The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making

Original
The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making / Parenti, O.; Zanoni, B.; Baldi, F.; Guerrini, L.. - In: JOURNAL OF CEREAL SCIENCE. - ISSN 0733-5210. - 108:(2022), p. 103569.103569. [10.1016/j.jcs.2022.103569]

Availability:
This version is available at: 11381/2937574 since: 2024-10-09T08:24:07Z

Publisher:
Academic Press

Published
DOI:10.1016/j.jcs.2022.103569

Journal of Cereal Science

The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making

--Manuscript Draft--

Manuscript Number:	YJCRS-D-21-00134R2
Article Type:	Research Paper
Keywords:	Process control; optimization; Kneading time; Dough rheology
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Abstract:	The interest in unrefined wheat flours for bread production has largely increased due to the scientific evidence on the health benefits associated to their consumption. However, they often resulted in dough difficult to be worked and in end-products with poor technological quality, limiting the use of unrefined wheat flour and compromising the acceptability of unrefined bakery products. In this work flours from four wheat cultivars of different technological quality and refinement degree were studied, and a two-stage methodological approach was proposed as innovative method to improve the use of weak and unrefined flours in bread-making. Firstly, an optimization stage trial was applied to determine the optimal dough water amount and kneading time to maximize the bread specific volume. Secondly, a monitoring stage was applied to perform an on-line monitoring of the kneading operation in the real operating conditions using the power consumption profile method. The power consumption profile method was able to predict the "Optimal kneading time" (i.e., the peak of the power consumption profile), which was significantly correlated to the optimal kneading time determined by the previous optimization stage. Moreover, several characteristic parameters were derived from the dough power consumption profile of wheat flours with different technological quality and refinement degree. This work showed the potentiality of the power consumption profile method for a real-time monitoring of the kneading operation of unrefined and weak wheat flours.
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Professor J.R.N. Taylor
Editor-in-Chief
Journal of Cereal Science

February 18, 2021

Dear Professor J.R.N. Taylor

I am pleased to submit an original research article entitled "The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making" for consideration for publication in *Journal of Cereal Science.*

For the first time the method of the power consumption was applied to monitor the kneading operation of unrefined wheat dough. Four wheat cultivars of different refinement degree and technological quality were studied following a two-stage experimental approach. At first, an optimization trial was performed to optimize the kneading conditions (i.e., kneading time and water amount). Then, the Alveograph parameters of standard and optimized dough samples were compared; the greatest improvements were obtained in unrefined optimized doughs. The optimized doughs were monitored with an energy analyser during kneading and power consumption curves were obtained. Several kneading parameters were determined from the power consumption curve; the optimal kneading time was highly correlated with that determined in the optimization trial. The power consumption and Farinograph parameters showed no correlations, except for dough stability. The power consumption method could represent an important tool to improve the exploitation of weak and unrefined flours by providing a better process control in the real kneading conditions.

We believe that this manuscript is appropriate for publication by *Journal of Cereal Science* since, to the best of the authors' knowledge the power consumption method has never been applied to monitor the kneading operation of unrefined bread dough. The present study emphasised the importance of adapting already-existing methods of process control to the specific requirements of unrefined and weak flours. The power consumption method could be particularly relevant to improve the use of weak and unrefined flours in bread-making, enhancing the exploitation of our wheat heritage and promoting the consumption of unrefined breads.

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Thank you for your consideration!

Sincerely,

Ottavia Parenti
Institute for Bioeconomy, National Research Council

R2
Manuscript Number: YJCRS-D-21-00134R1

The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making

The authors would like to thank Prof. Grant Campbell, Editor of the Journal of Cereal Science, and the reviewers for the time spent in improving the paper and for the valuable suggestions and corrections proposed. We hope to have addressed all the issues that Editor and the reviewers outlined. Here following, a point-by-point reply to the email received from the Editor and the comments received from the reviewers'.

Dear Miss Parenti,
Thank you for submitting your revised manuscript to Journal of Cereal Science.
The reviewers note the improvements to the manuscript, and are largely satisfied (although Reviewer 1 still considers there is scope to refine the language).Of greater concern, however, is the comment of Reviewer 1 that "[standard deviation] is given for parameters in Table 3. However, it is missing for parameters given in Tables 1, 2 and 4." Can you please either add standard deviations to Tables 1, 2 and 4, to make the data presentation consistent, or explain why SD is given in Table 3 but not in these other tables.
I invite you to resubmit your manuscript after addressing the comments below. Please resubmit your revised manuscript by Oct 14, 2022.
When revising your manuscript, please consider all issues mentioned in the reviewers' comments carefully: please outline every change made in response to their comments and provide suitable rebuttals for any comments not addressed. Please note that your revised submission may need to be re-reviewed.
To submit your revised manuscript, please log in as an author at https://www.editorialmanager.com/yjcrs/, and navigate to the "Submissions Needing Revision" folder under the Author Main Menu.

Journal of Cereal Science values your contribution and I look forward to receiving your revised manuscript.

Kind regards,
Grant Campbell
Editor
Journal of Cereal Science
Editor and Reviewer comments:

Reviewer #1: The authors have improved their manuscript. But still the language require improvement.
The authors are grateful for the reviewer's suggestion. The Manuscript has been revised by a mother-tongue speaker and in the R2 version Conclusions were further improved. Reviewer can find every change made outlined in the Manuscript.

SD is given for parameters in Table 3. However, it is missing for parameters given in Tables 1, 2 and 4.
The authors are grateful for the reviewer's observation. Here following the response about the SD of Tables 1, 2 and 4:
Table 1: as explained in Materials and Methods section at Paragraph 2.2.1 "*Trial 1 - The optimization stage*"(L 133-138) Table 1 shows the selected experimental ranges of the *W* and *T* variables, which are the ranges of independent variables selected by the researchers, hence they do not have SD. Bread

specific volume was the response variable to measure bread quality. The kneading conditions for the optimization of the eight dough samples were thus obtained. In detail, as explained in Paragraph 2.5.1 "*Trial 1 - The optimization stage*" (L 183-197), bread quality in terms of bread specific volume and the corresponding mechanical energy were estimated using a Central Composite Circumscribed (CCC) Design based on response surface methodology (RSM). In order to describe the relationship between the independent variables (*T*, *W*) and the dependent variable (bread specific volume) the response values were fitted with first order and second order polynomial (quadratic) regression models using a multiple regression analysis (Standard Least Square Fitting) and surface plots were obtained. The optimal kneading conditions were considered those that maximized the response variable bread specific volume. Following the above data processing method, the statistical significance of the obtained RSM models was reported as p and lack of fit values at Paragraph 3.1 "*Trial 1 - The optimization stage*" in the Results Section (L 215-280), and this is the reason why the optimized values of water, bread specific volume, and the corresponding specific mechanical energy reported in Table 2 are considered significant and do not have SD.

Table 3: The authors added the SD for the Farinograph analysis.

Table 4: In Table 4 the reviewer can find the statistical variance expressed as the Standard Error in the last column of the Table.

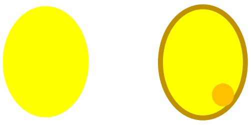
Reviewer #2: The manuscript has been revised according to the suggestions and comments of the reviewers. I suggest to accept the manuscript.

The authors are grateful for the reviewer's response.

Highlights

- Kneading variables were optimized for flour refinement degree and cultivar
- Optimized unrefined doughs showed the greatest Alveograph improvements
- Kneading parameters from the power consumption curve were determined and analysed
- Optimal kneading time from power consumption highly correlated with optimized time
- Farinograph and power consumption parameters showed no correlations

Graphical Abstract



Refined and unrefined wheat flour from four cvs

↓

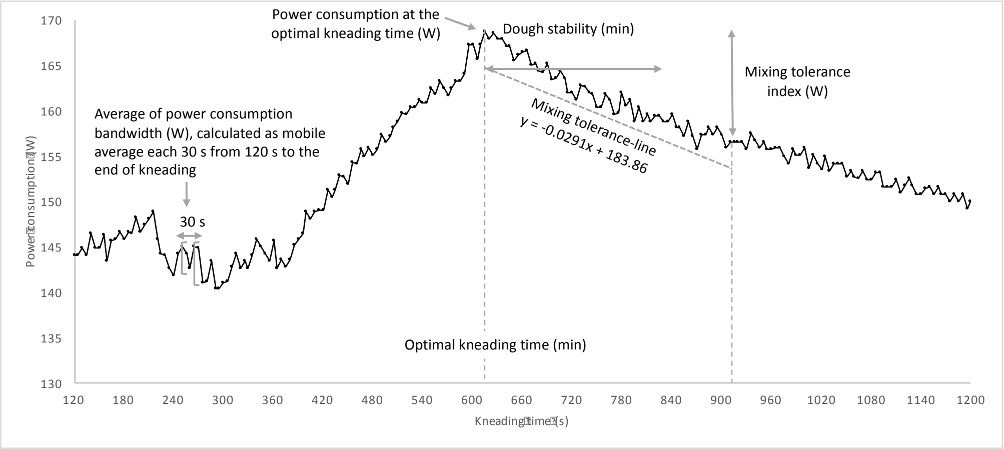
1. Optimization of kneading variables

Water amount

Kneading time

↓

2. Monitoring of the power consumption during kneading



↓

Power consumption kneading time was highly correlated with optimization kneading time

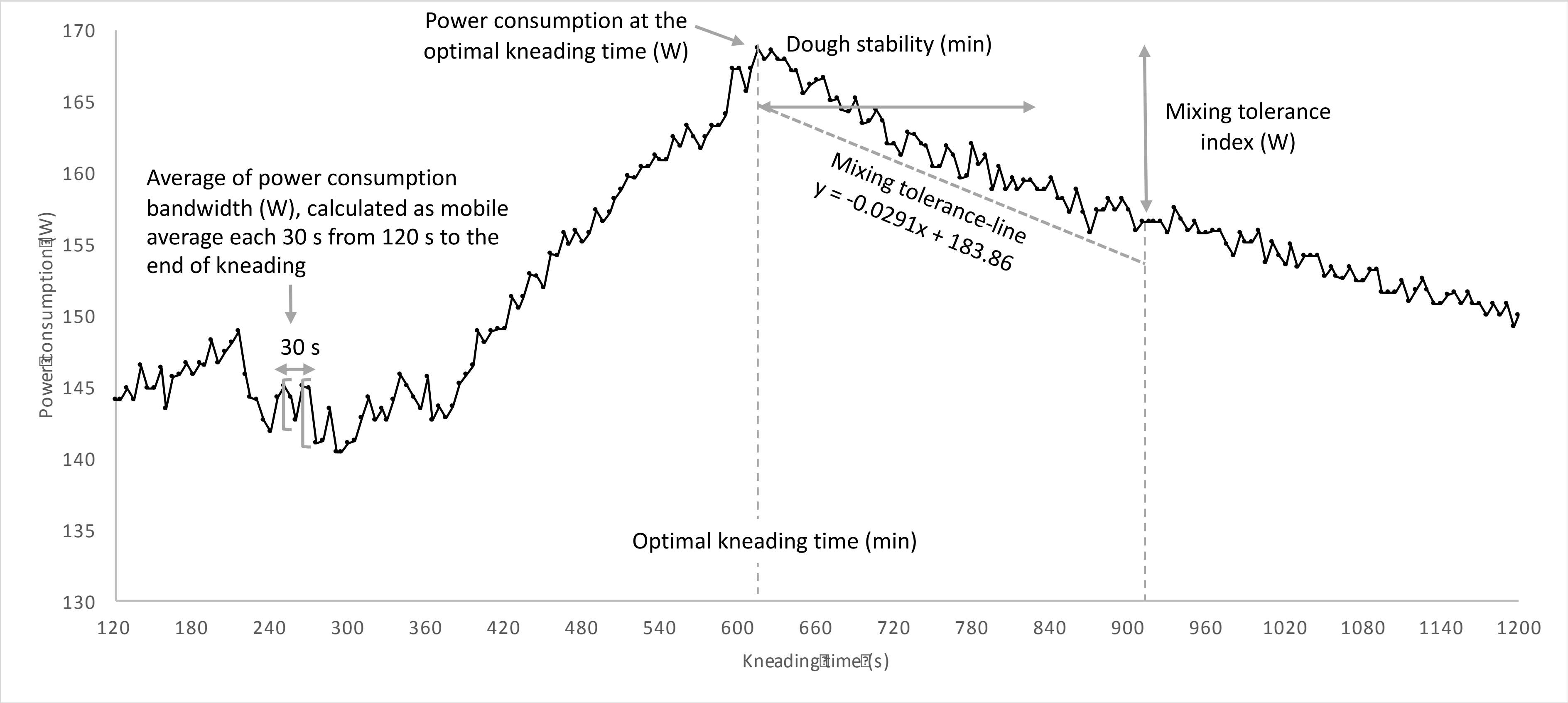


Figure 1. An example of the power consumption parameters related to the optimized dough samples from unrefined Verna cv. flour.

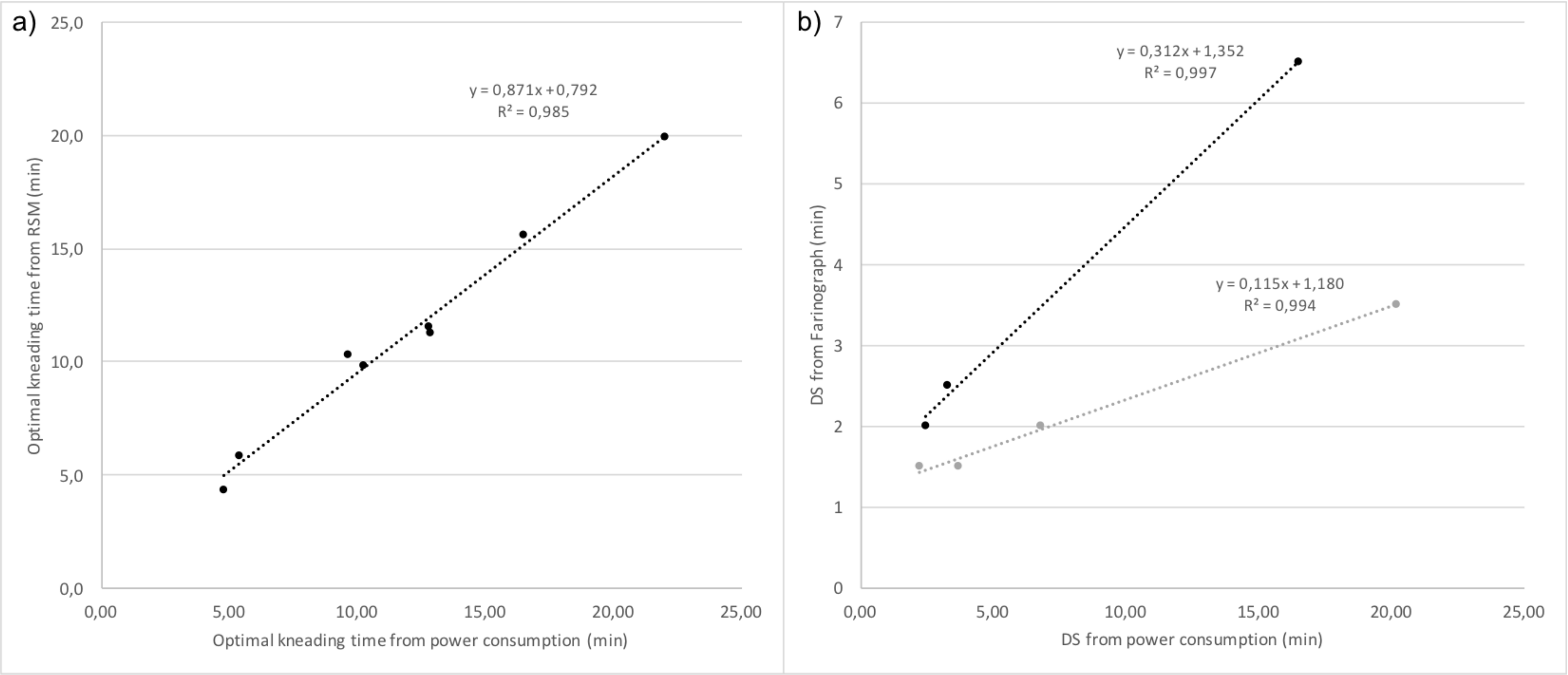


Figure 2. Relationships between the power consumption profile method, the RSM models and the Farinograph test. In the graph a) the relationship between the optimal kneading time values (power consumption profile method vs. RSM models) is shown; refined and unrefined samples are represented as black points, since flour refinement degree did not significantly affect the relationship. In the graph b) the relationship between dough stability values - *DS* (power consumption profile method vs. Fariograph test) is shown; since a significant effect of the flour refinement degree occurred, the different colours represent the flour refinement degree (i.e, black colour refers to unrefined flours, grey colour refers to refined flours).

Table 1. Experimental conditions and results obtained in the bread-making tests of the Trial 1.

Flour cv.	***Refinement degree***	***Kneading time range (min)***		***Water range (%, w/flour w)***		***Optimized conditions***		***Specific mechanical energy (kJ/kg)***	***Optimized bread specific volume (L/kg)***
		Min	***Max***	***Min***	***Max***	***Kneading time (min)***	***Water (%, w/flour w)***		
Verna	0	3	17	56.3	64.7	5.8	61.9	89.3	3.85
Verna	2	3	17	59.3	67.7	9.8	63.2	166.3	3.14
Andriolo	0	3	17	53.3	61.7	11.5	61.2	178.2	3.42
Andriolo	2	3	17	53.3	61.7	4.3	59.6	72.1	3.12
Bologna	0	2	16	52.8	61.2	10.3	63.1	162.2	4.04
Bologna	2	2	16	56.8	65.2	11.2	63.1	185.9	3.19
Pandas	0	7	21	61.8	70.2	19.9	65.6	305.2	3.66
Pandas	2	7	21	61.8	70.2	15.6	66.3	242.1	3.06

Kneading variable intervals (Kneading time – *T*, min; Water – *W*, %, w/flour w) reported as minimum (Min) and maximum (Max) values. The optimized values of the kneading variables and the corresponding Specific mechanical energy (kJ/kg) and Optimized bread specific volume (L/kg) obtained from the baking-trial of each flour tested (flour cv. x refinement degree).

Table 2. Experimental data of the Farinograph test of each flour sample (cv. x refinement degree)

Flour cv.	***Refinement degree***	***WA (%)***	***DDT (min)***	***DS (min)***	***MTI (BU)***	***DW (BU)***	***Average bandwidth (BU)***
Verna	0	51.5 ± 1.0	2.00 ± 0.05	1.50 ± 0.04	60 ± 10	140 ± 10	60 ± 5
Verna	2	54.5 ± 1.5	2.50 ± 0.06	2.50 ± 0.06	40 ± 10	80 ± 10	55 ± 5
Andriolo	0	51.0 ± 1.0	2.00 ± 0.04	1.50 ± 0.05	120 ± 10	210 ± 10	50 ± 5
Andriolo	2	55.0 ± 1.3	2.00 ± 0.06	2.00 ± 0.06	80 ± 10	160 ± 10	45 ± 5
Bologna	0	54.0 ± 0.8	2.00 ± 0.04	2.00 ± 0.03	80 ± 5	150 ± 5	90 ± 5
Bologna	2	59.0 ± 1.2	3.50 ± 0.06	9.00 ± 0.05	0 ± 5	50 ± 5	90 ± 5
Pandas	0	56.5 ± 0.9	2.50 ± 0.05	3.50 ± 0.03	40 ± 5	70 ± 5	120 ± 5
Pandas	2	60.0 ± 1.2	2.50 ± 0.05	6.50 ± 0.05	0 ± 5	70 ± 5	100 ± 5

Water absorption – *WA* (%), Dough development time – *DDT* (min), Dough stability – *DS* (min), Mixing tolerance index – *MTI* (BU), Dough weakening – *DW* (BU), Average bandwidth – average value of the bandwidth during 20 min of kneading (BU).

Table 3. Experimental data of the measured Alveograph parameters according to the standard alveographic procedure (*Std*) or applying the optimized kneading conditions (*Opt*).

Parameter	*Method*	*Verna 0*	*Verna 2*	*Andriolo 0*	*Andriolo 2*	*Bologna 0*	*Bologna 2*	*Pandas 0*	*Pandas 2*	*T-test*	*ANOVA*			
										p	*Refinement degree*	*Flour strength*	*Refinement degree*flour strength*	*SE*
***P* (mm H_2O)**	Std	39.20 ± 2.59^{ax}	50.80 ± 0.84^{ax}	22.80 ± 0.84^{ax}	39.20 ± 0.84^{ax}	53.50 ± 1.50^{ay}	104.20 ± 4.87^{ay}	72.60 ± 7.09^{ay}	103.60 ± 5.77^{ay}	**	*	**	ns	28.6
	Opt	23.00 ± 0.71^{bx}	28.50 ± 1.79^{bx}	13.00 ± 0.71^{bx}	26.60 ± 1.67^{bx}	20.25 ± 3.39^{by}	54.25 ± 3.85^{by}	34.00 ± 3.24^{by}	45.60 ± 3.21^{by}					
***L* (mm)**	Std	45.60 ± 4.79	16.60 ± 1.52	62.60 ± 9.71	32.20 ± 2.28	90.75 ± 8.61	38.20 ± 4.09	67.00 ± 6.65	26.40 ± 4.56	**	ns	ns	ns	335.1
	Opt	86.20 ± 9.29	36.75 ± 5.29	64.50 ± 3.51	45.80 ± 3.70	90.25 ± 5.77	54.25 ± 2.99	99.00 ± 4.24	51.60 ± 5.51					
***G* (mm)**	Std	14.98 ± 1.38	9.06 ± 0.41	17.48 ± 1.32	12.64 ± 0.46	21.15 ± 1.44	13.78 ± 0.77	18.16 ± 1.72	11.42 ± 0.96	*	ns	ns	ns	8.267
	Opt	20.60 ± 1.85	13.48 ± 0.98	17.88 ± 1.61	15.06 ± 0.61	21.08 ± 2.03	13.90 ± 1.60	22.15 ± 1.86	15.83 ± 1.56					
***W* (10^{-4} J)**	Std	67.60 ± 3.16^{a}	35.40 ± 3.65^{a}	38.40 ± 5.55^{a}	48.60 ± 2.19^{a}	173.50 ± 10.54^{a}	163.20 ± 8.11^{a}	182.00 ± 10.79^{a}	115.80 ± 11.76^{a}	*	*	ns	ns	861
	Opt	63.40 ± 8.05^{a}	39.75 ± 5.59^{a}	22.50 ± 2.97^{b}	42.00 ± 3.08^{b}	68.50 ± 18.24^{b}	110.50 ± 10.30^{b}	135.50 ± 4.51^{b}	94.40 ± 7.59^{b}					
P/L	Std	0.88 ± 0.18^{a}	3.08 ± 0.30^{a}	0.39 ± 0.11^{a}	1.22 ± 0.09^{a}	0.60 ± 0.09^{a}	2.77 ± 0.44^{a}	1.14 ± 0.36^{a}	4.03 ± 0.52	*	*	ns	ns	0.558
	Opt	0.27 ± 0.04^{b}	0.79 ± 0.09^{b}	0.20 ± 0.05^{a}	0.59 ± 0.07^{b}	0.23 ± 0.11^{b}	1.00 ± 0.31^{b}	0.34 ± 0.05^{b}	0.91 ± 0.18					
***Ie* (%)**	Std	34.22 ± 2.49	0.00 ± 0.00	27.94 ± 2.13	0.00 ± 0	44.43 ± 7.55	26.88 ± 1.31	57.36 ± 1.31	0.00 ± 0.00	*	ns	ns	ns	14.6
	Opt	50.14 ± 1.86	0.00 ± 0.00	29.63 ± 2.63	31.76 ± 2.38	60.28 ± 6.37	48.68 ± 0.53	69.13 ± 3.25	43.60 ± 1.29					

Dough tenacity – *P* (mm H_2O), Dough extensibility – *L* (mm), Dough swelling index – *G* (mm), Flour strength – *W* (10^{-4} J), dough tenacity - extensibility ratio – *P/L*, and Elasticity index – *Ie* (%). Flour refinement degree is reported as "0" and "2" for refined and brown flours, respectively. Results are expressed as mean ± Standard Deviation. *, **, *** indicate significant differences at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively; "ns" indicates no significant differences at $p < 0.05$. Means in a raw marked with different superscripts showed a significant effect of the flour refinement degree (a, b) and/or the flour technological quality – “Flour strength” (x, y) on the extent of the differences between optimized (*Opt*) and standard (*Std*) dough samples.

Table 4. The experimental data of the power consumption profile of the optimized dough samples.

Parameter	*Verna 0*	*Verna 2*	*Andriolo 0*	*Andriolo 2*	*Bologna 0*	*Bologna 2*	*Pandas 0*	*Pandas 2*	*Flour cv.*	*Refinement degree*	*Flour cv. * refinement degree*	*SE*
Optimal kneading time (min)	5.39	10.22	12.78	4.78	9.61	12.83	22.00	16.50	***	***	***	0.58
Power consumption at the optimal time (W)	132.55	164.04	138.50	151.65	139.27	159.53	130.60	126.97	ns	***	***	3.09
Dough stability (min)	3.69	3.25	2.19	2.47	6.78	4.72	20.17	16.50	***	***	***	0.23
Mixing tolerance index (W)	-4.08	6.79	5.21	10.27	3.91	12.43	-4.75	-5.79	***	**	ns	14.042
Angular coefficient of the curve trend-line	0.0190	-0.0291	-0.0280	-0.06559	-0.0108	-0.0361	0.0001	-0.0001	***	***	***	$1.53\ 10^{-5}$
Average bandwidth (W)	6.98	3.92	4.77	6.13	9.84	9.75	12.20	11.88	***	ns	*	1.070

Flour refinement degree is reported as “0” and “2” for refined and brown flours, respectively. Results are expressed as mean ± Standard Error. *, **, *** indicate significant differences at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively; “ns” indicates no significant differences at $p < 0.05$.

Conflict of Interest and Authorship Conformation Form

Please check the following as appropriate:

- ✓ ☒ The All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.
- ✓ ☒ This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.
- ✓ ☒ The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript
- ✓ ☒ The following authors have affiliations with organizations with direct or indirect financial interest in the subject matter discussed in the manuscript:

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Credit Author statement

Ottavia Parenti: Conceptualization, Methodology, Investigation, Resources, Dara curation, Writing - Original Draft, Writing - Review & Editing

Bruno Zanoni: Conceptualization, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration

Fabio Baldi: Writing - Original Draft, Writing - Review & Editing, Supervision, Funding acquisition

Lorenzo Guerrini: Conceptualization, Methodology, Formal analysis, Data curation, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration

The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making

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Keywords

Process control; Optimization; Kneading time; Dough rheology

Abstract

The interest in unrefined wheat flours for bread production has largely increased due to the scientific evidence on the health benefits associated to their consumption. However, they often resulted in dough difficult to be worked and in end-products with poor technological quality, limiting the use of unrefined wheat flour and compromising the acceptability of unrefined bakery products. In this work flours from four wheat cultivars of different technological quality and refinement degree were studied, and a two-stage methodological approach was proposed as innovative method to improve the use of weak and unrefined flours in bread-making. Firstly, an optimization stage trial was applied to determine the optimal dough water amount and kneading time to maximize the bread specific volume. Secondly, a monitoring stage was applied to perform an on-line monitoring of the kneading operation in the real operating conditions using the power consumption profile method. The power consumption profile method was able to predict the "Optimal kneading time" (i.e., the peak of the power consumption profile), which was significantly correlated to the optimal kneading time determined by the previous optimization stage. Moreover, several characteristic parameters were derived from the dough power consumption profile of wheat flours with different technological quality and refinement degree. This work showed the potentiality of the power consumption profile method for a real-time monitoring of the kneading operation of unrefined and weak wheat flours.

1. Introduction

Nowadays, the interest in unrefined wheat flours for bread production has largely increased (Parenti et al., 2020) due to the scientific evidence on the health benefits associated to their consumption (Ye et al., 2012). The demand for healthy food products is constantly growing, since the nutritional quality has become a key criterion driving consumers' choices (Parenti et al., 2020). Although the presence of bran and germ fractions positively affects the nutritional value of wheat flour, bran and germ have a detrimental effect on the flour technological performance resulting in sticky doughs and poor-quality end-products, which limited the use of unrefined flour and compromises the acceptability of unrefined bakery products (Hemdane et al. 2016; Boukid et al., 2018).

In order to improve the bread-making performance of unrefined wheat flours, the scientific literature proposed different solutions, such as the use of improvers in the bread formulation, the use of the sourdough as leavening agent, and specific pre-treatments of milling by-products (Parenti et al., 2020). However, bakers are not used to add improvers to unrefined flours, due to the consumer demand for clean-label formulas (Guerrini et al., 2019); they are used to carry out the leaving step using the sourdough, whereas performing treatments on milling by-products is not a common practice (Guerrini et al., 2019). In this context, the use of weak unrefined flours in bread-making is still an issue due to the poor and variable technological properties of these flours. Indeed, few scientific studies investigated processing strategies aiming to adapt the bread-making conditions to the requirements of unrefined and weak flours (Parenti et al., 2021a,b).

One of the most important step of the bread-making process is the kneading operation during which several physico-chemical phenomena occur: (i) The homogeneous mixing of dough ingredients, (ii) the hydration of flour constituents, (iii) the development of the gluten matrix, and (iv) the inclusion of gas bubbles within the dough structure (Zhou et al., 2014; Parenti et al., 2021c). Unrefined flours usually showed poor kneading properties as measured by Farinograph test, including increased dough development time (Penella et al., 2008; Noort et al., 2010; Messia et al., 2016; Gómez et al., 2011a; Gómez et al., 2012) and mixing tolerance index. Contradictory effects were obtained on the dough stability; some authors reported an increase of dough stability, whereas others found a decrease of dough stability with the addition of bran and/or germ (Srivastava et al., 2007; Noort et al., 2010; Gómez et al., 2012; Le Bleis et al., 2015). Alveograph properties of unrefined flours were negatively affected by bran and/or germ addition; a general decrease of the flour strength and an increase of the ratio between dough tenacity and extensibility were reported. As a result, breads from unrefined wheat flours often show poor quality parameters (Messia et al., 2016; Noort et al., 2010; Banu et al., 2012; Gómez et al., 2011a; Gómez et al., 2012). The detrimental impact of the bran and germ fractions on the quality of dough and breads from unrefined wheat flours changes in relation to the flour technological quality, showing the smallest impact on flours with high protein content (i.e., strong flours) compared to flours with low protein content (i.e., weak flours) (Aamodt et al., 2004). The key criterion of the 1960s Green Revolution was a wheat selection towards cultivars with medium-high protein content in order to have wheats with improved technological performances. However, at present time there has been a renewed interest in ancient wheat varieties (Guerrini et al, 2019), since scientific evidence reported that, despite some of these cultivars showed poor technological performances, they had an interesting nutritional profile and potential health benefits (Dinu et al., 2018). Moreover, regardless wheat genotype, weak flours are still present in the actual wheat heritage. The introduction of innovative strategies, able to improve the process control of bread-making using weak and unrefined flours could be important to increase their exploitation.

According to the official methods (AACC 10-09.01 and 10-10.03), the determination of bread dough readiness was mainly based on the Farinograph and Mixograph tests, baking trials, and bakers' visual inspection. However, Farinograph and Mixograph tests require standard operating conditions that are different from the real operating conditions, the baking trials require high amount of time and resources, and the visual inspection is a subjective method (AACC 10-09.01; AACC 10-10.03; Dobraszczyk & Morgenstern, 2003; Zhou et al., 2014). The unrefined flours showed high variability in the technological performances due to their chemical composition, genotype, environmental conditions, storage, and interactions among these factors. Hence, the process standardization usually adopted for refined flours could not be applied for unrefined flours. The different chemical composition of unrefined flours compared to that of refined flours was reported to require both different tests to evaluate the technological quality and tailored processing conditions to improve the bread-making performance (Guerrini et al., 2019; Parenti et al., 2020). The potentiality of already-existing tools for process control of the bread-making with refined flours should be explored and adapted to the specific requirements of unrefined flours to improve and standardize the technological quality of the end-products.

Concerning the kneading operation, the power consumption was proposed as an alternative method to the official methods (Farinograph and Mixograph) for the determination of the optimal kneading time of bread dough (Wang et al., 1993; Zounis & Quail, 1997; Hwang & Gunasekaran, 2001; Pereira et al., 2013; Aljaafreh, 2017). However, to the best of the authors' knowledge, there is still a lack of scientific studies that monitored the power consumption profile of unrefined dough, and a deep insight into the relationship between power consumption and rheological properties of dough is still required before the actual use of power consumption profile in bread-making. In this work flours from four wheat cultivars of different technological quality and refinement degree were studied, following a two-stage experimental approach: (i) an optimization stage to find the kneading operating conditions (i.e., time and water amount) which were able to maximize bread specific volume; (ii) a monitoring stage of dough samples processed using the optimized kneading conditions in order to test the potentiality of power consumption method for a real time monitoring of the kneading step of unrefined wheat flour dough.

2. Materials and Methods

2.1 Wheat flours

Trials were performed with eight batches of sp. *Triticum aestivum* L. flour, two for each of the following cultivars (cv.): (i) Verna, (ii) Andriolo, (iii) Bologna, (iv) Pandas. They were processed by the Molino Paciscopi (Montespertoli, Florence, Italy). Verna and Andriolo cv. flours were representative of low technological quality wheat flours; Pandas and Bologna cv. flours were representative of good technological quality wheat flours. The flours were processed using a stone grinding mill and a sieve to produce two different refinement degrees according to the Italian classification (Zhou et al., 2014), namely type 0 (i.e., refined wheat flour) and type 2 (i.e., unrefined wheat flour) wheat flours. Type 0 flour was produced by applying a passage through a 500 µm sieve, and type 2 flour by applying two consecutive passages through a 1,100–1,200 µm sieve.

2.2 The experimental design

2.2.1 Trial 1 - The optimization stage

A baking-trial based on Central Composite Circumscribed (CCC) Design and Response Surface Methodology (RSM) was applied to optimize the following kneading conditions:

(i) Dough water amount – *W* (%, w/flour w)

(ii) Kneading time – *T* (min)

Each factor was tested at five levels: - α, - 1, 0, + 1, + α. The CCC Design for 2 factors at 5 levels required 12 runs, including 4 replications of the centre point. A total of 96 bread–samples were produced, resulting from the above 12 runs x the above 8 flour cv. batches.

Trials of each flour cv. batch were performed in the same day, and the samples were processed in a randomized order. The proper experimental range and distance between levels of the tested variables were identified after preliminary trials. Table 1 shows the selected experimental ranges of the *W* and *T* variables; the distance between 0 and +/-1 points was 3% for *W* variable and 5 min for *T* variable; the corresponding level of +/- α was calculated according to the formula $(2^{k})^{¼}$, where k is the number of tested variables. Bread specific volume was the response variable to measure bread quality. The kneading conditions for the optimization of the eight dough samples were thus obtained.

2.2.2 Trial 2 – The monitoring stage

The kneading operation of the above eight optimized dough samples was monitored using an energy analyser as described below (see Paragraph 2.4.2).

2.3 Bread-making

500 g batches of dough were processed, using the following dough ingredients: Flour (310 g), water amount in relation with the above optimization stage, fresh brewer’s yeast (13 g). The mineral water (Sant’Anna, Vinadio, Italy) and fresh brewer’s yeast (Original, Casteggio, Italy) were purchased at a local market (Florence, Italy). The dough ingredients were stored at room temperature (22 ± 2°C). Dough batches were processed at room temperature using a Kitchen Aid Professional Mixer (mod. KSM35CDH) at constant kneading speed of 150 rpm. After kneading, the bread-making steps were carried out using a bread machine (Pain doré, Moulinex, Ecully, France). The dough samples were put into the machine bowl and the leavening step was carried out at room temperature and room relative humidity for 90 min. The leavened dough samples were baked for 50 min at 150 °C. The bread samples were cooled to room temperature before the measurement of bread specific volume.

2.4 Measurement methods

2.4.1 Dough rheological properties

The rheological characterisation of the flour samples was carried out according to the official methods using the Farinograph test (AACC 54-21.02) and Alveograph test (AACC 54-30.02). A modified Alveograph test was also carried out; the dough samples were kneaded in the Kitchen Aid Professional Mixer at constant kneading speed of 150 rpm using the optimized kneading conditions obtained from the optimization stage in the 2.2.1 paper section, and then, the standard Alveographic procedure was applied. Measurements were carried out in three replicates. The Farinograph and Alveograph results (Table 2 and Table 3) were in agreement with the flour supplier's statement, that is weak flours from Verna and Andriolo cvs, strong flours from Bologna and Pandas cvs; Pandas cv. resulted the strongest flour tested.

2.1.1 Power consumption profile

The power consumption of dough samples was monitored and recorded every 5 s in the mixer described in the 2.3 paper section, using an energy analyser (Fluke 434-II/435-II/437-II, Danaher Corporation, Everett, Washington, US). The measurements were carried out both in the optimization stage (i.e., Trial 1) for a total kneading time according to the experimental design, and in the monitoring stage (i.e., Trial 2) for a total kneading time corresponding to twice the amount of the optimized kneading time. At least three replications for each dough sample were performed in the Trial 2. Several parameters were derived from the power consumption profile as explained in the Results and Discussion paper section.

2.1.2 Bread specific volume

Bread volume (L) was measured using the standard millet displacement method (AACC 10-05.01), and specific volume (L/kg) was determined as the ratio between total volume (L) and mass (kg).

2.2 Data processing

2.5.1 Trial 1 – The optimization stage

Bread quality in terms of bread specific volume and the corresponding dough mechanical energy were estimated using a Central Composite Circumscribed (CCC) Design based on response surface methodology (RSM). In order to describe the relationship between the independent variables (*T*, *W*) and the dependent variable (bread specific volume) the response values were fitted with first order and second order polynomial (quadratic) regression models using a multiple regression analysis (Standard Least Square Fitting). The CCC Design for 2 factors at 5 levels resulted in a total of 12 runs including 4 replicates at the centre point. Adopting a full factorial design would require 5^2 = 25 runs for each replicate, whereas CCC only require 12 experiments. The four replicates at the centre point allowed to estimate the pure error of the analysis, which was used to predict the lack-of-fit of the model. In order to describe the effects of the independent variables on the dependent variable, surface plots were obtained. The optimal kneading conditions were considered those that maximized bread specific volume without causing apparent defects in the inner and outer surface of the product.

A t-test was performed to compare Alveograph parameters of dough samples obtained with the standard Alveograph procedure with the dough samples prepared in the optimized kneading conditions according to the optimization stage. The comparison was made on each flour sample (cv. x refinement degree) standard vs optimized. A two-way ANOVA was performed to test the effect of the flour refinement degree, the flour technological quality and their interaction on the extent of the differences between standard Alveograph samples and optimized samples. The above results were obtained with R software version 4.0.0.

2.5.2 Trial 2 – The monitoring stage

The effect of the flour refinement degree, the flour cv., and the interaction between the above variables on the parameters determined by the power consumption profile were tested with a two-way ANOVA. A linear regression analysis was used to test the effect of the flour refinement degree on the relationship between parameters obtained from the optimization stage (optimal kneading time)/ Farinograph curve (DS) and those determined from the power consumption profile, and their interaction; the relationships were tested with a two-way ANOVA and Tukey 's was used as post hoc test. The above results were processed with R software version 4.0.0.

3. Results and Discussion

3.1 Trial 1 – The optimization stage

3.1.1 Bread-making test

The RSM models of the Trial 1 resulted statistically significant ($p < 0.05$, and lack-of-fit tests > 0.05), hence they allowed to identify the optimal combination of kneading variables to maximize bread specific volume (Table 1). The specific mechanical energy (kJ/kg) was calculated integrating the area value under the power consumption profile, divided by the dough sample weight.

The effect of flour technological quality on kneading time, the water requirements and specific mechanical energy was consistent with the literature; the flours of good technological quality (i.e., Bologna and Pandas cvs) showed the longest kneading time, the highest water requirements and the greatest specific mechanical energy to optimize the bread specific volume (Wooding et al., 1997; Rao et al., 2000; Zhou et al., 2014).

Considering the effect of the flour refinement degree, an increase in kneading time and specific mechanical energy was observed in Verna and Bologna cvs unrefined flours compared to the respective refined controls, whereas the opposite trend was observed in Andriolo and Pandas cvs flours. In the literature an increase of kneading time with low flour refinement degree was reported (Penella et al., 2008; Noort et al., 2010; Gómez et al., 2011a; Gómez et al., 2012; Messia et al., 2016), whereas scant information was reported on the effect of refinement degree on specific mechanical energy (Campbell e al., 2008; Le Bleis et al., 2015).

Unrefined Verna and Pandas cvs flours showed an increase of the dough water amount compared to the respective refined controls according to the literature data (Penella et al., 2008; Noort et al., 2010; Gómez et al., 2011a; Gómez et al., 2012); however, Andriolo cv. flour showed a higher water requirement in the refined degree flour than that of brown flour, and no significant differences of dough water amounts were observed in Bologna cv. flour as a function of the flour refinement degree.

The above different behaviours could be related to different reasons, such as the variable effect of wheat bran due to the cv. and hence to the bran chemical composition (Rosell et al., 2006; Hemdane et al., 2016), and the presence of both wheat bran and germ in the experimental flour samples, whereas the literature data were mainly focused on the only effect of wheat bran. Furthermore, in the major part of literature studies, the effect of bran was tested at relatively higher levels compared to the amount naturally present in unrefined wheat flours as those tested in the present research (Hemdane et al., 2016).

The optimization trial represented a prerequisite to determine the optimal kneading conditions (*T* and *W*) of each flour sample (flour cv. x refinement degree); then, the optimized dough samples were analysed with the Alveograph test and monitored during kneading with the power consumption method.

The rheological properties of the dough samples of the Trial 1 were measured through the Alveograph test (Table 3); the rheological properties were measured both according to the standard alveographic procedure (*Std*) and applying the optimized kneading conditions found in Trial 1 (*Opt*).

The optimization of the kneading conditions had a significant effect on all the Alveograph parameters. The effect of flour refinement degree and flour technological quality on the difference between standard and optimized samples was tested.

The optimized dough samples showed a significant increase in dough extensibility – *L* ($p < 0.01$) and swelling index – *G* ($p < 0.05$), and a significant decrease in dough tenacity – *P* ($p < 0.01$), tenacity to extensibility ratio – *P/L* ($p < 0.05$), and flour strength – *W* ($p < 0.05$). Considering elasticity index – *Ie*, the optimization significantly increased the parameter; *Ie* values were measurable for all dough samples except for the samples processed by unrefined Verna cv. flours.

The flour refinement degree affected the extent of the differences between dough samples processed according to *Std* procedure and the *Opt* conditions on *P* ($p < 0.05$), *W* ($p < 0.05$) and *P/L* ($p < 0.05$) parameters. The *P* and *W* reduction was significantly greater in refined flours compared to unrefined flours, whereas the *P/L* values showed the opposite trend. The *Ie* values showed that the optimization had the greatest improvements in unrefined flours than in refined flours; the *Ie* values were measurable for the dough samples processed by unrefined Andriolo and Pandas cvs flours in optimized conditions, whereas they were not measurable in standard conditions. The flour technological quality significantly affected the extent of the differences on *P* ($p < 0.01$) values between dough samples processed according to *Std* procedure and the samples processed using the *Opt* conditions; the parameter decrease was greater in the experimental strong flours than in the experimental weak flours.

Therefore, the optimization of the kneading conditions particularly improved the dough rheology for the unrefined flours. Since the literature data expressed that the unrefined flours are generally characterised by *P/L* values too high to develop a good bread structure (Messia et al., 2016; Banu et al., 2012; Srivastava et al., 2007), it was important that the optimization made unrefined flours achieve *P/L* values in the optimal range for bread-making (i.e., 0.6-1.0 according to Zhou et al., 2014). Furthermore, the experimental “optimized” *P/L* values were significantly correlated with the specific volume of optimized breads ($R^2 = 0.64$ – $p = 0.02$), showing a predictive role of the *P/L* parameter for the quality of bread from unrefined wheat flours.

3.2 Trial 2 – The monitoring stage

Power consumption profiles of the optimized dough samples were recorded; the relevant experimental data were explained using the Farinograph test as reference for selection of the characteristic parameters (Zhou et al., 2014). For example, the Figure 1 shows the power consumption profile of dough samples from unrefined Verna cv. flour. The following characteristic parameters were derived and processed from the power consumption profiles:

- “Optimal kneading time” (min): The time interval from the beginning of kneading to the peak of the power consumption profile. In order to ensure that the peak of the power consumption profile was properly identified, a second order polynomial curve was fitted on the power consumption profile and the kneading time having the tangent equal to zero was considered the optimal value. The beginning of kneading was considered excluding the first 120 s in order to avoid biased results due to the motor inrush.
- “Power consumption at the optimal kneading time” (W): The value of the power consumption at the peak/tangent equal to zero of the profile.
- “Power consumption 5 min after the optimal kneading time” (W): The value of the power consumption 5 min after the peak/tangent equal to zero of the profile.
- “Dough stability - *DS*” (min): The time interval during which the power consumption showed small oscillations closed to the power consumption value at the optimal kneading time.
- ”Mixing tolerance index - *MTI*“ (W): The difference between the power consumption value at the optimal kneading time and that measured 5 min after the optimal kneading time.
- “Slope of the mixing tolerance line” (W/s): The slope of the regression straight line obtained using the power consumption experimental values ranging from the optimal kneading time to 5 min after the optimal kneading time. The above slope can be related to the dough mixing tolerance and it is less susceptible to power consumption oscillations than the *MTI*.

The bandwidth of the power consumption profiles - “Average bandwidth” (W) was also determined. For each sample replicate the minimum and maximum values of the power consumption were determined as moving average parameters in a time-range of 30 s which corresponded to 6 experimental measurements, each acquired every 5 s of kneading. The differences between the above minimum and maximum parameters were determined as the mobile average of the curve bandwidth in a 30 s time-range; the average bandwidth of the power consumption was determined as the average value of the power consumption bandwidth from 120 s of kneading to the end of kneading, which corresponded to twice the optimized kneading time of each flour sample.

The experimental data of the power consumption profile of the optimized dough samples are shown in Table 4.

The “Optimal kneading time” values of the power consumption profiles were significantly correlated ($R^2 = 0.976$; $p < 0.001$) to the optimal kneading time which was determined by the RSM models of the Trial 1 (Figure 2a). The power consumption profile method was also able to predict the optimal kneading time regardless of flour variables, since the flour refinement degree and the flour cv. did not significantly affect the above correlation. It should be noted that the power consumption profile method was already proposed to determine the optimal kneading time of bread dough (Wang et al., 1993; Zounis & Quail, 1997; Hwang & Gunasekaran, 2001; Pereira et al., 2013; Aljaafreh, 2017). However, this method was never tested for dough processed by unrefined flours.

The ”Power consumption at the optimal kneading time” values were significantly affected by the flour refinement degree ($p < 0.001$). The highest values of the power consumption were obtained for unrefined flours; the presence of milling by-products produced the highest dough consistency at the optimal kneading time. The flour technological quality did not affect the power consumption values; optimization of the kneading operating conditions (i.e., T, W) was able to achieve similar dough consistency of the samples. A significant interaction between flour refinement degree and flour cv. was also observed ($p < 0.001$). Indeed, the dough samples processed by Pandas cv. flour had no significant differences at the two tested degrees of refinement; according to the literature data (Aamodt et al., 2004) the presence of milling by-products did not affect the dough consistency of the strongest flour tested in this study.

The ”Dough stability - *DS* values were significantly affected by the interaction between the flour refinement degree and the flour cv. ($p < 0.001$). All unrefined flours except Andriolo cv. (i.e., no significant difference) showed smaller *DS* values compared to the respective refined controls. The poor technological quality of dough samples processed by Andriolo cv. flour, which showed the smallest *DS* values, could have masked the effects of flour refinement degree. Furthermore, the dough samples processed by Pandas cv. flour showed constant *DS* values for all the monitored kneading time; the shortest *DS* value observed for unrefined Pandas cv. flour was only due to the shorter optimal kneading time than that of the refined control, which reduced the total range of monitored time. The higher *DS* values of Bologna and Pandas cvs flours compared to Verna and Andriolo cvs flours clearly confirmed that the stronger the flours the lower the changes of dough consistency after the optimal kneading time (Wooding et al., 1997; Rao et al., 2000; Zhou et al., 2014).

The ”Mixing tolerance index - *MTI*” values were significantly affected by the flour refinement degree ($p < 0.01$) and the flour cv. ($p < 0.001$) (Table 4). The highest *MTI* values, corresponding to the highest decrease in dough consistency from the optimal value, were observed in unrefined flours compared to refined flours. The dough samples processed by Pandas cv. flour were not affected by the presence of milling by-products, as shown by the similar *MTI* values between Pandas unrefined and refined samples.

The “Slope of the mixing tolerance line” values showed a significant effect of the interaction between flour refinement degree and flour cv. ($p < 0.001$) (Table 4). In all the flours except Pandas cv., the above slope had higher negative value in unrefined flours then in the refined controls, meaning that the steepest decline of the power consumption profile occurred in doughs containing milling by-products. The dough samples processed by Pandas cv. flour were not affected by the flour refinement degree; after the optimal kneading time, both unrefined and refined samples showed almost unvaried dough consistency. A significant role of the flour technological quality occurred of the slope values. The lowest difference of dough consistency (approx. 0.02%) was obtained for the Pandas cv. (i.e., the strongest flour tested in this study), which did not change in consistency as a function of the flour refinement degree, confirming the smaller impact of milling by-products in strong flours than weak ones (Aamodt et al., 2004). Bologna cv. flour showed a difference of approx. 3.6% between unrefined and refined samples, showing that milling by-products significantly impacted the rheological properties. The similar difference observed for Andriolo cv. (approx. 3.8%) could be due to its low technological quality (as proven by the smallest *DS* value discussed above), which could have masked the effect of the flour refinement degree. Verna cv. flour, having slightly higher stability values than Andriolo cv. flour, showed a higher impact of milling by-products on the slope values (approx. 4.8%).

The “Average bandwidth” values were also studied as an index of dough elasticity and flour strength (Gras et al., 2000). A good correlation ($R^2 = 0.80$) between the above values and the Alveograph flour strength – *W* of the optimized dough samples was obtained, meaning that the higher the flour technological quality, the wider the power consumption oscillations during dough kneading. A significant effect of the interaction between flour refinement degree and flour cv. on the average bandwidth was obtained ($p < 0.001$). All flours tested except Andriolo cv. flour showed a decrease of the average bandwidth in unrefined brown flours compared to refined flours. The extent of the reduction seemed to reflect the flour technological quality: Verna cv. flour showed the greatest decrease (approx. 43.9%), whereas Bologna and Pandas cvs flours showed lower values (0.9% and 2.7%, respectively). Andriolo cv. flour revealed the opposite behaviour, showing an increased bandwidth of approx. 28.5% in the unrefined sample compared to the refined one. However, the smaller interval of optimal kneading time of Andriolo cv. unrefined sample compared to refined sample reduced the total monitored time, probably giving a higher average bandwidth as a result.

Since the Farinograph test represents a reference method to predict the bread dough behaviour at kneading, relationships between characteristic parameter values of the power consumption profile method applied to the optimized dough samples (Table 4) and characteristic parameter values of the Farinograph test applied to the flour samples (Table 2) were studied. A significant relationship occurred for the only "Dough stability – *DS*" characteristic parameter (Figure 2b), but a significant effect of the flour refinement degree was obtained ($p < 0.001$). The linear relationship between dough samples processed by unrefined flours showed an R^2 value of 0.997 and a slope of 0.312 (after the exclusion of Bologna 2 sample), whereas R^2 was 0.993 and the slope was 0.115 in the dough samples processed by refined flours. The *DS* values determined using the power consumption profile method resulted highly predictive of the *DS* values obtained using the Farinograph test; a correction factors between the two instruments should be applied as a function of the flour refinement degree.

4. Conclusions

This work clearly pointed out that kneading operating conditions, such as dough water amount and kneading time, should be tailored to flour characteristics in order to maximize bread volume. This perspective was especially proved in dough samples processed by unrefined and weak wheat flours. A kneading step according to the flour quality measured with official methods (i.e., Farinograph and Alveograph tests), was not suitable to maximize flour performance in the real kneading conditions; then, support the above methods with other methodological approach can be useful for the bread dough readiness by weak and unrefined flours.

A methodological approach was proposed in this work, based on application of a two-stage method as follows: (i) an optimization stage; (ii) a monitoring stage. The optimization stage was prerequisite for planning the optimal dough water amount and kneading time to maximize the bread specific volume. A CCC experimental design was able to give optimized kneading conditions in relation with flour technological quality, flour cv. and flour refinement degree. The monitoring stage was performed in the real kneading conditions using the power consumption profile method, which was suitable to reach an accurate on-line monitoring of the kneading performance. Indeed, the power consumption profile method was able to predict the "Optimal kneading time" (i.e., the peak of the power consumption profile), which was significantly correlated to the optimal kneading time determined by the previous optimization stage. No effect of the flour refinement degree and the flour technological quality occurred on the above correlation. Moreover, the power consumption profile method showed other characteristic parameters in order to control the rheological properties of dough processed by flours with different technological quality and refinement degree. Some practical applications of the above two-stage methodological approach could be tested in future studies, for example as follows: (i) to test if operating conditions optimized in a lab-kneading machine are also usable in an industrial-kneading machine, in which the new "Optimal kneading time" can be determined by application of the power consumption profile method; (ii) to find operating mistakes in flour quality and dough formulation during kneading operations by comparing the optimized power consumption profile with the real one.

In conclusion, the two-stage methodological approach based on the power consumption profile method could be especially useful to improve the kneading performance of unrefined and weak flours characterised by poor technological quality, enhancing the use of these flours for bread-making and promoting the consumption of healthy foods.

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The power consumption profile to improve the kneading operation of unrefined wheat flour in bread-making

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Keywords

Process control; Optimization; Kneading time; Dough rheology

Abstract

The interest in unrefined wheat flours for bread production has largely increased due to the scientific evidence on the health benefits associated to their consumption. However, they often resulted in dough difficult to be worked and in end-products with poor technological quality, limiting the use of unrefined wheat flour and compromising the acceptability of unrefined bakery products. In this work flours from four wheat cultivars of different technological quality and refinement degree were studied, and a two-stage methodological approach was proposed as innovative method to improve the use of weak and unrefined flours in bread-making. Firstly, an optimization stage trial was applied to determine the optimal dough water amount and kneading time to maximize the bread specific volume. Secondly, a monitoring stage was applied to perform an on-line monitoring of the kneading operation in the real operating conditions using the power consumption profile method. The power consumption profile method was able to predict the "Optimal kneading time" (i.e., the peak of the power consumption profile), which was significantly correlated to the optimal kneading time determined by the previous optimization stage. Moreover, several characteristic parameters were derived from the dough power consumption profile of wheat flours with different technological quality and refinement degree. This work showed the

potentiality of the power consumption profile method for a real-time monitoring of the kneading operation of unrefined and weak wheat flours.

1. Introduction

Nowadays, the interest in unrefined wheat flours for bread production has largely increased (Parenti et al., 2020) due to the scientific evidence on the health benefits associated to their consumption (Ye et al., 2012). The demand for healthy food products is constantly growing, since the nutritional quality has become a key criterion driving consumers' choices (Parenti et al., 2020). Although the presence of bran and germ fractions positively affects the nutritional value of wheat flour, bran and germ have a detrimental effect on the flour technological performance resulting in sticky doughs and poor-quality end-products, which limited the use of unrefined flour and compromises the acceptability of unrefined bakery products (Hemdane et al. 2016; Boukid et al., 2018).

In order to improve the bread-making performance of unrefined wheat flours, the scientific literature proposed different solutions, such as the use of improvers in the bread formulation, the use of the sourdough as leavening agent, and specific pre-treatments of milling by-products (Parenti et al., 2020). However, bakers are not used to add improvers to unrefined flours, due to the consumer demand for clean-label formulas (Guerrini et al., 2019); they are used to carry out the leaving step using the sourdough, whereas performing treatments on milling by-products is not a common practice (Guerrini et al., 2019). In this context, the use of weak unrefined flours in bread-making is still an issue due to the poor and variable technological properties of these flours. Indeed, few scientific studies investigated processing strategies aiming to adapt the bread-making conditions to the requirements of unrefined and weak flours (Parenti et al., 2021a,b).

One of the most important step of the bread-making process is the kneading operation during which several physico-chemical phenomena occur: (i) The homogeneous mixing of dough ingredients, (ii) the hydration of flour constituents, (iii) the development of the gluten matrix, and (iv) the inclusion of gas bubbles within the dough structure (~~Cuq et al., 2003;~~ Zhou et al., 2014; Parenti et al., 2021c). Unrefined flours usually showed poor kneading properties as measured by Farinograph test, including increased dough development time (Penella et al., 2008; Noort et al., 2010; Messia et al., 2016; Gómez et al., 2011a; Gómez et al., 2012) and mixing tolerance index. Contradictory effects were obtained on the dough stability; some authors reported an increase of dough stability, whereas others found a decrease of dough stability with the addition of bran and/or germ (Srivastava et al., 2007; Noort et al., 2010; Gómez et al., 2012; Le Bleis et al., 2015). Alveograph properties of unrefined flours were negatively affected by bran and/or germ addition; a general decrease of the flour strength and an increase of the ratio between dough tenacity and extensibility were reported. As a result, breads from unrefined wheat flours often show poor quality parameters (Messia et al., 2016; Noort et al., 2010; Banu et al., 2012; Gómez et al., 2011a; Gómez et al., 2012). The detrimental impact of the bran and germ fractions on the quality of dough and breads from unrefined wheat flours changes in relation to the flour technological quality, showing the smallest impact on flours with high protein content (i.e., strong flours) compared to flours with low protein content (i.e., weak flours) (Aamodt et al., 2004). The key criterion of the 1960s Green Revolution was a wheat selection towards cultivars with medium-high protein content in order to have wheats with improved technological performances. However, at present time there has been a renewed interest in ancient wheat varieties (Guerrini et al, 2019), since scientific evidence reported that, despite some of these cultivars showed poor technological performances, they had an interesting nutritional profile and potential health benefits (~~Gotti et al., 2018;~~ Dinu et al., 2018). Moreover, regardless wheat genotype, weak flours are still present in the actual wheat heritage. The introduction of innovative strategies, able to improve the process control of bread-making using weak and unrefined flours could be important to increase their exploitation.

According to the official methods (AACC 10-09.01 and 10-10.03), the determination of bread dough readiness was mainly based on the Farinograph and Mixograph tests, baking trials, and bakers' visual inspection. However, Farinograph and Mixograph tests require standard operating conditions that are different from the real operating conditions, the baking trials require high amount of time and resources, and the visual inspection is a subjective method (AACC 10-09.01; AACC 10-10.03; Dobraszczyk & Morgenstern, 2003; Zhou et al., 2014). The unrefined flours showed high variability in the technological performances due to their chemical composition, genotype, environmental conditions, storage, and interactions among these factors. Hence, the process standardization usually adopted for refined flours could not be applied for unrefined flours. The different chemical composition of unrefined flours compared to that of refined flours was reported to require both different tests to evaluate the technological quality and tailored processing conditions to improve the bread-making performance (Guerrini et al., 2019; Parenti et al., 2020). The potentiality of already-existing tools for process control of the bread-making with refined flours should be explored and adapted to the specific requirements of unrefined flours to improve and standardize the technological quality of the end-products.

Concerning the kneading operation, the power consumption was proposed as an alternative method to the official methods (Farinograph and Mixograph) for the determination of the optimal kneading time of bread dough (Wang et al., 1993; Zounis & Quail, 1997; Hwang & Gunasekaran, 2001; Pereira et al., 2013; Aljaafreh, 2017). However, to the best of the authors' knowledge, there is still a lack of scientific studies that monitored the power consumption profile of unrefined dough, and a deep insight into the relationship between power consumption and rheological properties of dough is still required before the actual use of power consumption profile in bread-making. In this work flours from four wheat cultivars of different technological quality and refinement degree were studied, following a two-stage experimental approach: (i) an optimization stage to find the kneading operating conditions (i.e., time and water amount) which were able to maximize bread specific volume; (ii) a monitoring stage of dough samples processed using the optimized kneading conditions in order to test the potentiality of power consumption method for a real time monitoring of the kneading step of unrefined wheat flour dough.

2. Materials and Methods

2.1 Wheat flours

Trials were performed with eight batches of sp. *Triticum aestivum* L. flour, two for each of the following cultivars (cv.): (i) Verna, (ii) Andriolo, (iii) Bologna, (iv) Pandas. They were processed by the Molino Paciscopi (Montespertoli, Florence, Italy). Verna and Andriolo cv. flours were representative of low technological quality wheat flours; Pandas and Bologna cv. flours were representative of good technological quality wheat flours. The flours were processed using a stone grinding mill and a sieve to produce two different refinement degrees according to the Italian classification (Zhou et al., 2014), namely type 0 (i.e., refined wheat flour) and type 2 (i.e., unrefined wheat flour) wheat flours. Type 0 flour was produced by applying a passage through a 500 µm sieve, and type 2 flour by applying two consecutive passages through a 1,100–1,200 µm sieve.

2.2 The experimental design

2.2.1 Trial 1 - The optimization stage

A baking-trial based on Central Composite Circumscribed (CCC) Design and Response Surface Methodology (RSM) was applied to optimize the following kneading conditions:

(i) Dough water amount – *W* (%, w/flour w)
(ii) Kneading time – *T* (min)

Each factor was tested at five levels: - α, - 1, 0, + 1, + α. The CCC Design for 2 factors at 5 levels required 12 runs, including 4 replications of the centre point. A total of 96 bread-samples were produced, resulting from the above 12 runs x the above 8 flour cv. batches.

Trials of each flour cv. batch were performed in the same day, and the samples were processed in a randomized order. The proper experimental range and distance between levels of the tested variables were identified after preliminary trials. Table 1 shows the selected experimental ranges of the *W* and *T* variables; the distance between 0 and +/-1 points was 3% for *W* variable and 5 min for *T* variable; the corresponding level of +/- α was calculated according to the formula $(2^k)^{¼}$, where k is the number of tested variables. Bread specific volume was the response variable to measure bread quality. The kneading conditions for the optimization of the eight dough samples were thus obtained.

2.2.2 Trial 2 – The monitoring stage

The kneading operation of the above eight optimized dough samples was monitored using an energy analyser as described below (see Paragraph 2.4.2).

2.3 Bread-making

500 g batches of dough were processed, using the following dough ingredients: Flour (310 g), water amount in relation with the above optimization stage, fresh brewer's yeast (13 g). The mineral water (Sant'Anna, Vinadio, Italy) and fresh brewer's yeast (Original, Casteggio, Italy) were purchased at a local market (Florence, Italy). The dough ingredients were stored at room temperature (22 ± 2°C). Dough batches were processed at room temperature using a Kitchen Aid Professional Mixer (mod. KSM35CDH) at constant kneading speed of 150 rpm. After kneading, the bread-making steps were carried out using a bread machine (Pain doré, Moulinex, Ecully, France). The dough samples were put into the machine bowl and the leavening step was carried out at room temperature and room relative humidity for 90 min. The leavened dough samples were baked for 50 min at 150 °C. The bread samples were cooled to room temperature before the measurement of bread specific volume.

2.4 Measurement methods

2.4.1 Dough rheological properties

The rheological characterisation of the flour samples was carried out according to the official methods using the Farinograph test (AACC 54-21.02) and Alveograph test (AACC 54-30.02). A modified Alveograph test was also carried out; the dough samples were kneaded in the Kitchen Aid Professional Mixer at constant kneading speed of 150 rpm using the optimized kneading conditions obtained from the optimization stage in the 2.2.1 paper section, and then, the standard Alveographic procedure was applied. Measurements were carried out in three replicates. The Farinograph and Alveograph results (Table 2 and Table 3) were in agreement with the flour supplier's statement, that is weak flours from Verna and Andriolo cvs, strong flours from Bologna and Pandas cvs; Pandas cv. resulted the strongest flour tested.

2.1.1 Power consumption profile

The power consumption of dough samples was monitored and recorded every 5 s in the mixer described in the 2.3 paper section, using an energy analyser (Fluke 434-II/435-II/437-II, Danaher Corporation, Everett, Washington, US). The measurements were carried out both in the optimization stage (i.e., Trial 1) for a total kneading time according to the experimental design, and in the monitoring stage (i.e., Trial 2) for a total kneading time corresponding to twice the amount of the optimized kneading time. At least three replications for each dough sample were performed in the Trial 2. Several parameters were derived from the power consumption profile as explained in the Results and Discussion paper section.

2.1.2 Bread specific volume

Bread volume (L) was measured using the standard millet displacement method (AACC 10-05.01), and specific volume (L/kg) was determined as the ratio between total volume (L) and mass (kg).

2.2 Data processing

2.5.1 Trial 1 – The optimization stage

Bread quality in terms of bread specific volume and the corresponding dough mechanical energy were estimated using a Central Composite Circumscribed (CCC) Design based on response surface methodology (RSM). In order to describe the relationship between the independent variables (*T*, *W*) and the dependent variable (bread specific volume) the response values were fitted with first order and second order polynomial (quadratic) regression models using a multiple regression analysis (Standard Least Square Fitting). The CCC Design for 2 factors at 5 levels resulted in a total of 12 runs including 4 replicates at the centre point. Adopting a full factorial design would require $5^2 = 25$ runs for each replicate, whereas CCC only require 12 experiments. The four replicates at the centre point allowed to estimate the pure error of the analysis, which was used to predict the lack-of-fit of the model. In order to describe the effects of the independent variables on the dependent variable, surface plots were obtained. The optimal kneading conditions were considered those that maximized bread specific volume without causing apparent defects in the inner and outer surface of the product.

A t-test was performed to compare Alveograph parameters of dough samples obtained with the standard Alveograph procedure with the dough samples prepared in the optimized kneading conditions according to the optimization stage. The comparison was made on each flour sample (cv. x refinement degree) standard vs optimized. A two-way ANOVA was performed to test the effect of the flour refinement degree, the flour technological quality and their interaction on the extent of the differences between standard Alveograph samples and optimized samples. The above results were obtained with R software version 4.0.0.

2.5.2 Trial 2 – The monitoring stage

The effect of the flour refinement degree, the flour cv., and the interaction between the above variables on the parameters determined by the power consumption profile were tested with a two-way ANOVA. A linear regression analysis was used to test the effect of the flour refinement degree on the relationship between parameters obtained from the optimization stage (optimal kneading time)/ Farinograph curve (DS) and those determined from the power consumption profile, and their interaction; the relationships were tested with a two-way ANOVA and Tukey ‘s was used as post hoc test. The above results were processed with R software version 4.0.0.

3. Results and Discussion

3.1 Trial 1 – The optimization stage

3.1.1 Bread-making test

The RSM models of the Trial 1 resulted statistically significant ($p < 0.05$, and lack-of-fit tests > 0.05), hence they allowed to identify the optimal combination of kneading variables to maximize bread specific volume (Table 1). The specific mechanical energy (kJ/kg) was calculated integrating the area value under the power consumption profile, divided by the dough sample weight.

The effect of flour technological quality on kneading time, the water requirements and specific mechanical energy was consistent with the literature; the flours of good technological quality (i.e., Bologna and Pandas cvs) showed the longest kneading time, the highest water requirements and the greatest specific mechanical energy to optimize the bread specific volume (Wooding et al., 1997; Rao et al., 2000; Zhou et al., 2014).

Considering the effect of the flour refinement degree, an increase in kneading time and specific mechanical energy was observed in Verna and Bologna cvs unrefined flours compared to the respective refined controls, whereas the opposite trend was observed in Andriolo and Pandas cvs flours. In the literature an increase of kneading time with low flour refinement degree was reported (Penella et al., 2008; Noort et al., 2010; Gómez et al., 2011a; Gómez et al., 2012; Messia et al., 2016), whereas scant information was reported on the effect of refinement degree on specific mechanical energy (Campbell e al., 2008; Le Bleis et al., 2015).

Unrefined Verna and Pandas cvs flours showed an increase of the dough water amount compared to the respective refined controls according to the literature data (Penella et al., 2008; Noort et al., 2010; Gómez et al., 2011a; Gómez et al., 2012); however, Andriolo cv. flour showed a higher water requirement in the refined degree flour than that of brown flour, and no significant differences of dough water amounts were observed in Bologna cv. flour as a function of the flour refinement degree.

The above different behaviours could be related to different reasons, such as the variable effect of wheat bran due to the cv. and hence to the bran chemical composition (Rosell et al., 2006; Hemdane et al., 2016), and the presence of both wheat bran and germ in the experimental flour samples, whereas the literature data were mainly focused on the only effect of wheat bran. Furthermore, in the major part of literature studies, the effect of bran was tested at relatively higher levels compared to the amount naturally present in unrefined wheat flours as those tested in the present research (Hemdane et al., 2016).

The optimization trial represented a prerequisite to determine the optimal kneading conditions (*T* and *W*) of each flour sample (flour cv. x refinement degree); then, the optimized dough samples were analysed with the Alveograph test and monitored during kneading with the power consumption method.

The rheological properties of the dough samples of the Trial 1 were measured through the Alveograph test (Table 3); the rheological properties were measured both according to the standard alveographic procedure (*Std*) and applying the optimized kneading conditions found in Trial 1 (*Opt*).

The optimization of the kneading conditions had a significant effect on all the Alveograph parameters. The effect of flour refinement degree and flour technological quality on the difference between standard and optimized samples was tested.

The optimized dough samples showed a significant increase in dough extensibility – *L* ($p < 0.01$) and swelling index – *G* ($p < 0.05$), and a significant decrease in dough tenacity – *P* ($p < 0.01$), tenacity to extensibility ratio – *P/L* ($p < 0.05$), and flour strength – *W* ($p < 0.05$). Considering elasticity index – *Ie*, the optimization significantly increased the parameter; *Ie* values were measurable for all dough samples except for the samples processed by unrefined Verna cv. flours.

The flour refinement degree affected the extent of the differences between dough samples processed according to *Std* procedure and the *Opt* conditions on *P* ($p < 0.05$), *W* ($p < 0.05$) and *P/L* ($p < 0.05$) parameters. The *P* and *W* reduction was significantly greater in refined flours compared to unrefined flours, whereas the *P/L* values showed the opposite trend. The *Ie* values showed that the optimization had the greatest improvements in unrefined flours than in refined flours; the *Ie* values were measurable for the dough samples processed by unrefined Andriolo and Pandas cvs flours in optimized conditions, whereas they were not measurable in standard conditions. The flour technological quality significantly affected the extent of the differences on *P* ($p < 0.01$) values between dough samples processed according to *Std* procedure and the samples processed using the *Opt* conditions; the parameter decrease was greater in the experimental strong flours than in the experimental weak flours.

Therefore, the optimization of the kneading conditions particularly improved the dough rheology for the unrefined flours. Since the literature data expressed that the unrefined flours are generally characterised by *P/L* values too high to develop a good bread structure (Messia et al., 2016; Banu et al., 2012; Srivastava et al., 2007), it was important that the optimization made unrefined flours achieve *P/L* values in the optimal range for bread-making (i.e., 0.6-1.0 according to Zhou et al., 2014). Furthermore, the experimental "optimized" *P/L* values were significantly correlated with the specific volume of optimized breads ($R^2 = 0.64$ – $p = 0.02$), showing a predictive role of the *P/L* parameter for the quality of bread from unrefined wheat flours.

3.2 Trial 2 – The monitoring stage

Power consumption profiles of the optimized dough samples were recorded; the relevant experimental data were explained using the Farinograph test as reference for selection of the characteristic parameters (Zhou et al., 2014). For example, the Figure 1 shows the power consumption profile of dough samples from unrefined Verna cv. flour. The following characteristic parameters were derived and processed from the power consumption profiles:

- “Optimal kneading time” (min): The time interval from the beginning of kneading to the peak of the power consumption profile. In order to ensure that the peak of the power consumption profile was properly identified, a second order polynomial curve was fitted on the power consumption profile and the kneading time having the tangent equal to zero was considered the optimal value. The beginning of kneading was considered excluding the first 120 s in order to avoid biased results due to the motor inrush.
- “Power consumption at the optimal kneading time” (W): The value of the power consumption at the peak/tangent equal to zero of the profile.
- “Power consumption 5 min after the optimal kneading time” (W): The value of the power consumption 5 min after the peak/tangent equal to zero of the profile.
- “Dough stability - *DS*” (min): The time interval during which the power consumption showed small oscillations closed to the power consumption value at the optimal kneading time.
- ”Mixing tolerance index - *MTI*“ (W): The difference between the power consumption value at the optimal kneading time and that measured 5 min after the optimal kneading time.
- “Slope of the mixing tolerance line” (W/s): The slope of the regression straight line obtained using the power consumption experimental values ranging from the optimal kneading time to 5 min after the optimal kneading time. The above slope can be related to the dough mixing tolerance and it is less susceptible to power consumption oscillations than the *MTI*.

The bandwidth of the power consumption profiles - “Average bandwidth” (W) was also determined. For each sample replicate the minimum and maximum values of the power consumption were determined as moving average parameters in a time-range of 30 s which corresponded to 6 experimental measurements, each acquired every 5 s of kneading. The differences between the above minimum and maximum parameters were determined as the mobile average of the curve bandwidth in a 30 s time-range; the average bandwidth of the power consumption was determined as the average value of the power consumption bandwidth from 120 s of kneading to the end of kneading, which corresponded to twice the optimized kneading time of each flour sample.

The experimental data of the power consumption profile of the optimized dough samples are shown in Table 4.

The “Optimal kneading time” values of the power consumption profiles were significantly correlated ($R^2 = 0.976$; $p < 0.001$) to the optimal kneading time which was determined by the RSM models of the Trial 1 (Figure 2a). The power consumption profile method was also able to predict the optimal kneading time regardless of flour variables, since the flour refinement degree and the flour cv. did not significantly affect the above correlation. It should be noted that the power consumption profile method was already proposed to determine the optimal kneading time of bread dough (Wang et al., 1993; Zounis & Quail, 1997; Hwang & Gunasekaran, 2001; Pereira et al., 2013; Aljaafreh, 2017). However, this method was never tested for dough processed by unrefined flours.

The ”Power consumption at the optimal kneading time” values were significantly affected by the flour refinement degree ($p < 0.001$). The highest values of the power consumption were obtained for unrefined flours; the presence of milling by-products produced the highest dough consistency at the optimal kneading time. The flour technological quality did not affect the power consumption values; optimization of the kneading operating conditions (i.e., T, W) was able to achieve similar dough consistency of the samples. A significant interaction between flour refinement degree and flour cv. was also observed ($p < 0.001$). Indeed, the dough samples processed by Pandas cv. flour had no significant differences at the two tested degrees of refinement; according to the literature data (Aamodt et al., 2004) the presence of milling by-products did not affect the dough consistency of the strongest flour tested in this study.

The ”Dough stability - *DS* values were significantly affected by the interaction between the flour refinement degree and the flour cv. ($p < 0.001$). All unrefined flours except Andriolo cv. (i.e., no significant difference) showed smaller *DS* values compared to the respective refined controls. The poor technological quality of dough samples processed by Andriolo cv. flour, which showed the smallest *DS* values, could have masked the effects of flour refinement degree. Furthermore, the dough samples processed by Pandas cv. flour showed constant *DS* values for all the monitored kneading time; the shortest *DS* value observed for unrefined Pandas cv. flour was only due to the shorter optimal kneading time than that of the refined control, which reduced the total range of monitored time. The higher *DS* values of Bologna and Pandas cvs flours compared to Verna and Andriolo cvs flours clearly confirmed that the stronger the flours the lower the changes of dough consistency after the optimal kneading time (Wooding et al., 1997; Rao et al., 2000; Zhou et al., 2014).

The ”Mixing tolerance index - *MTI*” values were significantly affected by the flour refinement degree ($p < 0.01$) and the flour cv. ($p < 0.001$) (Table 4). The highest *MTI* values, corresponding to the highest decrease in dough consistency from the optimal value, were observed in unrefined flours compared to refined flours. The dough samples processed by Pandas cv. flour were not affected by the presence of milling by-products, as shown by the similar *MTI* values between Pandas unrefined and refined samples.

The "Slope of the mixing tolerance line" values showed a significant effect of the interaction between flour refinement degree and flour cv. ($p < 0.001$) (Table 4). In all the flours except Pandas cv., the above slope had higher negative value in unrefined flours then in the refined controls, meaning that the steepest decline of the power consumption profile occurred in doughs containing milling by-products. The dough samples processed by Pandas cv. flour were not affected by the flour refinement degree; after the optimal kneading time, both unrefined and refined samples showed almost unvaried dough consistency. A significant role of the flour technological quality occurred of the slope values. The lowest difference of dough consistency (approx. 0.02%) was obtained for the Pandas cv. (i.e., the strongest flour tested in this study), which did not change in consistency as a function of the flour refinement degree, confirming the smaller impact of milling by-products in strong flours than weak ones (Aamodt et al., 2004). Bologna cv. flour showed a difference of approx. 3.6% between unrefined and refined samples, showing that milling by-products significantly impacted the rheological properties. The similar difference observed for Andriolo cv. (approx. 3.8%) could be due to its low technological quality (as proven by the smallest *DS* value discussed above), which could have masked the effect of the flour refinement degree. Verna cv. flour, having slightly higher stability values than Andriolo cv. flour, showed a higher impact of milling by-products on the slope values (approx. 4.8%).

The "Average bandwidth" values were also studied as an index of dough elasticity and flour strength (Gras et al., 2000). A good correlation ($R^2 = 0.80$) between the above values and the Alveograph flour strength – *W* of the optimized dough samples was obtained, meaning that the higher the flour technological quality, the wider the power consumption oscillations during dough kneading. A significant effect of the interaction between flour refinement degree and flour cv. on the average bandwidth was obtained ($p < 0.001$). All flours tested except Andriolo cv. flour showed a decrease of the average bandwidth in unrefined brown flours compared to refined flours. The extent of the reduction seemed to reflect the flour technological quality: Verna cv. flour showed the greatest decrease (approx. 43.9%), whereas Bologna and Pandas cvs flours showed lower values (0.9% and 2.7%, respectively). Andriolo cv. flour revealed the opposite behaviour, showing an increased bandwidth of approx. 28.5% in the unrefined sample compared to the refined one. However, the smaller interval of optimal kneading time of Andriolo cv. unrefined sample compared to refined sample reduced the total monitored time, probably giving a higher average bandwidth as a result.

Since the Farinograph test represents a reference method to predict the bread dough behaviour at kneading, relationships between characteristic parameter values of the power consumption profile method applied to the optimized dough samples (Table 4) and characteristic parameter values of the Farinograph test applied to the flour samples (Table 2) were studied. A significant relationship occurred for the only "Dough stability – *DS*" characteristic parameter (Figure 2b), but a significant effect of the flour refinement degree was obtained ($p < 0.001$). The linear relationship between dough samples processed by unrefined flours showed an R^2 value of 0.997 and a slope of 0.312 (after the exclusion of Bologna 2 sample), whereas R^2 was 0.993 and the slope was 0.115 in the dough samples processed by refined flours. The *DS* values determined using the power consumption profile method resulted highly predictive of the *DS* values obtained using the Farinograph test; a correction factors between the two instruments should be applied as a function of the flour refinement degree.

4. Conclusions

This work clearly ~~evidenced~~ pointed out that kneading operating conditions, such as dough water amount and kneading time, should be tailored to flour characteristics in order to maximize bread volume ~~technological quality~~. This perspective was especially proved ~~right, especially~~ in dough samples processed by unrefined and weak wheat flours. ~~Performing a kneading step~~ A kneading step according to the flour quality ~~determined~~ measured with official methods (i.e., Farinograph and Alveograph tests), was ~~proved to be~~ not suitable to maximize flour performance in the real kneading conditions~~.~~; then, support the above methods with other methodological approach can be useful for the bread dough readiness by weak and unrefined flours. ~~The introduction of other methodological approach supporting the above reference methods, can be important for the bakery industry in order to improve the use of weak and unrefined flours.~~

~~In this work, a two-stage methodological approach was proposed, which is based on application~~ A methodological approach was proposed in this work, based on application of a two-stage method as follows: (i) an optimization stage; (ii) a monitoring stage. The optimization stage was prerequisite for planning ~~to identify~~ the optimal dough water amount and kneading time to maximize the bread specific volume. A CCC experimental design was able to give optimized kneading conditions in relation with flour technological quality, flour cv. and flour refinement degree ~~considering the following flour variables: flour technological quality, flour cv., and flour refinement degree~~. The monitoring stage was performed in the real kneading conditions using the power consumption profile method, which was suitable to reach an accurate on-line monitoring of the kneading performance. ~~which proved to be a promising tool for an on-line process control~~. Indeed, the power consumption profile method was able to predict the "Optimal kneading time" (i.e., the peak of the power consumption profile), which was significantly correlated to the optimal kneading time determined by the previous optimization stage. No effect of the flour refinement degree and the flour technological quality occurred on the above correlation. Moreover, the power consumption profile method showed other characteristic parameters ~~several characteristic parameters were derived from the power consumption profile method related to~~ in order to control the rheological properties of dough processed by flours with different technological quality and refinement degree. Some practical applications of the above two-stage methodological approach could be tested in future studies, for example as follows: (i) to test if operating conditions optimized in a lab-kneading machine are also usable in an industrial-kneading machine, in which the new "Optimal kneading time" can be determined by application of the power consumption profile method; (ii) to find operating mistakes in flour quality and dough formulation during kneading operations by comparing the optimized power consumption profile with the real one.

In conclusion, the two-stage methodological approach based on the power consumption profile method could be especially useful to improve the kneading performance of unrefined and weak flours characterised by poor technological quality, enhancing the use of these flours for bread-making and promoting the consumption of healthy foods.

~~The present experimental results showed the potentiality of the power consumption method applied to the kneading step in the real operating conditions. This approach appeared particularly promising as an on-line method for process control which could improve the exploitation of unrefined and weak wheat flours and the quality of their end-products~~.

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