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Influence of process parameters on bulgur quality

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RESEARCH ARTICLE

Abstract

In this study, conditions for producing high-quality bulgur were improved by studying the effects of cooking time (CT), moisture content before debranning (MC) and debranning time (DT). Bulgur quality was then assessed based on yield, colour and ash content. A central composite plan and an analysis of variance were used to test the adequacy, significance and meaningfulness of all the responses using the mathematical model developed. The results showed that CT had a positive effect on both bulgur yield and lightness of colour. DT had a negative effect on yield, red colour and ash content, but a positive effect on lightness (L*) of bulgur. There was a significant effect on bulgur yield and red colour (a*) due to the interaction between CT and MC. In addition, the effect of interaction of CT and DT on the later response was also significant (R^2=0.95%). The optimal conditions for high-quality precooked wheat were a CT of 43 min, MC of 15.5% and a DT of 1.6 min. Under these conditions, optical microscopy observation showed the presence of an aleuronic layer, the most nutritive branny wheat layer.

Keywords: precooked wheat, optimisation, debranning conditions, bulgur

1. Introduction

Bulgur is an industrially processed ancient durum wheat product, very popular in near Eastern and Mediterranean regions. It can be classified either as a semi-ready-to-eat food (pilaf etc.) or a ready-to-eat food (köfte, kısır, etc.) (Bayram, 2000). Bulgur can be considered as a practical food since it is highly nutritional (Caba *et al.*, 2012). It is also an important source of dietary fibre because it contains 18.3 g per 100 g (Bayram and Öner, 2007; Dreher, 2001) and has a low glycaemic index (Jenkins *et al.*, 1986). Generally, durum wheat is preferred to produce bulgur, but some researchers choose to use bitter, sweet lupin (Yorgancilar and Bilgiçli, 2014), barley (Köksel *et al.*, 1999), soybean (Bayram *et al.*, 2004a) or chickpea (Ertas and Türker, 2014) instead of durum wheat. The quality of durum wheat has a direct impact on bulgur quality, and a high positive correlation has been found between bulgur yield and the thousand kernel weight and also between bulgur cooking quality and protein content (Özboy and Köksel, 2002; Tekdal *et al.*, 2016).

To produce bulgur, cleaned and washed wheat grains are boiled for 45-60 min for complete starch gelatinisation. 40 min is proposed as the optimum cooking time (CT), where the starch appears totally gelatinised without any deformation of the wheat kernel (Bayram, 2005). During this step, both CT and temperature directly affect the dimensions, volume and crease of the wheat kernel (Bayram *et al.*, 2004b). This step is the most important in controlling bulgur quality due to the possible risk of deformation or dispersion of the wheat kernel (Stapley *et al.*, 1997).

The product is then dried in order to decrease moisture content from 45 to 10% (dry basis). Traditionally, the cooked wheat is spread onto a flat surface and left to dry under sun for 8-10 h. This technique has some disadvantages including difficulty in controlling operation parameters (quantity of sun ray, uneven drying, percentage product loss), a non-standardised product and some hygienic issues (Balci and Bayram, 2005). However, various other drying methods have been studied for effect on bulgur quality. Hayta (2001) showed that microwave-drying methods positively affect protein extractability, bulgur yield, and water and oil absorption of bulgur. However, when this technique is assisted by spouted bed drying, the bulgur has a more porous microstructure and lower water absorption capacity and therefore, drying time is decreased (Kahyaoglu *et al.*, 2010). Savas and Basman (2016) used infrared treatment at various power levels and time periods as an alternative bulgur drying technique. The results showed that infrared-dried samples were comparable to sun-dried samples in terms of quality and at the same time decreased drying time, thus indicating that infrared drying is a promising technique.

After drying, precooked wheat is tempered at a fixed moisture content (around 17%) to facilitate the debranning process, which consists of removing the outer layers all around the dorsal part of the grain by abrasion and friction (Rios *et al.*, 2009).These tissues have considerable nutritional potential and contain most of the micronutrients, phytochemicals and fibre of the grain (Hemery *et al.*, 2007). Hence, the degree of debranning is very important since it affects the qualities of the final product (Gys *et al.*, 2004) by changing the flour characteristics (such as ash and pericarp content) and its performance in bread making (Lin *et al.*, 2012). It also affects the distribution of pentosan and the antioxidant activity of wheat (Sapirstein *et al.*, 2013). In the case of durum wheat, debranning prior to milling improved both yield and degree of refinement of the semolina. Debranning up to 4% revealed better physico-chemical, cooking and textural properties in this kind of wheat (Singh and Singh, 2010). Debranning significantly changed the cooking characteristics of the grain where a decrease in CT was observed after debranning to 4 and 8% (Singh and Singh., 2010).

Many works have studied the effect of each step of bulgur processing on quality but no literature has studied the interaction of these different unit operation steps on bulgur quality. Moreover, the quality of bulgur is defined by taking into account different parameters such as colour, carotenoid pigment (Balci and Bayram, 2005), CT and cooking loss (Savas and Basman, 2016), bulk density (Hayta, 2001) and other such factors (total organic matter, bulgur surface image analysis, etc.). Hence, the aim of this work was to study the effect of three processing parameters and their interaction on bulgur quality using a response surface methodology in order to produce bulgur both with high quality and nutritive value.

2. Materials and methods

Physical analysis of raw material

For this study, bulgur was prepared from a Tunisian durum wheat (*Triticum durum*), Maali variety, for one cultivation with high quality. It's the most cultivated variety in the country. The moisture, protein and ash content were 11, 13 and 1.69% (d.b), respectively. The yellow berry percentage was 1.29% and the thousand kernel weight was 83 kg/hl. Moisture content before debranning (MC) was determined according to the AACC approved method 44-15A (AACC, 2000). Grain protein was evaluated using a NIR System (Perten-Inframatic-8600, Perten Co, Hägersten, Sweden) (Sgrulletta and De Stefanis, 1997). Ash content was evaluated according to TN 51.34 (ISO 2171, 2007). Thousand kernel weight was determined using the Numigral Chopin (Chopin technologies, Villeneuve-la-Garenne, France). Yellow berry rate was determined by inspecting 50 kernels sliced using a Pohl's farinator (Chopin technologies).

Bulgur processing

The grain was cleaned with distilled water for 1 min to remove any adhesive particles stuck on the surface of the kernels. The grain was then cooked in boiling water for various times set by the experimental design (Table 1). Precooked grain (100 g) was dried using a convective heat dryer (Monferrina EC50, Imperia & Monferrina S.p.a., Moncalieri, Italy) to an MC set according to the experimental design (Table 1). The temperature and time of drying processes were predetermined by modelling the bulgur kinetic drying at different conditions (Smirani and Sfayhi, 2016).

After cooking, the grains were debranned with an abrasive laboratory mill (Strong-Scott, England) at a constant speed of 830 rpm. The debranning operation was monitored by time according to the experimental design (Table 1). The debranned grains were separated from the dehulled fraction with a sieve of 1.04 mm set in the apparatus. For this study, bulgur is considered the recovered sample and is defined as a cooked, dried and debranned durum wheat grain (whole grain).

Experiment design

Response surface methodology was used to determine optimum conditions for bulgur processing. A central composite face-centred experimental design was planned in the present study to model and analyse the effect of different independent variables, i.e. CT, MC and debranning time (DT), and their interactions. The experimental design was generated by combining a two-level full factorial design with axial experiments requiring a number of experiments equal to $N = Lk + 2 \times k + Nc$. L represents the number of levels for the investigation (two in our case), k is the number of variables (three in our case) and N_c is the number of central experiments (Mangili *et al.*, 2015).

Table 1 shows maximum (coded as +1), minimum (coded as −1) and central (coded as 0) levels for each processing

Table 1. The central composite experimental design arrangement and the observed responses.

Run no.	Value of parameters[1]			Yield (%)	Responses			
	CT	MC	DT		Ash content (%) d.b	Colour parameters		
						a*	b*	L*
1	10.13	11.6	1.6	47.59	0.61	-0.86	11.76	94.11
2	40	11.6	1.6	76.40	0.78	-0.7	11.57	93.29
3	10.13	16	1.6	69.73	0.78	-0.38	11.07	92.87
4	40	16	1.6	76.66	0.88	-0.43	11.43	93.13
5	10.13	11.6	3.5	15.33	0.54	-1.06	11.85	94.12
6	40	11.6	3.5	53.59	0.68	-0.71	11.43	93.19
7	10.13	16	3.5	44.53	0.74	-0.55	10.59	92.66
8	40	16	3.5	62.79	0.59	-1.03	11.09	94.11
9	0	13.8	2.5	58.00	0.9	-0.52	11.46	92.34
10	50	13.8	2.5	77.33	0.77	-0.51	11.17	93.51
11	25	10	2.5	30.13	0.44	-1.11	11.05	94
12	25	17.5	2.5	62.53	0.89	-0.6	11.27	92.68
13	25	13.8	1	86.53	0.94	-0.37	10.47	91.26
14	25	13.8	4	43.73	0.82	-0.62	9.56	93.04
15	25	13.8	2.5	61	0.82	-0.77	9.56	93.62
16	25	13.8	2.5	61.86	0.81	-0.68	9.45	93.64
17	25	13.8	2.5	61.03	0.77	-0.66	9.26	93.19
18	25	13.8	2.5	62.13	0.87	-0.7	10.27	93.65
19	25	13.8	2.5	62.93	0.83	-0.7	10.56	93.04
20	25	13.8	2.5	63.20	0.82	-0.62	10.73	93.61
21	25	13.8	2.5	61.20	0.71	-0.7	10.62	93.81
22	25	13.8	2.5	64.40	0.89	-0.65	10.79	93.04
23	25	13.8	2.5	62.13	0.86	-0.67	10.61	93.33

[1] CT = cooking time (min); DT = debranning time (min); MC = moisture content before debranning (%).

variable, i.e. CT, MC and DT. A CT range of 10.13-40 min, MC range of 11.6-16% and DT range of 1.6-3.5 min were selected based on primary experiments (data non shown). Twenty-three experiments were carried out and the bulgur yield, grain colour and ash content were chosen as experimental responses. Table 1 summarizes the experimental design and the responses observed.

A preliminary regression model was given by Equation 1 which contains the significant factors and interactions:

$$Y_i = b_0 + \sum b_j X_j + \sum_{j \neq k} b_{jk} X_j X_k + \sum b_{jj} X_j^2 \quad (1)$$

Where Y_i is the chosen response *i*, b_0 indicates the offset term, b_j the estimation of the significant factor effect *j* and X_j is its level. b_j is the linear effect, b_{jj} is the squared effect of the variables. b_{jk} is the interaction effect between the variables X_i and X_k. The experimental design and statistical analyses were analysed by using NemrodW Software (version 3, Marseille, France)

Three sets of contour plots for the significant responses were generated by NemrodW software using the equation above. Each set of the contour plots was produced for a combination of two variables by holding one variable constant at the medium level and varying the other two variables.

Yield measurement

During the debranning operation, a percentage of outer layers are removed, some grains lose their shape, and some others break. The yield of debranned grains is expressed using the ratio of the debranned grain (entire kernel shape) to initial whole grain mass (%).

Colour measurement

Colour values of bulgur samples were determined by a Minolta Chroma Meter CR-200 (Minolta Camera Co., Ltd., Osaka, Japan) in reflection mode. The instrument was standardised with a white ceramic plate (Calibration Plate CR-A43, Minolta Camera Co., Ltd., Osaka, Japan). The parameters determined were L* values corresponding to lightness, greenness (-a*)/ redness (+a*), blueness (-b*)/ yellowness (+b*).

Microscopic observations

Samples were fixed overnight in formaldehyde acetic acid ethanol (10 : 5 : 85) for 24 h. The following steps of histological protocol consisted of dehydrating through a graded ethanol-xylene series and embedding in paraffin wax. The samples were carefully oriented in the moulds to facilitate subsequent longitudinal sectioning. Afterwards, 8 µm sections were made with a rotary microtome (RM2125RT, Leica, Appareillage et Equipement Scientifique, Mahdia, Tunisia) and double-stained with haematoxylin (Fluka, St Quentin Fallavier, France) for 15 min and safranin (Riedel-de Haën, Seelze, Germany) for 48 h. Slides were viewed with an optical microscope (Leica DMLB2) and photographed using the same digital camera (Canon S50, Mahdia, Tunisia) (Jedidi *et al.*, 2015).

3. Results and discussion

Responses for bulgur yield, colour parameters (a*, b*, L*) and ash content were measured for bulgur under different combinations of CT, MC and DT, as defined in the design (Table 1). From Table 1, bulgur yield varied from 15.33 to 86.53%, ash content varied from 0.44 to 0.94% (d.b), colour parameters varied from -1.11 to -0.43 for red colour (a*), from 9.26 to 11.76 for yellowness (b*) and from 91.26 to 94.12 for lightness L*.

Effect of processing factors on bulgur yield

Table 2 recapitulates the effect of all the studied unit operation parameters on bulgur yield. DT had the strongest negative effect on bulgur yield since it had the lowest coefficient of the investigated factors. This result was

Table 2. Regression coefficient (RC) of the second-order polynomials showing the relationship between response variables and independent variables.[1]

Coefficients	Bulgur yield (%)				Ash content (% d.b)			
	RC	SD	*t*-exp	SIGN	RC	SD	*t*-exp	SIGN
b_0	62.289	0.378	164.74	<0.01***	0.822	0.018	45.24	<0.01***
b_1	9.14	0.307	29.75	<0.01***	0.003	0.015	0.21	83.6
b_2	8.44	0.307	27.49	<0.01***	0.083	0.015	5.64	<0.01***
b_3	-12.16	0.307	-39.60	<0.01***	-0.051	0.051	-3.48	<0.01***
b_{11}	1.2	0.285	4.06	<0.01***	-0.014	0.014	-1	34.8
b_{22}	-6.34	0.285	-22.43	<0.01***	-0.074	0.014	-5.39	<0.01***
b_{33}	0.26	0.285	0.91	39.2	0.002	0.014	0.16	87.1
b_{12}	-5.23	0.401	-13.05	<0.01***	-0.045	0.019	-2.33	<0.01***
b_{13}	2.6	0.401	6.47	0.024***	-0.035	0.019	-1.81	10.5
b_{23}	2.00	0.401	4.98	<0.01***	-0.02	0.019	-1.04	33.2

Coefficients	a*				b*				L*			
	RC	SD	*t*-exp	SIGN	RC	SD	*t*-exp	SIGN	RC	SD	*t*-exp	SIGN
b_0	-0.6812	0.01403	-48.541	<0.01***	10.1952	0.20274	50.2861	<0.000***	93.43	0.0968	964.20	<0.000***
b_1	-0.0002	0.0114	-0.0204	0.9842	-0.0174	0.16468	-0.1057	0.91841	0.141	0.078	1.793	0.1106
b_2	0.1316	0.01140	11.5465	<0.01***	-0.1508	0.16468	-0.9158	0.353	-0.304	0.078	-3.870	0.004**
b_3	-0.1025	0.0114	-8.9947	<0.01***	-0.176	0.16468	-1.0672	0.279	0.2689	0.078	3.4178	0.009**
b_{11}	0.0393	0.01056	3.7268	<0.01***	0.49186	0.15265	3.22203	0.012**	-0.042	0.072	0.5806	0.5774
b_{22}	-0.0807	0.01056	-7.646	<0.01***	0.43707	0.15265	2.86314	0.021**	0.104	0.072	1.4301	0.1905
b_{33}	0.04645	0.01056	4.3657	0.002**	0.03236	0.15265	0.21195	0.8374	-0.3163	0.072	-4.335	0.002**
b_{12}	-0.13	0.01489	-8.7275	<0.01***	0.18375	0.21518	0.85393	0.386	0.4325	0.1028	4.205	0.002**
b_{13}	-0.03	0.01489	-2.014	0.07884	-0.0112	0.21518	-0.0522	0.9595	0.135	0.1028	1.312	0.22566
b_{23}	-0.07	0.01489	-4.6994	0.001**	-0.0962	0.21518	-0.4472	0.644	0.1075	0.1028	1.045	0.3264

[1] ** significant at $P \leq 0.01$, *** significant at $P \leq 0.05$

expected since increased DT induces increased abrasion of the wheat kernel; the bulgur samples thus cannot completely maintain their structure intact during debranning and differences occur in particle size distribution.

CT had the most significant effect on yield, and a positive correlation was observed. Cooking conditions are the most important factor in bulgur quality (Bayram *et al.*, 2004b). Hence, a second-order polynomial (Equation 2) was proposed to predict bulgur yield:

$$\text{Bulgur Yield (\%)} = 62.15 + 9.14CT + 8.44MC - 12.16DT - 6.34MC^2 - 5.23CT \times MC + 2.6CT \times DT \quad (2)$$

The % adjusted R^2 for bulgur yield was 0.95%. This indicates the adequacy of the model, confirmed by the analysis of variance (Table 3) where *P*-values were less than 0.05.

Figure 1 (A-B) shows the surface response curves concerning the response bulgur yield, generated from significant interactions between CT/MC and CT/DT. Taking MC at the medium level of the independent variable, it was found that bulgur yield decreased with increased DT, going from 76% for 1.6 min of DT to 47% for 3.5 min, but increased with increased CT (Figure 1A). Reduced bulgur yield at high DT could be due to the increase of wheat fractions under debranning where the grain loses its shape (Bayram and Öner, 2007). However, the increase of this parameter with CT could be explained by the fact that, during cooking, there is reduced adhesion between starch and protein which directly decreases the hardness of the wheat kernel and therefore raises bulgur yield values (Dobraszczyk *et al.*, 2002).

At the medium level of DT, MC significantly affected bulgur yield depending on CT (Figure 1B), where an increase of bulgur yield was observed with an increase of MC at different CT. This positive correlation could be explained by the fact that increasing moisture content in the grain results in an increase in the plasticity of both the nucleus and the bran (Glenn and Johnston, 1992) and a decrease in the hardness of the kernel (Warechowska *et al.*, 2016) and therefore an increase of bulgur yield after debranning.

Effect of processing parameters on bulgur colour

Visual appearance, especially colour, is the most important parameter in defining bulgur quality and determining whether the product will be chosen or rejected by consumers. In durum wheat, the carotenoid pigment and lipoxygenase activity are responsible for b* of the grain.

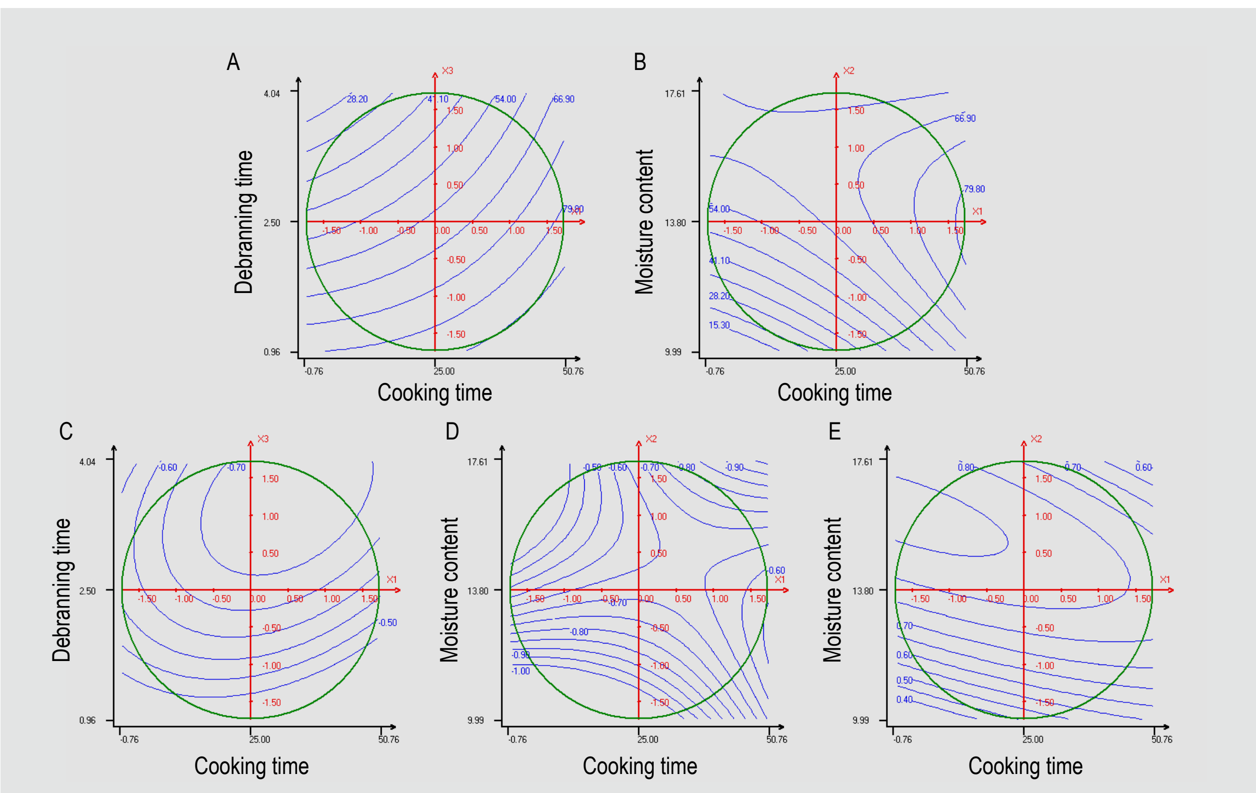

Figure 1. Response surface curves showing the effect interaction between significant factors cooking time, moisture content before debranning before drying and debranning time, on bulgur yield (A,B), on bulgur red colour (a*) (C) and on bulgur luminosity L* (D) and ash content (E).

Peroxidase and polyphenoloxidase activity and ash content are the main factors contributing to the a* of the grain (Borelli *et al.,* 2003; Kobrehel *et al.,* 1974).

Bulgur a* values were significantly affected by the linear terms of DT (-0.103) and its quadratic term (0.046) (Table 2), and they decreased as DT increased (Table 1). This behaviour can be attributed to the removal of the outer layers of the kernel including the pericarp and the aleuronic layers, which are very rich in carotenoid pigments and display high peroxidase activity (Borelli *et al.,* 2008) sequentially during debranning.

This result is consistent with that previously reported by Singh and Singh (2010) who found a decrease of a* values to 5.9 and 4.1 after debranning of uncooked wheat grain to 4% and 8%, respectively.

In contrast, MC had a strong positive effect on the redness of bulgur (a*) since its linear coefficient was the highest (Table 2). This result is consistent with that previously reported by Balci and Bayram (2005) who found a similar correlation when they compared two tempering methods for bulgur and showed that a* values increased with spray tempering in contrast with steam tempering.

A second polynomial equation was proposed to predict the a* of bulgur, where the percentage of adjusted R^2 was 0.95%. This indicates the adequacy of the model and was confirmed by the analysis of variance (Table 3) where *P*-values were less than 0.05.

$$a^* = -0{,}681 + 0.132MC - 0.103\,DT + 0.039\,CT^2 - 0.081\,MC^2 + 0.046\,DT^2 - 0.13CT \times MC - 0.07\,CT \times DT \quad (3)$$

The contour plot (Figure 1C) confirms the decrease of a* values with DT, which go from -0.37 at 0.9 min to -0.7 at 4.2 min. This result confirms that the pericarp and aleuronic fractions of branny tissues are very rich in the anti-oxidant compounds and beta carotenoid compounds responsible for wheat colour (Borelli *et al.*, 2008; Harry *et al.,* 2013).

Concerning the response chosen for the b* of bulgur, only the quadratic effect of MC and CT was significant (Table 2). The latter factor had the strongest effect on b*, but the proposed model for b* was not predictive (R^2=0.21, Table 3) and therefore no surface curve could be presented. However, other studies have shown a decrease in b* values in various cereal products during cooking, where a loss of carotenoid pigments was observed for bread (29%) (Hidalgo *et al.*, 2010), when manufacturing breakfast cereal (Horrobin *et al.,* 2003), or during the pasta-making process (Trono *et al.,* 1999). This tendency can be explained by the degradation of pigments due to high temperature (Feillet *et al.,* 2000; Horrobin *et al.,* 2003; Kahyaoglu *et al.,* 2010).

Lightness (L*) refers to the capacity of an object to reflect or transmit light (Hidalgo *et al.,* 2010). As seen in Table 2, DT had a positive effect and increased L* values. This result is in agreement with work done by Singh and Singh (2010) who showed an increase in L* values with a higher percentage of debranning common wheat varieties. A second-order polynomial equation was proposed to predict L* as a function of different factors in the following equation:

Table 3. Analysis of variance on the effect on independent variables an linear, quadratic and interaction terms on the responses variables.[1]

Source of variation		SS	DF	MS	Ratio	Signification
Bulgur yield (%)	Regression	5,115.7	9	567.952	440.8499	<0.01***
	Residual	182.840	13	14.0646		
	Total	5,294.41	22			
a*	Regression	0.7257	9	0.0806	45.4283	<0.01***
	Residual	0.1040	13	0.0080		
	Total	0.8297	22			
b*	Regression	7.9279	9	0.8809	2.6609	0.053
	Residual	4.3036	13	0.3310		
	Total	12.2315	22			
L*	Regression	6.0591	9	0.6732	7.9579	<0.01***
	Residual	3.4563	13	0.2659		
	Total	9.5155	22			
Ash content (% d.b)	Regression	0.2495	9	0.0277	9.3183	<0.01***
	Residual	0.1006	13	0.0077		
	Total	0.3501	22			

[1] DF = degree of freedom; MS = mean square; SS = sum of squares.

$$L^* = 93.422 - 0.304MC + 0.26DT - 0.3169\,DT^2 + 0.4325CT \times MC \quad (4)$$

The postulated models for L* were predictive since the percentage adjusted R^2 was 0.99%. This result was confirmed in the analysis of variance of bulgur colour parameters (Table 3). *P*-values were smaller than 0.05, meaning that the proposed coefficients used to model have a significant effect on the chosen responses.

The response surface curve shows that the only significant interaction was between CT/MC (Figure 1D). At the medium level of DT, high lightness values were observed with high CT and high MC suggesting that grains become lighter while cooking. Their lightness goes from 93.29 at 10.13 min of CT to 94.11 at 40 min.

Effect of processing parameters on bulgur ash content

The outer layers of wheat are high in mineral and nutritional components, and measuring ash content is the method most frequently used to indicate product purity (Hemery *et al.*, 2007).

The effect of unit operation of bulgur processing on ash content is presented in Table 2. Only MC and DT and their interaction were significant. A negative correlation between ash content and DT was observed due to its negative coefficient. In fact, increased DT caused a high percentage of the outer layers to be removed, thus reducing the ash content of the bulgur. This result is reasonable as debranning gradually removes the layers from the surface of the cereal grain from the outside inwards, and only the aleurone layer can remain on the kernel, attached to the starchy endosperm. Singh and Singh (2010) reported a decrease in ash content from 1.61-2.08 to 1.4-1.86% and 1.2-1.56% after debranning to the 4 and 8% level, respectively. In earlier studies, ash content was removed between 10 to 11% and 8% in two common wheat varieties and one durum wheat variety, respectively, at around 4% debranning level (Singh *et al.*, 1998). A second polynomial equation was proposed to describe the variation in ash content as a function of the unit operation of bulgur processing, as following:

$$\text{Ash (\%)} = 0.822 + 0.083MC - 0.051DT - 0.074MC^2 - 0.045CT \times MC \quad (5)$$

The proposed model is predictive (R^2=0.66), and the analysis of variance confirms this result (Table 3). Moreover, it was found that ash content increased with increased MC but decreased with increased CT (Figure 1E). Moisture content of the grain had a significant effect on its mechanical properties (Warechowska *et al.*, 2016). Where wheat fraction was decreased from debranning, high levels of bulgur ash content were obtained.

Optimisation

The most important criteria for determining the quality of bulgur is high yield for producers and bright-yellow colour with high nutritional value for consumers. Hence, in this work, high yield, low a*, high L* and high ash content were taken as references for optimising bulgur processing conditions.

Central composite design is a powerful tool for determining optimal levels of relevant factors and their interactions. Therefore, in our experimental conditions, the optimal conditions for bulgur processing were found to be: 43 min of CT, 15.5% of MC and 1.6 min of DT. Bulgur prepared under these conditions gives a yield of 79.9%, colour parameters a*, b* and L* of 0.43, 11.38 and 93.3, respectively, and ash content around 0.76. Moreover, microscopic observations of bulgur prepared at these optimal conditions showed the presence of aleuronic layers (Figure 2). The aleuronic layer

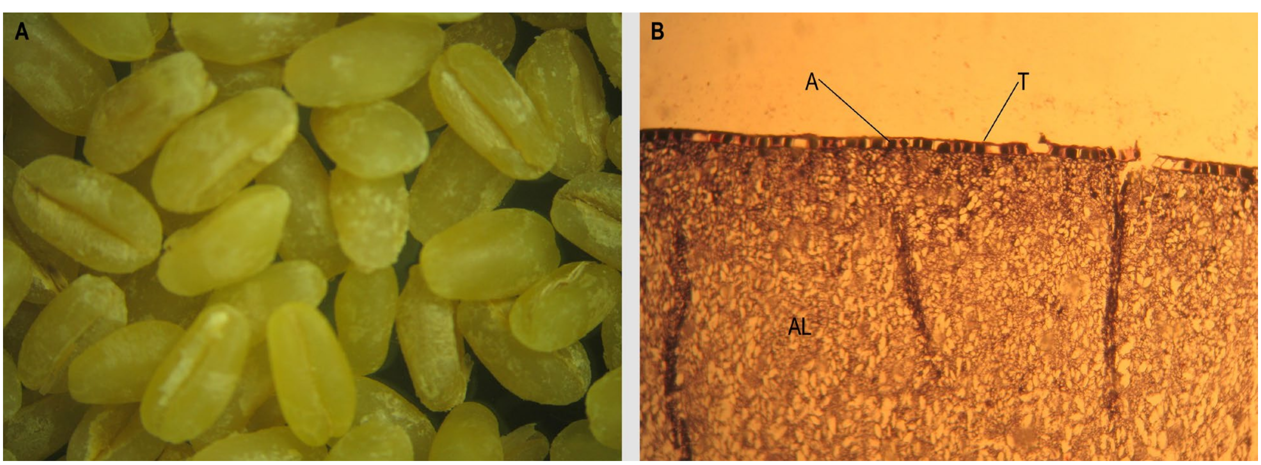

Figure 2. (A) Morphological observation of the samples G×10; (B) Histological sections of debranned bulgur (cooking time = 43 min, moisture content = 15.5%, debranning time = 1.6 min). A = aleurone layer; AL = albumen; T = testa. G×50.

is composed of living cell walls with tissues containing high level of beta glucan and arabinoxylan compared with the whole grain (Hemery *et al.,* 2007). These optimal bulgur processing conditions make it possible to produce high-quality bulgur with aleuronic layers and therefore a high nutritional value.

4. Conclusions

In this study, the effects of unit operations such as CT, MC and DT on bulgur quality were studied. Yield, colour (a*, b*, L*) and ash content were taken as parameters to characterise bulgur quality. The results showed a significant negative effect of DT on bulgur yield, a* and ash content while a positive correlation and significant effect was observed on L*. CT had a positive effect on bulgur yield, since it directly influences kernel hardness, and MC had a positive effect on bulgur yield.

The optimal conditions determined by using surface contour plots were CT of 43 min, MC before drying of 15.5% and DT of 1.6 min. Under these conditions, the bulgur prepared had a yield around 82% and the colour parameters (a*, b*, L*) were -0.43, 11.45 and 92.87, respectively. The ash content was around 0.9% (d.b.) suggesting a high mineral content. Microscopic observation confirmed the high nutritional value at these processing conditions due to the presence of aleuronic layers, suggesting bulgur rich in fibre and mineral compounds.

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