Production of Functional Wheat Flour by Heat Moisture Treatment using optimization by Response Surface Methodology

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Abstract

The functionalization of native wheat flours was carried out by using the heat moisture treatment (HMT). This HMT process was executed according a full factorial design and the independent variables selected were initial moisture content of flours, temperatures and the duration of treatment. The heat moisture treatment was optimized by using response surface method (RSM) for three different responses: gelatinization temperature, swelling capacity and lightness color of flours. The effects of three factors were found to be significant at different level for all responses. The optimal HMT process conditions for having functional flours with high gelatinization temperature, high swelling capacity and high lightness of color, were found at 27.5% (db) for initial moisture content of native flour treated at 120°C during 1 hour. The predictable values of the response variables were 67.95 °C for gelatinization temperature, 7.49 g/g for swelling capacity and 67.67 for lightness of color.

Keywords— *optimization, heat moisture treatment, wheat flour, full factorial design, response surface method.*

I. INTRODUCTION

Wheat flour is a component of many culinary meals and the main ingredient in bread making and infant food formula [5]. Depending on the variety of wheat from which it was formed and the milling process used, various kind of native wheat flours can be produced. Despite the diversity of native wheat flour, they do not cover all of the needs of wheat-based food industry. Their incorporation in some formulations is limited by the lack of desirable characteristics and the excessive development of undesirable functionalities.

To overcome these limitations, wheat industry undergo the development of atypical wheat varieties, or the modification of some properties of native flours, by eliminating undesired fractions, or by correcting insufficient functionalities of raw flour, thanks to various additives (external functionalization) or by modifying chemically, biochemically or physically the native flour's structure or composition (internal functionalization). These functionalized flours bring benefits such as better dough hydration, machinability, cold and hot water or oil binding capacity, textural enhancement, and may substitute some hydrocolloid used as additives or replace fats in some food formulations.

The cereal flours where initial properties have been modified without using chemical reaction and by environmentally friendly processes are designed as clean label functionalized cereal flour. Most of commercial clean label functionalized flours are made by the heat, mechanical and/or enzymatic processes which allow users to claim their natural character.

Numerous previous studies have shown that during the thermal functionalization of cereal flour, the extent of modifications obtained depends on the rate of time and temperature treatment applied and the water environment of the major components of wheat grains ([10]; [7]; [16]; [12]; [8]; [4]). According to the treatment temperature and moisture content of flour one may differentiate heat treatments leading to the production of completely gelatinized of the starch contained in ~~at~~ flour, and heat treatments that do not completely alter the granular structure of starches. Due to this starch granules damaging, treated flours will display a different level of viscosity in cold water. Among heat treatments those functionalizes cereal flour without destroying completely the structural feature of their starch granules, one may distinguished Heat-moisture treatment (HMT) that is carried out under minimum conditions of humidity (10-30%), at relatively high temperatures (90-120 °C) and in the relatively short time duration. ([7]; [1] and [6]).

The Heat Moisture Treatment (HMT) of cereal flour involves three key parameters: temperature, moisture content of the system and the duration of treatment. To date, there is not sufficient information on how the rates of these parameters affect the characteristics of wheat flours. Most of publications in this field being focused on the HMT of extracted starches. Only few research paper has addressed the effect of the heat moisture treatment processes parameters on complex starchy systems like cereal flour [17] [18].

In the present study some changes induced upon the heat moisture treatments of native wheat flours are characterized. Data collected during the experimental study allow determining the level of some parameters that lead to optimal characteristic of functional wheat flour using the method of response surfaces.

II. MATERIAL AND METHODS

A. Preparation of wheat flours

Native wheat flour (Natura -11/680) was provided by "Moulins de Statte" to Huy (Belgium). For experimental design, native wheat flours with moisture content varying from 18 to 30% (in dry basis) were prepared by adding the appropriate amount of distilled water to the initial flour and equilibrated for 24 hours at 4°C.

B. Heat Moisture Treatment (HMT) process and experimental design

To perform the heat moisture treatment, about 80 g of wheat flour rewetted at a controlled humidity were weighed into a cylindrical cans (0.030 m height and 0.073 m diameter (1/4b) and sealed tightly.

According to the experimental design, the procedure was performed at 10 rpm in a rotating batch retort A091 inside an Autoclave (FMC- Zwevegem, Belgium) equipped with a Siemens Simatic TP25 command pilot and a digital interface El lab TA 9616 for temperature measurement as described in Malumba et al. [13]. Canned wheat flour was rapidly heated from 20°C to the set point temperature by hot water spray and maintained for a predetermined duration. The set temperatures used varied between 80 and 120 °C at duration of treatment ranging from 1 to 3 hours. The temperatures were kept constant throughout the duration of desired precooking. Then, boxes were cooled at room temperature until product temperature reaches 29 °C. Treated flours have been frozen (-20°C), lyophilized and re-milled using a laboratory mill (IKA M20) until obtaining a functionalized flour withparticle sizes less than 225 µm.

A Full Factorial Design (FFD) of response surface methodology (RSM) (Design Expert 9 trial version) was used for the experiment. Three levels of each factors were applied according to the experimental domain presented in table 1. The design consists of 27 experimental conditions [11].

Table 1- Experimental domain of full factorial design

Coded level	**X_f (g[H_2O]/g DM)**	**T (°C)**	**D (h)**
Lower: -1	0.18	100	1
Central: 0	0.24	110	2
Higher: +1	0.30	120	3

X_f : Final Moisture Content, T : temperature of HMT D: Time of HMT

Three independent variables were considered: the moisture content of flour (X_f), the temperature of HMT (Tp) and the time of HMT (D). Responses analyzed were gelatinization temperature (Tp) of functionalized flour, The Water Binding Capacity (WBC) of flours, and intensity of wheat flour gel color (L*).

This study allowed to investigate the influence of three factors simultaneously (X_f) relative to the product and then the temperature (Tp) and the time heating (D) in the autoclave related to the HMT-process) on responses related to flour functionality. The experimental data were used to assess the quality of models and coefficients of the quadratic equations by analysis of variance (ANOVA).

C. Measurement of gelatinization temperature

The thermal properties of flours were examined with a DSC 2920 TA Instruments (New Castle, Delaware, USA) with a Refrigerated Cooling Accessory and modulated capability. Samples (around 2.5 mg, db) with distilled water (moisture 70%), were hermetically sealed in aluminum pan and equilibrated at temperature of 10°C for 24 h. Then sample pans were heated from 20 °C to 120 °C at a heating rate of 2°C/min modulated at ±0.5 °C every 100 s. The instrument was calibrated with indium (T_{onset}: 156.6°C, ΔH: 28.7 Jg^{-1}) and eicosane (T_{onset}: 36.8°C, ΔH: 247.4 Jg^{-1}) and an empty pan was used as reference. Gelatinization enthalpy ΔH was calculated by integrating the area of the gelatinization endothermic signal divided by the amount of dry flour used for measurement. The onset temperature (To) and peak temperatures (Tp) were computed using NV Thermal analysis software (Universal analysis, New Castle, Delaware, USA) [14].

D. Determination of Water Binding Capacity of samples

Samples (S) of 0.1 g of flour (HMT) were accurately weighed into 15 mL Falcon® tubes previously tared. 5 mL of distilled water were added to each tube followed by their incubation at 70 ° C for 10 minutes in a shaking water bath. The tubes were subsequently transferred to a boiling water bath for 10 minutes and then cooled for 10 minutes in a cold water bath. The tubes were then centrifuged at 3220 g for 30 minutes at a temperature of -10 ° C. After centrifugation, the supernatant was frayed and the pellet in the falcon weighed (m). The Water Binding Capacity of the flour WBC is determined by the following expression:

$$\mathrm{WBC}(g/g) = \frac{m - T}{S} \qquad (1)$$

With m: pellet mass (g); T: falcon tare (g); S: mass of sample (g)

E. Measurement of color

60 mL of suspension at 20% of HMT-flour was prepared in cans (1 / 4b) tightly crimped. For each test, the can was heating in an autoclave FMC® A091 (Zwevegem, Belgium). The temperature program included a gradual temperature rise of 5 ° C / min between 30 and 95 ° C. The cans were then cooled to room temperature and stored for 1 hour prior to the color measurement. The gels flour-HMT obtained have undergone the color measurement using the Spectrocolorimeter Hunterlab Miniscan® XE (Reston, USA). This allowed to know the parameters L * a * b * of gels on white backgrounds. Only the value of L was used as response variable.

F. Optimization of HMT process

1)Mathematical modelling and statistical analysis

The experimental data were fitted to a second order polynomial model as:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j \qquad (2)$$

Where Y is the response variable, β_0, β_i, β_{ii}, β_{ij} are the regression coefficients of variables for intercept, linear, quadratic and interaction terms, respectively. Xi and Xj are independent variables.

Model terms were selected or rejected based on the *P value* with 95% confidence level and the criteria of Morineau and Chatelin [15]. The results were completely analyzed using analysis of variance (ANOVA) by a free trial version of the Design-Expert software version 9 (Stat-Ease Inc., Minneapolis, U.S.A).

The coefficient of determination, R^2, is the proportion of variation in the response attributed to the model rather than to random error. It has been suggested that a good-fitting model should have R2 no less than 80%. When R^2 is close to unity, the empirical model is suitable for fitting the actual data. A lower value of R^2 indicates that the model is inappropriate for explaining the relation between variables [9].

Design-Expert was also used to fit the equations developed and for the assessment of the statistical significance of the equations.

The significance of the coefficient term is proved by the value of F and *p*. $p < 0.05$ indicates that the model is statistically significant and *p* higher than 0.1 are not significant [3]. The coefficients of the independent variables Xi, were identified as significant when their absolute value was greater than the standard error (SE) [15]:

/coeff/> SE so the model factor coefficient is significant;

/coeff/< SE so the model factor coefficient is not significant.

2)Optimization by RSM method

Numerical and graphical method of the Design Expert software were used. The three responses were superimposed by maximizing the gelatinization temperature (Tp) and the Water Binding (WBC) and minimizing the treatment time (D). And the three responses had the same weight (1).

III. RESULTS AND DISCUSSION

Table 2 summarizes the code values of response according to the experimental design and real values of the responses shown on functionalized wheat flour.

It can be seen that, according to experimental parameters used, the temperature of peak of gelatinization varies between 63.01 and 75.2 °C, the highest value of gelatinization being observed for samples treated at the highest HMT temperature, for the highest duration of treatment and the highest initial moisture content of flour, while the lowest values are observed for samples obtained from the less wet flour, treated at the lowest temperature. These observation suggest that the experimental parameters certainly affect the gelatinization behavior of recovered flours. Samples those presented higher gelatinization temperatures showed the lowest enthalpy of gelatinization. This suggests a pregelatinization phenomenon for those samples and is in accordance to what have been previously observed for the heat-moisture treatment of cereal flour [14].

Sui et al., [19] on their study of the HMT of corn starch showed that the increase of moisture content of native flour resulted in greater changes in temperature and enthalpy of gelatinization. They also demonstrated that the gelatinization temperatures of both normal corn starch (NMS) and waxy corn starch (WMS) increased with the increase of moisture content but remained unchanged with increasing heating length.

The increase of gelatinization temperature with HMT temperature and moisture content of flour was also mentioned by Adebowale et *al*., [1] for the hydrothermal treatments of finger millet starch. They attributed the increasing of Tp to the partial melting of crystallite inside starch granules and the increase of amylose–amylose interaction and amylose–amylopectin interaction along the chains, which is stronger in HMT. A similar hypothesis has been assumed by Malumba et al. [14] in their study comparing the effect of HMT with that of high temperature drying of grains.

In contrast to what has been observed for the gelatinization, the WBC of samples recovered varied between 5.13 and 6.97 g of water by fo g of samples used, extremes values observed for flour treated at the highest HMT temperature (120°C). The lightness of gel prepared using the flour recovered, seems to decrease either when the HMT treatment and the initial moisture content of flour increase. The clarity of HMT- wheat flour gel (L*) ranged from 63.06 to

75.20. Compared to the native flour, loss of clarity is observed with the HMT process. All of these results suggest that responses followed do not change following a similar trend. The optimization of the HMT process for such kind of responses has to take into account simultaneous change of all of these parameters in the experimental domain. The dynamic of responses change according the process parameters were modelled using polynomial models.

Table 2- Full Factorial Design: Three Factors, Three Levels, Real and Coded Data, Experimental Values.

Run	Factors			Responses		
	Xf:: MC (g[H2O]/gDM)	T: Temp.(°C)	D: Time (h)	Tp (°C)	WBC (g/g)	Gel lightness (L*)
1	-1(0.18)	-1(100)	-1(1)	63.37	5.988	71.83
2	0(0.24)	-1(100)	-1(1)	65.14	6.373	71.37
3	1(0.30)	-1(100)	-1(1)	66.00	5.521	70.38
4	-1(0.18)	-1(100)	0(2)	63.06	6.156	70.96
5	0(0.24)	-1(100)	0(2)	67.01	6.462	70.79
6	1(0.30)	-1(100)	0(2)	67.07	5.673	69.04
7	-1(0.18)	-1(100)	1(3)	63.95	5.694	69.69
8	0(0.24)	-1(100)	1(3)	67.18	6.490	69.4
9	1(0.30)	-1(100)	1(3)	68.90	6.106	65.68
10	-1(0.18)	0(110)	-1(1)	64.66	6.630	71.45
11	0(0.24)	0(110)	-1(1)	65.57	6.936	71.07
12	1(0.30)	0(110)	-1(1)	68.33	5.818	69.59
13	-1(0.18)	0(110)	0(2)	65.48	6.453	67.81
14	0(0.24)	0(110)	0(2)	66.41	6.312	68.22
15	1(0.30)	0(110)	0(2)	67.57	5.909	65.94
16	-1(0.18)	0(110)	1(3)	67.95	6.545	62.39
17	0(0.24)	0(110)	1(3)	69.63	6.851	62.39
18	1(0.30)	0(110)	1(3)	73.48	5.619	58.71
19	-1(0.18)	1(120)	-1(1)	65.14	7.426	66.25
20	0(0.24)	1(120)	-1(1)	65.52	7.670	64.57
21	1(0.30)	1(120)	-1(1)	69.63	7.698	67.78
22	-1(0.18)	1(120)	0(2)	65.52	6.941	67.1
23	0(0.24)	1(120)	0(2)	67.62	6.890	62.99
24	1(0.30)	1(120)	0(2)	72.62	6.444	66.92
25	-1(0.18)	1(120)	1(3)	66.96	6.972	59.2
26	0(0.24)	1(120)	1(3)	68.69	6.873	59.35
27	1(0.30)	1(120)	1(3)	75.2	5.138	56.2

Xf: final moisture content of wheat flour; Temp: Temperature of autoclave in HMT; Time: duration of HMT; Tp: Gelatinization temperature; WBC: Water binding capacity; L*: chroma index of gel color.

Table 3- Regression Coefficients of Polynomial Function, Significant Level Analysis of Variance And Standard Error (SE) For Each Response.

	Tp: Temperature of gelatinization			**WBC**: Water Binding Capacity			**L***: Wheat flour gel lightness		
	Coeff.	SE	P-value	Coeff.	SE	P-value	Coeff.	SE	P-value
Constant	**66.94***	0.58	< 0.0001	**6.60**	0.18	0.000	**67.72**	0.88	<0.0001s
X_f	**2.37**	0.27	< 0.0001	**-0.27**	0.08	0.004	**-0.91**	0.41	0.038s
T	**1.40**	0.27	< 0.0001	**0.42**	0.08	0.000	**-3.27**	0.41	0.000
D	**1.59**	0.27	< 0.0001	**-0.21**	0.08	0.022	**-3.40**	0.41	0.000
X_f*T	**0.69**	0.33	0.051	**-0.13**	0.10	0.228	0.48	0.50	0.351
X_f*D	**0.66**	0.33	0.059	**-0.11**	0.10	0.286	**-0.74**	0.50	0.155
T*D	**0.42**	0.33	0.216	**-0.35**	0.10	0.003	**-1.25**	0.50	0.022
X_f^2	**0.52**	0.46	0.277	**-0.50**	0.14	0.003	-0.19	0.70	0.793
T^2	**0.53**	0.46	0.265	0.13	0.14	0.371	0.24	0.70	0.735
D^2	**0.59**	0.46	0.220	0.10	0.14	0.479	**-1.79**	0.70	0.021

*In bold coefficients retained for models according Morineau and Chatetin (2005) criteria : /coeff/ >SE

A. Model fitting and evaluation of responses parameters

Table 3 summarizes the statistical parameters that have been found.

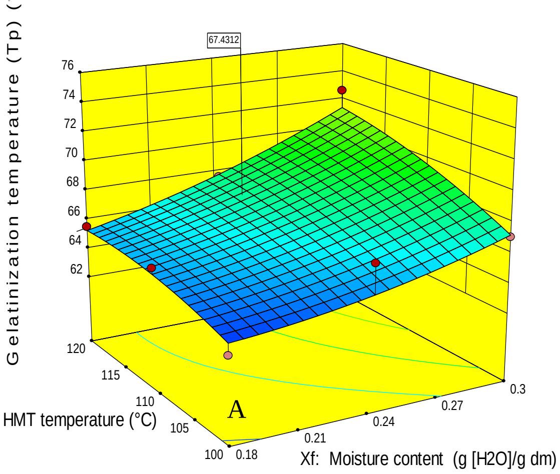
1) Temperature of gelatinization

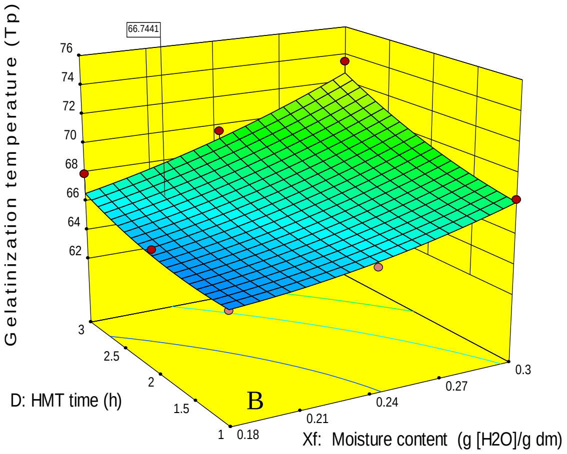
Fitting the polynomial models used on experimental data, the most significant model that better described the change of gelatinization temperature was can be exhibit as follows:

$$Tp= 66.94 + 2.37X_f + 1.40T + 1.59D + 0.69X_f*T + 0.66X_f*D + 0.42T*D + 0.52X_f^2 + 0.53T^2 + 0.59D^2 \quad (3)$$

After the application of criteria for *P-value* significant and that of /coeff/ > *Standard Error (SE)* (Table 4) ([15], criteria noted (MCC)), all the regression coefficient reported were selected for Tp model.

Figure 1 (A, B, C) presents the response surfaces and isopleths plot of the simultaneous effects of final moisture content of wheat flour (X_f) HMT-temperature (T) and HMT-time on the gelatinization temperature (Tp).





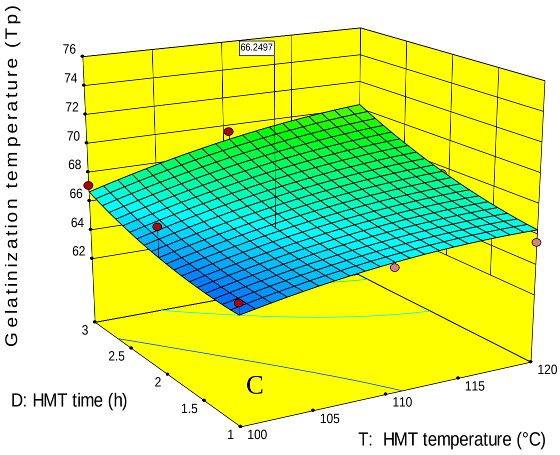


Figure 1- Response surface and Contour Plots for Gelatinization Temperature (Tp) at Constant HMT-time (2 h, A), HMT-Temperature (110°C, B) and Moisture Content (0.24 g [H2O]/g dm), C), Respectively.

The initial moisture content of flour (X_f) showed a linear effect and a marginal quadratic effect on the gelatinization temperature ($p < 0.0001$, $p > 0.1$). HMT temperature (T) showed a linear effect ($p < 0.0001$) and a low quadratic effect ($p > 0.1$) on Tp. Similarly the duration of treatment HMT (D) showed a significant linear effect ($p < 0.0001$) and low quadratic effect on Tp ($p > 0.1$). It was also noted that all the interaction effects (Xf*T, Xf*D and T*D) were marginally significant ($p >0.1$) as observed by Ayeni et al., [2] in the course of optimization of pretreatment conditions using full factorial design in enzymatic convertibility of shea tree sawdust.

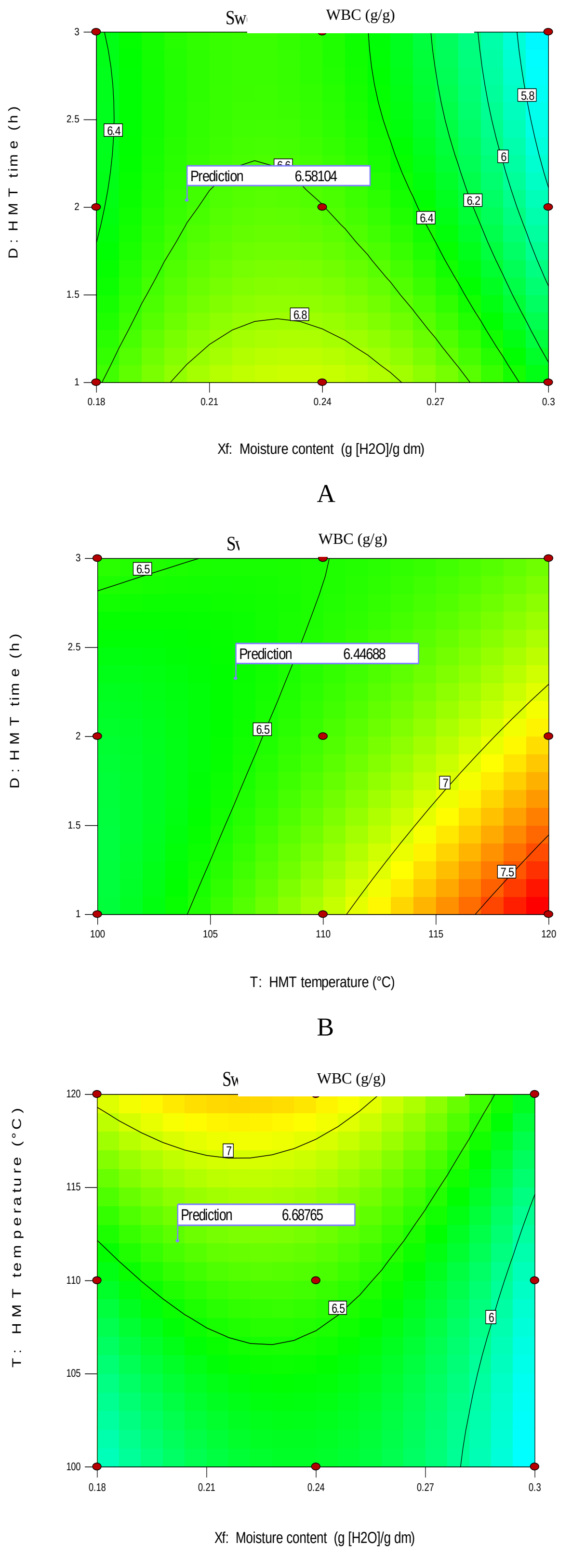
2) Water Binding Capacity of HMT-flours

The swelling capacity (SC) is used to determine the amount of water retained in the granule of the starch after gelatinization. More this capacity is high, more it is of interest, particularly in the field of pastry.

After analyzing the results of multiple regression and applied MCC criteria, it appears that only the coefficients of independent quadratic variables T^2 and D^2 cannot be taken into account by the SC model. Thus the Water Binding Capacity model that gives the best fit of WBC is:

$$WBC = 6.60 - 0.27X_f + 0.42T - 0.21D - 0.13X_f*T - 0.11X_f*D -0.35\ T*D -0.50X_f^2 \quad (4)$$

Figure 2 presents the isopleths plot of the simultaneous effects of final moisture content of wheat flour (X_f), HMT-temperature (T) and HMT-time on the Water Binding Capacity of HMT-flour.



A

B

C

Figure 2- Isopleths Plots for Gelatinization Temperature (SC) at Constant HMT-time (2 h, A), HMT-Temperature (110°C, B) and Moisture Content (0.24 g [H2O]/g dm), C), Respectively.

Moisture content showed a high significant linear effect and a small significant quadratic effect ($p < 0.01$; $p < 0.1$) on WBC. HMT temperature presented a significant linear effect on WBC ($p < 0.0001$). HMT duration showed a linear effect on WBC. The effect of change of HMT-temperature on WBC of wheat flour was more marked than that of moisture content and HMT-duration since the response surface changed more heavily when HMT-temperature varied. Malumba *et al.*, [14] showed that when starch granules are heat-treated below the gelatinization temperature (T ≤ 60 °C), they tend to bind more water after gelatinization and to swell significantly after a complete gelatinization. This trend was inverted when starch was heat-treated above 60 °C under a limit moisture content environment. This is in accordance to what is shown in the figure 3 A. Where it can be seen that samples pretreated at higher temperature and moisture content tend to bind less water after their gelatinization.

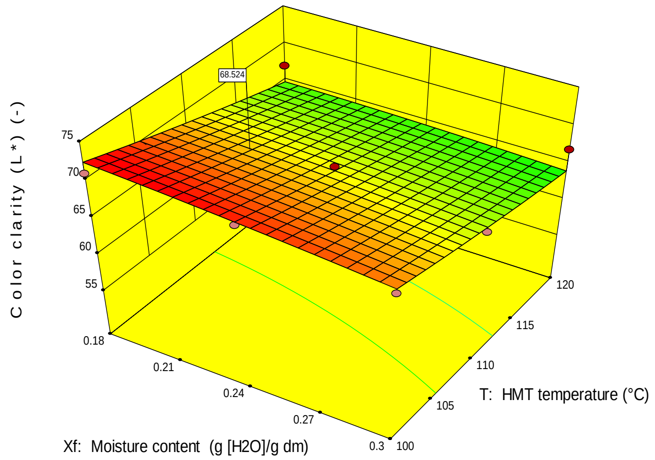
As shown in Fig. 2A and B for similar moisture content, the WBC increased and then decreased when the HMT-temperature increased.

C. Lightness of HMT wheat flour gels

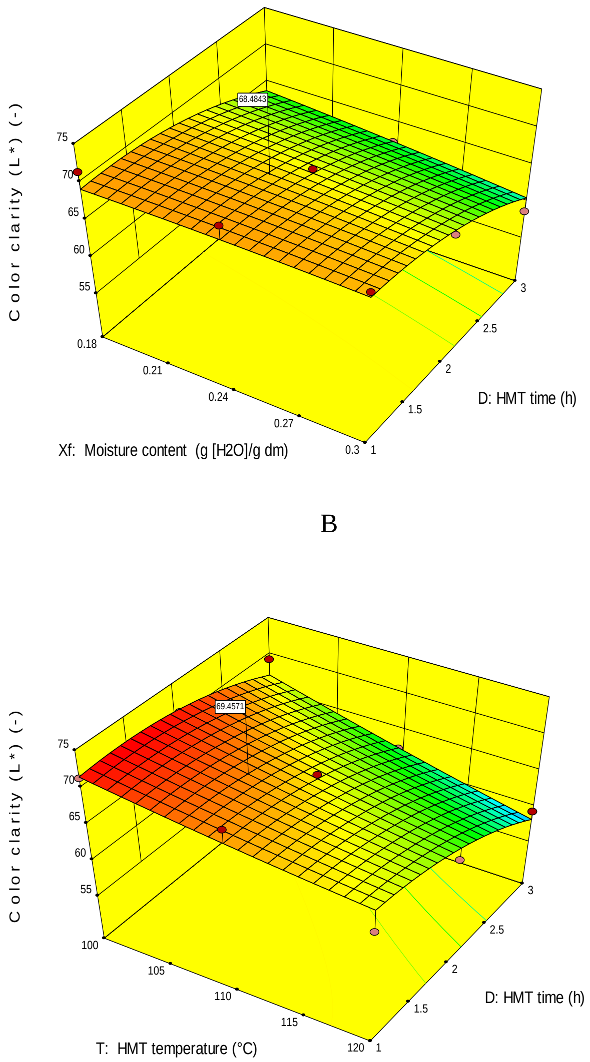
After removing the non-significant terms (based on independent variables *P-value* and MCC criteria, the estimated regression coefficients are reported in Table 4. All independent variables exhibited significant effects on L*. Only the duration of treatment exhibited a quadratic effect on the lightness of flour.

$$L^* = 67.72 - 0.91X_f - 3.27T - 3.40D - 0.74X_f{*}D - 1.25T{*}D - 1.79D^2 \qquad (5)$$

Figure 3 Presents the Response Surfaces and the Isopleths Plot the Effect of HMT Parameter on the Lightness of Flours (L*).



A



B

C

Figure 3- Response Surface and Contour Plots for Color Lightness (L*) at Constant HMT-time (2 h, A), HMT-Temperature (110°C, B) and Moisture Content (0.24 g [H2O]/g dm), C), Respectively.

According to Eq. (5) and Fig. 3, the lower moisture content, lower HMT temperature and lower HMT duration contributed to maintain higher the lightness of flours. The effect of time and temperature treatment on L* of wheat flour gel was more distinct than that of moisture content since the response surface changed more severely when time and temperature of HMT varied. Odjo et al. [18] on their study of the influence of drying and hydrothermal treatment of corn demonstrated that lightness (L*) and color intensity (ΔE) decrease with increasing of temperature treatment. Model coefficients also showed that time has greater impact on color lightness than temperature. However the significant curvature effect of time has reduced the overall effect of the treatment time on the color lightness.

B. Optimization of HMT process

The model equations for the various responses (Eqs. (3) - (5)), response surface outputs and contour plots were utilized in order to determine the optimum HMT conditions. Numerical and graphical optimization techniques were adopted to optimize the HMT process in order to have the desired functionalities for wheat flour. The three sets of independent variables were fixed in range of lower and upper limits. The response "gelatinization temperature" has been maximized with as weight to lower limit at 0.1 and 1 at the upper limit.

Gelatinization temperature is important for the stabilization of texture and rheology of the dough preparation in pastry and bakery. For this, a medium-sized of 3.5 points was assigned to this response.

The response "Water Binding Capacity" was also maximized with the same criteria on weight limits. However value of 5/5 was assigned to that response due to its importance for the consumer. For the last response "flour gel lightness", a maximization was also performed with a lowest importance rating of 1/5. Indeed, the sensitivity to color changing is not a real concern in much application of functional flour. After compute by the software Design-Expert, the following optimal conditions exhibited in table 5 was obtained for a desirability of 0.962 close to unity.

Table 5- Optimized independent variables and predicted and experimental values of responses at optimum conditions (n = 3).

Factors	**Optimum condition**
Moisture content (g[H2O]/g dm)	0.275
HMT-Temperature (°C)	120
HMT-Duration (h)	1.0
Response	**Predicted real value**
Tp: Gelatinization temperature (°C)	67.95
WBC: Water Binding Capacity (g/g)	7.49
L*: Color lightness (-)	67.67

For graphical optimization, isoresponse curves for each dependent variable were overlaid. Figure 4 describes the overlay plot for final moisture content of wheat flour and HMT-temperature with HMT-time at its low value (1 hour).

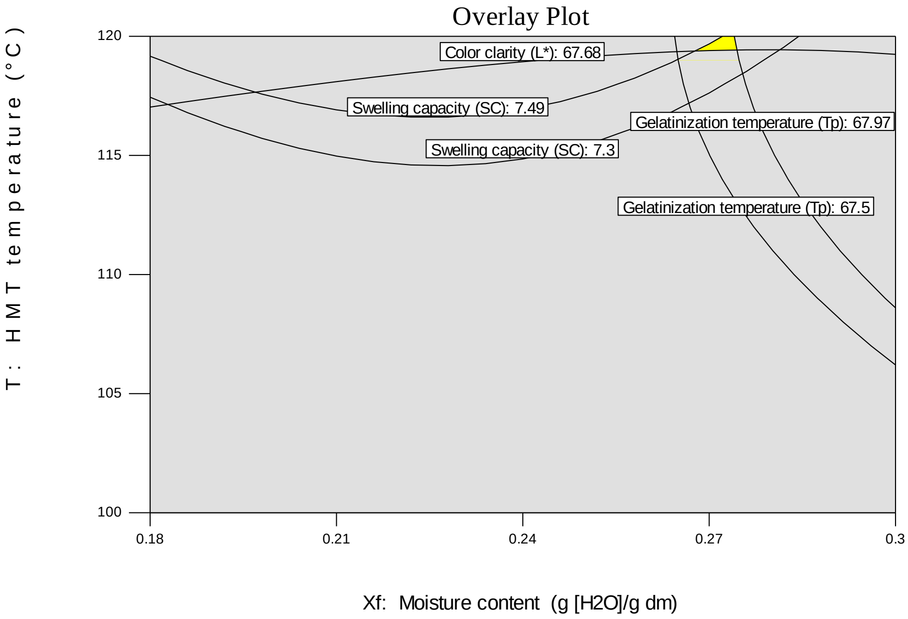


Figure 4- The Superimposed Contour Plots of Pretreatment Variables for Wheat Flour as a Function of Moisture Content and HMT-Temperature For 1 Hour Of HMT- Time.

The yellow area within the overlay plot highlighted the most advantageous zone for a given set of variables. The most favorable ranges drawn from the overlay plot were found to be 0.27 -0.275 g [H2O]/g) for moisture content, 119.5-120°C for HMT-temperature, and 1-1.02 h for HTM-time. The numerically derived optimized conditions were in close proximity to the graphically derived ones.

C. Validation of the optimum

Optimum parameters resulting from the RSM were validated by carrying out three tests. Validation results are shown in Figure 5.

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Figure 5. Validation by comparison of experimental with predicted values of RSM

Figure 5 shows that the application of the optimal parameters of the HMT (final water content of the flour (27.5%), treatment temperature (120 ° C) and treatment time (1h)) gives flours with functional properties close to those predicted by the models.

IV. CONCLUSION

The aim of this study was to optimize the heat moisture treatment (HMT) for producing a wheat flour with functionalities desired. A full factorial design applied with response surface method was used for the optimizing. For independent variables, there was a factor related to the product (the final moisture content (Xf)) and two factors related to the process (the temperature (T) and duration (D) of HMT treatment). The experiments have been conducted on HMT process on wheat flour for different operating conditions: Xf (0.18-0.30 g [H_2O]/g), T (80-120°C) and D (1-3 hours). Full factorial design was applied to study the effect of the three factors mentioned above on the functionality of the flour. The conventional graphical base on RSM and desirability function methods have been effective at determining the optimum zone within the experimental region. From the response surface quadratic model, it was found that the HMT conditions were significantly affected more by moisture content and treatment temperature and less by treatment time. At optimum, the heat moisture treatment condition of wheat flour, the gelatinization temperature, swelling capacity and color lightness were found to be 67.95 °C, 7.49 (g/g) and 67.67 respectively. This study also reveals that the optimal conditions for HMT to have desired functionalities for wheat flours were 27.5 g [H2O]/g of DM, 120°C for the treatment temperature and 1 hour for the length of treatment.

ACKNOWLEDGMENT

I want to thank the University of Liège-Gembloux Agro-Biotech and the WBI for the financial support of his post-doctoral training in Belgium.
Some of application developed in this paper were supported by the Walloon Government through the project Startech.

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