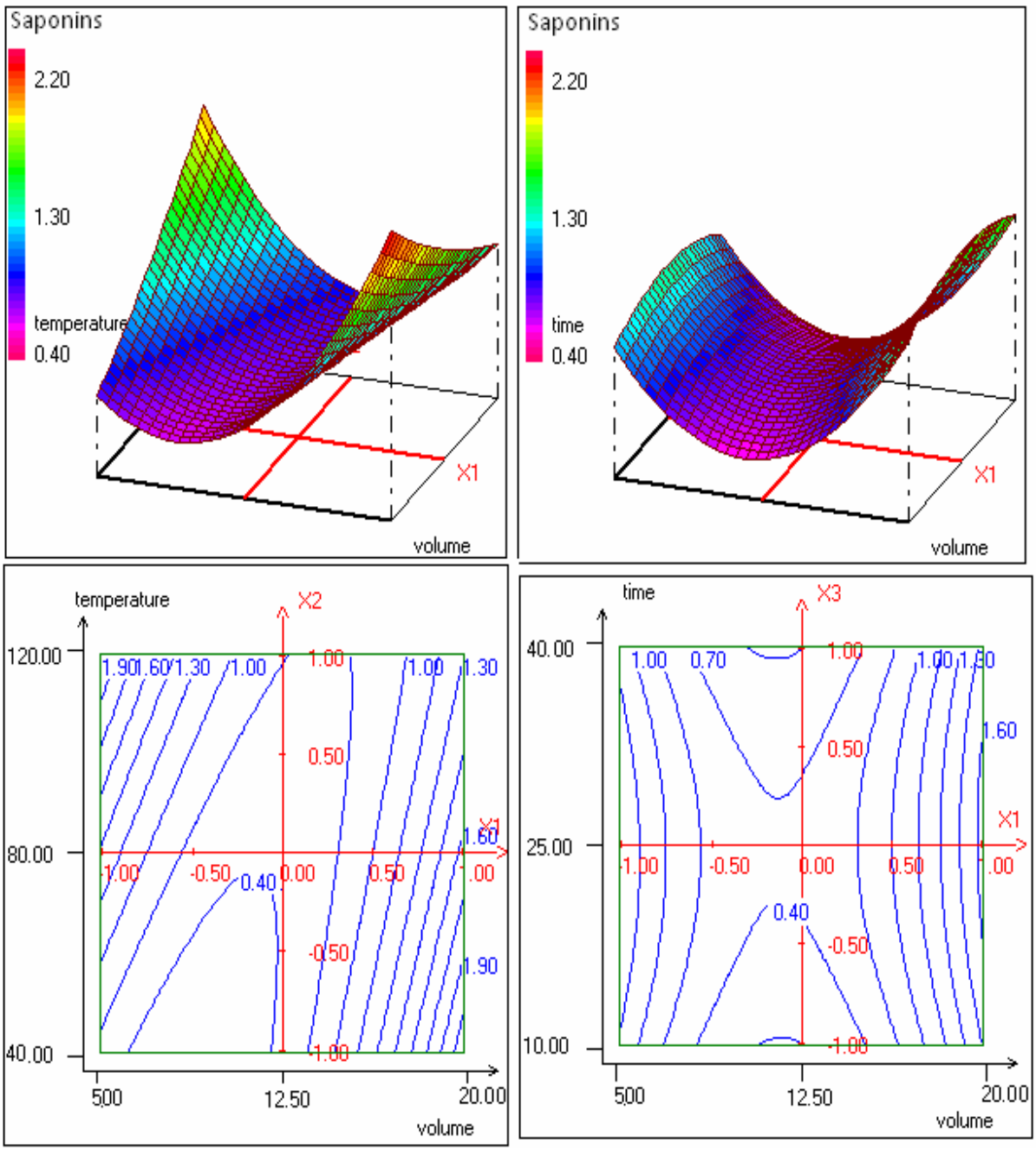

Figure 5 Response surface and contour plots showing the effect of boiling in distilled water on level of saponins from argane press cake

The polynomial model from the data obtained in the central composite design for total saponin levels is presented in equation (2):

Saponin content (mg/g of DM)= 0.654 + 0.009 × X1 - 0.061 × X2 - 0.418 × X3 + 0.086 × X4 + 0.272 × (X1×X1) + 0.167 × (X2×X2) + 0.057 × (X3×X3) + 0.187 × (X4×X4) + 0.290 × (X1×X2) - 0.203 × (X1×X3) - 0.051 × (X2×X3) - 0.079 × (X1×X4) + 0.175 × (X2×X4) - 0.120 × (X3×X4)

Where:
X1, X2, X3, and X4: respectively,concentration, volume, temperature and time of boiling.

The degradation of saponins under different boiling conditions followed the second order polynomial with a correlation coefficient (R^2=0.96) for boiling in citric acid; the correlation coefficients for boiling in distilled water and sodium bicarbonate were 0.71 and 0.80, respectively.

This study, using the response surface methodology to optimize the elimination of saponins from APC, showed that the thermal treatments had more pronounced effects on saponin degradation than the soaking treatments.

Effect of different treatment on the nutritional composition of APC

The optimal conditions for each treatment to induce the maximum reduction of the saponin content was chosen to study their impact on APC nutritional quality. The compositions of APC, untreated and treated by soaking as well as by boiling, are presented in Table 5. The data indicate that untreated APC contains 93% dry matter, 48% protein, 4.75% ash, 17.72% fiber, and 23.45% fat.

However, some studies reported that the APC contains dry matter, protein, ash, fiber and fat at levels equal to 91, 48.4, 5.3, 17.6, and 18.9%, respectively. On the other hand, Maallah *et al*. (1995) reported a lower value of protein (19 to 23%) and a higher value of fat (18 to 28%).

Regarding the APC treated by soaking in distilled water, sodium bicarbonate solution, and citric acid, the data show that it contained, respectively, 89, 90, and 92% dry matter values very similar to those obtained during heat treatment (Table 5). These experimental results showed a significant difference between the detoxified meal and the non detoxified meal in terms of dry matter. The method used for detoxification, i.e., soaking only, increased APC moisture content.

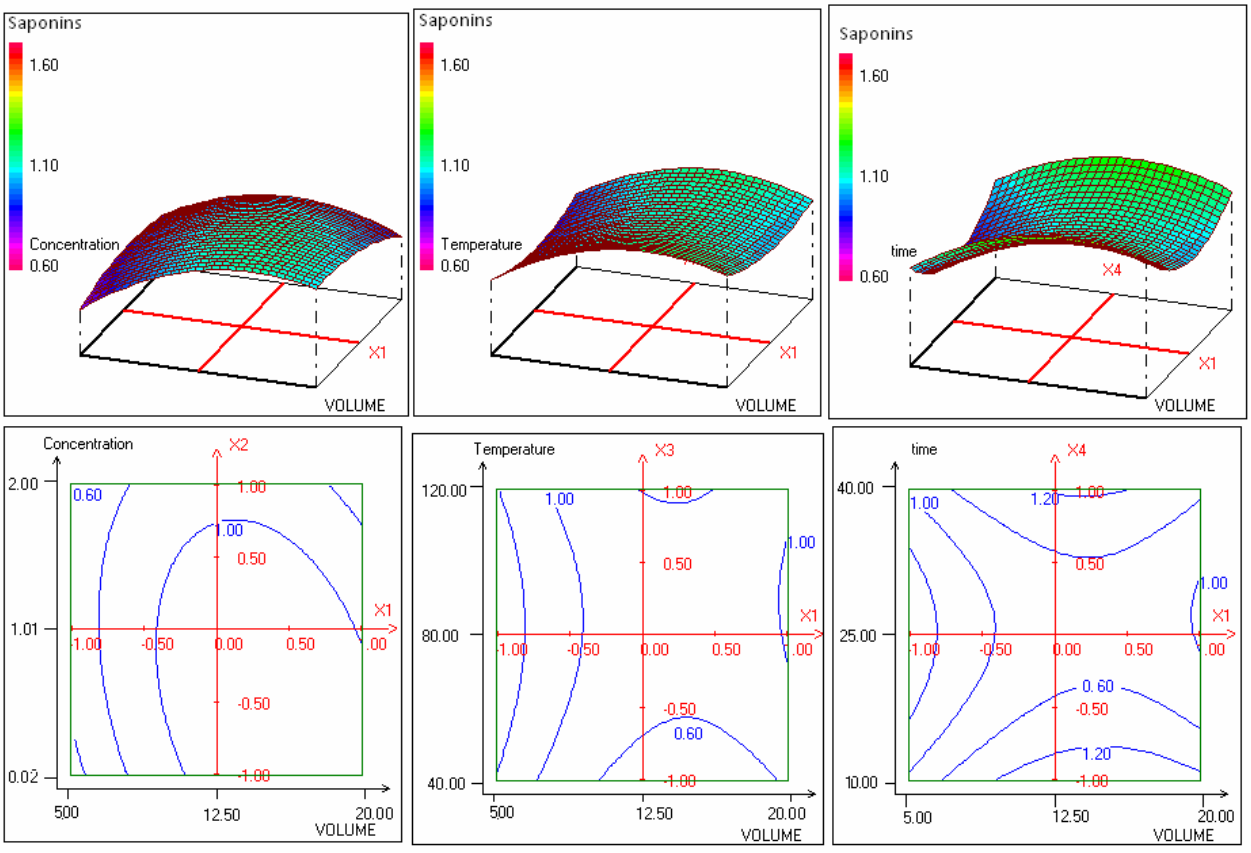

Figure 6 Response surface and contour plots showing the effect of boiling in sodium bicarbonate on level of saponins of argane press cake

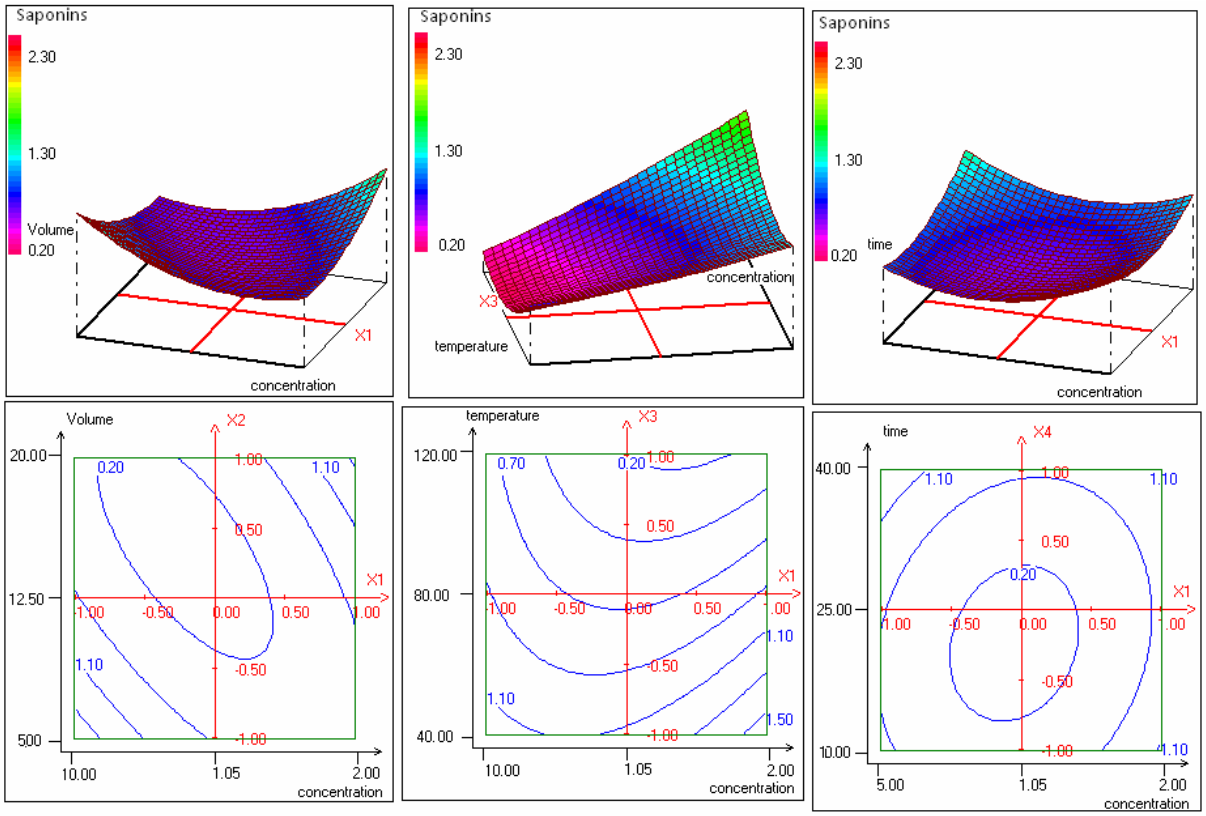

Figure 7 Response surface and contour plots showing the effect of boiling in citric acid on level of saponins of argane press cake

Table 5 The nutritional composition of APC treated by different methods and untreated ones

Nutrients	Argane press cake untreated	Argane press cake treated					
		Soaking treatment			Boiling treatment		
		Distilled water	$NaHCO_3$	$C_6H_8O_7$	Distilled water	$NaHCO_3$	$C_6H_8O_7$
Dray matter (%)	93.02±0.01^a	89.46±0.04^b	90.42±0.02^b	92.39±0.09^a	89.14±0.32^b	90.98±0.08^b	93.77±0.13^a
Crude protein (%)	48±0.28^a	47.90±0.02^a	40.94±0.08^c	47.80±0.16^a	47.43±0.11^b	40.38±0.09^c	47±0.09^b
Ash (%)	4.75±0.03^a	3.02±0.02^b	3.50±0.02^b	2.79±0.06^b	3.10±0.02^b	3.23±0.01^b	2.80±0.02^b
Crude fiber (%)	16.72±0.00^a	16.66±0.02^a	16.33±0.02^a	16.67±0.03^a	13.65±0.05^b	12±0.06^c	12.27±0.06^c
Fat (%)	23.45±0.06^a	20.46±0.09^b	19.83±0.05^b	17.33±0.02^c	17.05±0.01^c	17.46±0.04^c	16.73±0.04^c

The means within the same column with at least one common letter, do not have significant difference (P>0.05).

The protein content of APC soaked in distilled water, sodium bicarbonate, and citric acid were 47.90, 40.94, and 47.8%, respectively again, values very similar to those obtained during boiling treatment (Table 5). Compared to the protein content of untreated APC (48%), a slight reduction in protein content was observed during the soaking and boiling of the APC in distilled water and in citric acid.

Larger decreases in protein were found only when the APC was detoxified by soaking or boiling in sodium bicarbonate (40.94 and 40.38%, respectively). This difference might be due to the solubility of the protein in water and/or its denaturation by temperature (Gabrial and El Nahry, 1981).

Soaking changed the ash content significantly from 4.75% in untreated APC to 3.02, 3.50, and 2.79% in APC soaked in distilled water, sodium bicarbonate, and in citric acid, respectively. In addition, the values obtained when APC was subjected to the thermal process (3.10, 3.23, and 2.80%) were lower than those obtained in the untreated sample (Table 5). Both processes, soaking or boiling, had almost the same effect, and both differed from the untreated sample.

The fiber content of untreated APC (16.72%) was not significantly changed by the soaking treatment in distilled water, sodium bicarbonate, and in citric acid, which reduced fiber levels to 16.66, 16.33, and 16.67%, respectively.

However, boiling APC significantly (P<0.05) decreased fiber content during treatment (Table 5), dropping in distilled water to 13.65%, in sodium bicarbonate to 12%,and in citric acid to 12.27%.

The fat content decreased from 23.45% in untreated APC to 20.46, 19.83, and 17.33% from soaking APC in distilled water, sodium bicarbonate, and in citric acid, respectively. Boiling decreased APC fat content further to 17.05, 17.46, and 16.73% in distilled water, sodium bicarbonate, and citric acid, respectively.

CONCLUSION

APC is an interesting source of protein and fiber and contains appreciable amounts of antinutrients, especially saponins. Though currently underutilized, APC is nutritionally promising, and detoxifying it by soaking and / or by boiling in solution reduces their saponin levels to more than half. Despite the slight reduction of protein level due to the detoxification method; this process improves protein digestibility of argane press cake by making APC more appetizing for livestock, valorize it as livestock feed, and ameliorate protein malnutrition, which is a major animal feed problem in Morocco.

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