



UNIVERSITÀ DI PARMA

ARCHIVIO DELLA RICERCA

University of Parma Research Repository

Techniques and technologies for the breadmaking process with unrefined wheat flours

This is the peer reviewed version of the following article:

Original

Techniques and technologies for the breadmaking process with unrefined wheat flours / Parenti, O., Guerrini, L., Zanoni, B.. - In: TRENDS IN FOOD SCIENCE & TECHNOLOGY. - ISSN 0924-2244. - 99:(2020), pp. 152-166. [10.1016/j.tifs.2020.02.034]

Availability:

This version is available at: 11381/2937437 since: 2024-10-09T08:11:13Z

Publisher:

Published

DOI:10.1016/j.tifs.2020.02.034

Terms of use:

Anyone can freely access the full text of works made available as "Open Access". Works made available

Publisher copyright

note finali coverpage

(Article begins on next page)

Manuscript Details

Manuscript number	TIFS_2020_91_R1
Title	Techniques and technologies for the breadmaking process with unrefined wheat flours
Article type	Review Article

Abstract

Background: In recent years there has been an increasing interest in the production of wholegrain products owing to the positive effects shown on human health. Although refined flour still represents the standard reference in breadmaking technology, consumer demand for unrefined breads has grown greatly. The different chemical composition of unrefined wheat flours (UWFs), which includes specific fractions of milling by-products (i.e., wheat bran and wheat germ), favours the nutritional value, but it has a negative effect on technological performance. Therefore, it is useful to develop new strategies specifically designed to improve the quality of UWF breads. Scope and approach: The present review aims to set out the techniques and technologies that have been reported in the literature for the breadmaking process with UWFs, that is, from raw material processing to bread formulation and breadmaking methods. Key findings and conclusion: The evaluation of UWF quality is still based on the tests developed for refined flour, which cannot properly estimate UWF technological properties. The greatest efforts to improve the breadmaking performance of UWF have been focused on modifying the bread formula, mainly with the addition of improvers. Conversely, very little investigation has been carried out on adapting the breadmaking process to the different characteristics of the raw material. Overall, the use of UWF in breadmaking may require further investigations into processing strategies to improve the quality of the end product, hence increasing the consumption of healthy foods.

Keywords	bread; wholewheat flour; milling by-products; wheat germ; wheat bran
Manuscript region of origin	Europe
Corresponding Author	Lorenzo Guerrini
Corresponding Author's Institution	University of Florence
Order of Authors	Ottavia Parenti, Lorenzo Guerrini, Bruno Zanoni
Suggested reviewers	Eleonora Carini, Kati Katina, Jan Delcour, Cristina M. Rosell

Submission Files Included in this PDF

File Name [File Type]

Cover letter.docx [Cover Letter]
Response to reviewers.docx [Response to Reviewers]
Highlights.docx [Highlights]
Abstract.docx [Abstract]
Manuscript revised.docx [Manuscript File]
Figure.pdf [Figure]
Tables revised.docx [Table]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Lorenzo Guerrini
University of University of Florence
Piazzale delle Cascine 16, 50144, Florence, Italy
Tel: +39 055 2755932
lorenzo.guerrini@unifi.it

Dr. Paul Finglas
Executive Editor
Trends in Food Science & Technology

January 27, 2020

Dear Dr. Paul Finglas:

I am pleased to submit an original research article entitled “Techniques and technologies for the breadmaking process with unrefined wheat flours” for consideration for publication in *Trends in Food Science & Technology*.

This manuscript aims to report the processing strategies that have been developed until now for the breadmaking process with unrefined wheat flours, while suggesting some processing innovations to improve the exploitation of unrefined wheat flours. The main chapters of this manuscript include: (i) the introduction section, (ii) the evaluation of bread quality, (iii) the breadmaking process (reporting the scientific literature about breadmaking with unrefined wheat flours), (iv) the carbon footprint of unrefined wheat flour bread and (v) the conclusion.

We believe that this manuscript is appropriate for publication by *Trends in Food Science & Technology* since the use of unrefined flours for bread production has recently gained attention of the scientific research as well as of consumers. Moreover, reporting the processing strategies that improve the breadmaking process of unrefined wheat flours, may increase their consumption, which is associated to positive effects on human health.

To the authors’ best knowledge, the use of unrefined wheat flour in breadmaking has never been reviewed before. The relevance of this study is a literature review about the breadmaking with unrefined wheat flours, from the raw materials to the storage phase.

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,

Dr. Lorenzo Guerrini
Department of Agricultural, Food and Forestry Systems Management (DAGRI)
University of Florence, Italy

The authors would like to thank the Reviewers for the time spent in improving the paper, and for the important suggestions and corrections proposed. We hope to have addressed all the issues the reviewers outlined. Here following, a point by point reply to the comments received.

-Reviewer 1

- I really enjoyed reading the article, it is written in a clear way and is easy to follow. The different aspects of bread making are discussed in relation to the different flours that can be used and the challenges one faces when shifting from refined to unrefined flour. Mostly, the authors refer to recent literature, outlining the up to date literature available on the topic.

There were a few items that I would like to draw attention to:

Lines 263-265. It is mentioned that the fact that bran addition goes along with increase in ash content is contributing to a decrease in flour properties. Is that what the authors, Banu (2012) concluded? could it also relate to addition of bran fibres which affect flour properties? when you speak about technological properties, are there specific ones you are referring to? if yes, I recommend clarifying that.

Lines 263-265: Banu et al. (2012) studied the rheological properties and bread physical parameters of white flour enriched with different bran streams (3-30%). As reviewer observed, the conclusion of the study is that ash content, a measure of the bran and germ "contamination" on the white flour produced with the only starchy endosperm, significantly decreased the rheological properties of the dough and physical characteristics of breads. However, although they observed a negative impact of ash content on dough and bread quality, the authors identified in the 25% sample a level of ash content equal to that in wholewheat sample, but associated with a significant improvement of dough and bread quality.

According to reviewer observation we added some specifications about the study by Banu et al. (2012) (L 268-273).

L268: This sentence was a little unclear to me. was wheat pearled to 2-25% and was that used to make bread? or, was wheat pearled to X% and added to refined flour at 5-25% level?

Blandino et al. (2013) added 5 different levels of pearled fractions from wheat kernels (5-25%) on refined flours and tested the flour mixtures on dough rheology, bread quality and nutritional properties. We clarified the sentence in the Manuscript (L274-275) according to reviewer observation.

L339. I feel increase needs to be changed into decrease

The sentence has been rephrased (L346).

L400, 429 and 540. Are these percentages additions to the total recipe or expressed on flour weight? Also table 2 mentions percentages of addition and it would be good to clarify whether these are on flour weight or total recipe.

In accordance with reviewer's observation we specified the percentages of addition in L414, 444-445, 556-557. We also modified Table 2 adding the required specifications.

L417: Why does a farinograph not work for UWF?

The farinographic official method was developed to evaluate the water absorption (WA) and the behaviour during the mixing step of refined flour. In refined flour the main components responsible for the WA are the gluten network proteins, which can adsorb up to three times their weight in water (Zaidul, I.S.M., Karim, A.A., Manan, D.M.A., Ariffin, A., Norulaini, N.A.N. & Omar, A.K.M. (2004). A farinograph study on the viscoelastic properties of sago/wheat flour dough. *Journal of Science and Food Agriculture*, 84, 616–622). In unrefined products the presence of soluble and insoluble fibres as flour constituents significantly increases the flour water absorption (Schmiele et al., 2012). In fact, the hydroxyl groups in fibre structure bind to water molecules and compete with starch and proteins for hydration, altering the water distribution in the dough (Khalid et al., 2017; Curti et al., 2013). Hence, the farinographic WA in unrefined wheat flours does not reflect the amount of water required for the optimal hydration of the gluten proteins to reach the 500BU of consistency, but this value results also from the fibre water absorption.

The authors also added the reference Schmiele et al. (2012) to support the statement in L431 and in the reference list L1149.

L473: Which studies report and increase in stabilisation by DATEM? Tebben (2018) seems to indicate a decrease in stability

Tebben et al. (2018) reported that monoglycerides and diglycerides decreased the final proof time, while DATEM increased the final proof time as measured by Mathurograph. It means that mono- and di- glycerides allowed the dough to perform a faster leavening, whereas DATEM reduced the dough rise. Hence, the authors reported DATEM to increase the fermentation stability in terms of a larger window of time during which the dough can be moved to the leavening to the baking step without losing its optimal volume (Hrušková, M., Švec, I., & Jirsa, O., 2006. Correlation between milling and baking parameters of wheat varieties. *Journal of Food Engineering*, 77, 439–444; Mettler, E., & Seibel, W., 1993. Effects of emulsifiers and hydrocolloids on whole wheat bread quality - a response-surface methodology study. *Cereal Chemistry*, 70, 373–377). Converseley, a study by Armero, E., & Collar, C., 1996b. Antistaling additives, flour type and sourdough process effects on functionality of wheat doughs. *Journal of Food Science*, 61, 299–303, found that DATEM decreased the fermentation stability and final proof time; for this reason in the present review we reported that controversial results about the effect of DATEM on fermentation stability are still present in the current literature.

L 474.: You speak about studies looking at emulsifiers, but in the whole paragraph only one reference is used. Was there only one study? If yes, mention that you could identify just one study. That indicates a gap in the research simultaneously.

The authors agree with reviewer's observation. As we stated at the beginning of the paragraph 3.2.3 "UWF bread improvers" (L442-443), the addition of common bread improvers on the breadmaking performance of wholewheat flours has been recently reviewed by Tebben et al. (2018). In a previous version of the Manuscript we included all the references cited in the review Tebben et al. (2018), but unfortunately the final number of references exceeded those allowed by the Journal (at maximum 100 ref). Hence, we had to remove some of the scientific studies, and we limited to cite the review article where the reader could find all the specific references that are briefly summarized in the present review.

At the end of the paragraph we reported that the mentioned studies tested the effects of bread improvers on wholewheat flour, whereas information on the impacts of the same improvers on unrefined flour performances are still missing in the current literature (L519-521). We specify in the text that Tebben et al is a review.

L706-707: The sentence is a little confusing. were 13 or 14 attributes tested by a sensory panel?

We corrected the sentence in L723 according to reviewer's observation. In the mentioned study (Jensen et al., 2011a) a total of 13 sensory attributes was chosen for each of the tested bread samples.

Reference list: the reference to Tebben (2018) is mentioned in the text and tables but missing in the list. Please add this one

We added Tebben et al. (2018) in the reference list (L1173).

Table 2: treatments on whole grain, mainly germination are given. This is what Richter (2014) did as well. I see it in the reference list but not in the table. could it be added?

Table 2: There was an error in the reference name of Table 2, but the reference Ritcher et al. (2014) was already included in the Table. We corrected the mistaken reference, hence Ritcher et al. (2014) is now present in reference of the Table as well as in the reference list of the Manuscript.

Table 4 and 5 show '?' in the last column. What is meant with these? It would be good to clarify that in the foot note of the table. Or, use a - if no real conclusions can be drawn from the study.

Table 3: the authors added some specification about the article by Zilic et al (2016) in the columns "Measurements" and "Main Results".

Table 4: the authors made an in-depth research to include additional information in Table 4, studying the specific literature references of the cited review by Hemdane et al. (2016) and Boukid et al. (2018).

Table 5: the authors added some specification as suggested by the reviewer.

Table 6: the authors added some specification consistently with Table 5.

-Reviewer 2

-

The topic is interesting and current, the paper is well written and well argued.

Some suggestions:

- **Page 3 line 67:** In 2019 Whole Grain Initiative sets the following definition of whole grains also approved by ICC, Healthgrain and Cereal & Grain Association: "Whole grains shall consist of the intact, ground, cracked, flaked or otherwise processed kernel after the removal of inedible parts such as the hull and husk. All anatomical components, including the endosperm, germ, and bran must be present in the same relative proportions as in the intact kernel". I suggest referring to this definition because is the most recent.

The authors added the reference suggested by the reviewer in L67-68.

- page 3 line 79, page 4 lines 126 and 127, page 5 line 132..... : I suggest changing the term sensory, throughout the text, with sensorial.

As reviewer suggested we changed the word “sensory” with “sensorial” (L80, L127, L128, L133).

- page 11 line 336: the term gelatinizing should be changed with gelatinization.

We changed the term “gelatinizing” with “gelatinization” according to reviewer’s suggestion (L342-343)

- page 14 line 439-442: other authors than Tebben et al, 2018 reported about the positive role exerted by xylanase:

Katina K., Heiniö R.L., Autio K., Poutanen K. *Lebensm. Wiss. Technol.*, 2006, 39, 1189-1202.

Messia M.C., Reale A., Maiuro L., Candigliota T., Sorrentino E., Marconi M. *J. Cereal Sci.*, 2016, 69, 134-144.

Santala O. , Lehtinen P. , Nordlund E. , Suortti T. , Poutanen K. *J. Cereal Sci.*, 2011, 54 187-194.

However, Tebben et al., 2018 (page 14 line 444) is missing from the references !!

The reference list of the Manuscript already included “Katina, K., Heiniö, R. L., Autio, K., & Poutanen, K. (2006a). Optimization of sourdough process for improved sensory profile and texture of wheat bread. *LWT - Food Science and Technology*, 39, 1189–1202” in L1030 and in the Manuscript L138, L147, L614, L624. However, the aim of the paper was to (i) investigate the effect of sourdough process parameters (ash content of flour, fermentation temperature and fermentation time) on bread quality parameters performing two different types of fermentations (a single strain of lactic acid bacteria or a combination of lactic acid bacteria + yeasts) and (ii) to improve flavour, volume and shelf life of breads by optimizing the fermentation variables. Was the reviewer referring to this or to another paper for the missing reference about xylanase positive effects?

The authors added the reference proposed by the reviewer “Messia, M. C., Reale, A., Maiuro, L., Candigliota, T., Sorrentino, E., & Marconi, E. (2016). Effects of pre-fermented wheat bran on dough and bread characteristics. *Journal of Cereal Science*, 69, 138–144” in the reference list (L1078) and in the Manuscript Paragraph 3.1.2.2 L369. Furthermore, the authors included this reference in Table 4 and L372 since the study also tested the effect of bran pre-soaking on dough rheology and bread physical properties.

The authors added the reference “Santala, O., Lehtinen, P., Nordlund, E., Suortti, T., & Poutanen, K. (2011). Impact of water content on the solubilisation of arabinoxylan during xylanase treatment of wheat bran. *Journal of Cereal Science*, 54, 187–194” in the Manuscript Paragraph 3.1.2.2 L368-369 and in the reference list L1142.

The authors added Tebben et al. (2018) in the reference list (L1173).

- **References section:** page 32 line 938, page 32 line 947, page 35 line 1039, page 36 line 61, page 37 line 1095: in the references section Authors must pay attention to how the surnames and names of the authors are reported. Here are some correct underlined surnames: Fadda C, Sanguinetti A.M., Del Caro A., Collar C., Piga A (2014); Gobbetti M., Rizzello C.G., Di Cagno R., De Angelis M. (2014); Marti A., Cardone G., Nicolodi A., Qualgia L., Pagani M.A., (2017); Otoni C.G., Pontes S.F.O., Medeiros E.A.A., Soares Nde F. (2014).

We corrected the references in the reference list and throughout the Manuscript as reviewer suggested (L965, L1066, L322, L1101).

Furthermore, the authors added in the paragraph 3.1.2.1 (L352-356) "Pre-treatment of wheat kernels: germination" the interesting results recently showed in the paper by Cardone et al. (2020), which was published during the submission process of the present review. The article studied the application of a controlled germination process on rheological characteristics of doughs and physical quality of breads from wholewheat flour showing promising results.

Highlights

- Positive effects on human health shown by the consumption of unrefined wheat products
- Review of the use of unrefined wheat flours in the breadmaking process
- Discussion of the standard criteria for the evaluation of unrefined bread quality
- Description of modifications to the bread formula and process for unrefined flours
- Proposal for new research to improve the employment of unrefined flours

Abstract:

Background: In recent years there has been an increasing interest in the production of wholegrain products owing to the positive effects shown on human health. Although refined flour still represents the standard reference in breadmaking technology, consumer demand for unrefined breads has grown greatly. The different chemical composition of unrefined wheat flours (UWFs), which includes specific fractions of milling by-products (i.e., wheat bran and wheat germ), favours the nutritional value, but it has a negative effect on technological performance. Therefore, it is useful to develop new strategies specifically designed to improve the quality of UWF breads.

Scope and approach: The present review aims to set out the techniques and technologies that have been reported in the literature for the breadmaking process with UWFs, that is, from raw material processing to bread formulation and breadmaking methods.

Key findings and conclusion: The evaluation of UWF quality is still based on the tests developed for refined flour, which cannot properly estimate UWF technological properties. The greatest efforts to improve the breadmaking performance of UWF have been focused on modifying the bread formula, mainly with the addition of improvers. Conversely, very little investigation has been carried out on adapting the breadmaking process to the different characteristics of the raw material. Overall, the use of UWF in breadmaking may require further investigations into processing strategies to improve the quality of the end product, hence increasing the consumption of healthy foods.

1 **Techniques and technologies for the breadmaking process with unrefined wheat flours**

2

3 **Authors:**

4 **Ottavia Parenti, Lorenzo Guerrini* , Bruno Zanoni**

5

6 Department of Agricultural, Food and Forestry Systems Management (DAGRI), University of
7 Florence, Piazzale Delle Cascine 16, 50144, Florence, Italy

8

9 *Corresponding author. E-mail address: lorenzo.guerrini@unifi.it (L. Guerrini)

10 Tel: +39 055 2755932

11

12 **Abstract:**

13

14 *Background:* In recent years there has been an increasing interest in the production of wholegrain
15 products owing to the positive effects shown on human health. Although refined flour still
16 represents the standard reference in breadmaking technology, consumer demand for unrefined
17 breads has grown greatly. The different chemical composition of unrefined wheat flours (UWFs),
18 which includes specific fractions of milling by-products (i.e., wheat bran and wheat germ), favours
19 the nutritional value, but it has a negative effect on technological performance. Therefore, it is
20 useful to develop new strategies specifically designed to improve the quality of UWF breads.

21 *Scope and approach:* The present review aims to set out the techniques and technologies that have
22 been reported in the literature for the breadmaking process with UWFs, that is, from raw material
23 processing to bread formulation and breadmaking methods.

24 *Key findings and conclusion:* The evaluation of UWF quality is still based on the tests developed for
25 refined flour, which cannot properly estimate UWF technological properties. The greatest efforts to
26 improve the breadmaking performance of UWF have been focused on modifying the bread formula,
27 mainly with the addition of improvers. Conversely, very little investigation has been carried out on
28 adapting the breadmaking process to the different characteristics of the raw material. Overall, the
29 use of UWF in breadmaking may require further investigations into processing strategies to improve
30 the quality of the end product, hence increasing the consumption of healthy foods.

31

32 **Keywords:** bread; wholewheat flour; milling by-products; wheat germ; wheat bran

33

34 **Abbreviations:** unrefined wheat flour (UWF), wheat germ (WG), wheat bran (WB)

35

36 **1. Introduction**

37 Wheat bread is the staple food in many diets, representing one of the main sources of the daily
38 energy intake. Bread composition is the result of several factors including wheat genotypes,
39 agronomic treatments, environmental conditions, flour composition, breadmaking conditions and
40 product storage.

41 The wheat species most widely used for breadmaking is *Triticum aestivum* L. or “common” wheat,
42 accounting for 95% of wheat production, followed by *Triticum durum* or “durum” wheat, which is
43 widely used in Mediterranean cuisine for making special breads, couscous, pasta and bulgur.

44 For most of human history, flour was produced using stone mills, which simultaneously crushed and
45 ground wheat kernels in a single millstream, giving wholewheat flour. The milling process was
46 completely revolutionized during the second half of the 19th century with the introduction of the
47 roller mill, which allowed the three fractions of the caryopsis (i.e., starchy endosperm, bran and
48 germ) to be separated at the beginning of the process, resulting in different millstreams (Jones,
49 Adams, Harriman, Miller, & Van der Kamp, 2015). The refined flour obtained from the starchy
50 endosperm alone shows better technological quality and gives breads with sensory properties that
51 are widely appreciated by consumers. Hence, refined flour has become the standard for the further
52 technological developments in the bakery industry up to the present day. This means that all the
53 knowledge on bread formulation and process implementation has been made by considering
54 refined wheat flour, characterized by a chemical composition mainly composed of starch (80%-85%)
55 and proteins (8%-14%). The other millstreams (i.e., bran, germ) are instead considered milling by-
56 products and mainly used as animal feed.

57 However, in recent years there has been renewed interest in unrefined wheats, since several studies
58 have shown that regular consumption of these products is associated with health benefits such as
59 a lower risk of chronic-degenerative diseases and improved body weight regulation (Ye, Chacko,
60 Chou, Kugizaki, & Liu, 2012; Hauner et al., 2012) The increased interest in healthy and functional
61 foods has led to a consequent growth in the demand for high nutritional value breads (Gani, &
62 Hameed, 2012). As a result, it has been necessary to re-interpret bread quality, also including
63 nutritional value.

64 Unrefined wheat flour (UWF) is a composite class which includes flours supplemented with milling
65 by-products at the same or a different relative proportion compared to that of the intact caryopsis
66 (Fig. 1). The official definition for flours containing the same components in the same relative
67 proportions as the wheat kernel is “wholewheat” flour (AACC International, 1999 Whole Grain
68 Initiative approved by ICC, Healthgrain and Cereal & Grain Association, 2019), although the modern
69 milling process does not allow for the inclusion of wheat germ (WG), but only recovers wheat bran
70 (WB). Hence, the resulting “wholewheat” flour is no more than flour enriched with bran.
71 Despite the nutritional benefits, the introduction of milling by-products in the breadmaking process
72 has some drawbacks, the solutions to which are still open challenges for bread makers.
73 First, the outer layers are the most susceptible to contaminants, i.e., mycotoxins and heavy metals
74 (Sovrani et al., 2012). Hence, the possibility of using milling by-products to produce high nutritional
75 value breads requires an integrative approach from the field to the breadmaking. Therefore,
76 appropriate agronomical and/or post-harvest strategies must be adopted to reduce the safety risk
77 and preserve the high nutritional value of the outer layers. Secondly, WG and WB negatively affect
78 the technological quality of doughs and breads (Boukid, Folloni, Ranieri, & Vittadini, 2018; Hemdane
79 et al., 2016). Finally, since the sensorial characteristics of unrefined bakery products are little
80 appreciated by consumers, several scientific studies have dealt with the sensory sensorial profile to
81 increase their acceptability (Gani et al., 2012; Heiniö et al., 2016).
82 The present review aims to report the processing strategies that have been developed until now for
83 the breadmaking process with UWFs (Fig.2), while suggesting some processing innovations to
84 improve the exploitation of UWFs.

85

86 Contents

87 1. Introduction

88 2. Bread quality

89 3. Breadmaking process

90 3.1 UWF quality and composition

91 3.1.1 Unprocessed UWFs

92 3.1.2 Processed UWFs

93 3.1.2.1 Pre-treatment of wheat kernels: germination

94 3.1.2.2 Pre-treatments of milling by-products

95 3.2 Bread formulation and improvers for UWF

96 3.2.1 *Optimization of water amount for UFW breads*

97 3.2.2 *Modification of the flour for UFW bread*

98 3.2.3 *Improvers for UFW breads*

99 3.3 *The breadmaking process with UWFs*

100 3.3.1 *Mixing*

101 3.3.2 *Leavening*

102 3.3.3 *Baking*

103 3.4 *UFW bread storage and packaging*

104 3.4.1 *Storage of UFW bread*

105 3.4.2 *Packaging of UFW breads*

106 **4. The carbon footprint of UFW bread**

107 **5. Conclusions**

108

109 **2. Bread quality**

110 According to the common good manufacturing practices, "bread" must be prepared by baking a
111 dough which consists of flour, yeast, and a moistening ingredient, usually water. In the present
112 review this term refers to all typologies of leavened breads, not including flat breads obtained
113 without any leavening. Bread is one of the most ancient and widespread foods of all over the world.
114 Progressive technical developments over many thousands of years have led to a high diversification
115 of the product. Hence, a "good bread" presents different features depending on cultural
116 background, individual experiences, and personal likes and dislikes. Moreover, quality features
117 change over space, in different regions, and over time, together with food technology innovations.
118 However, despite the large diversity of bread characteristics, in the literature bread quality is mainly
119 evaluated as: (i) bread specific volume, (ii) crumb characteristics and (iii) crust colour (Zhou et al.,
120 2014; Cauvain, 2015). These features are the results of the raw materials and processing conditions
121 adopted during bread production. Almost all of the quality characteristics are related to the gluten
122 network, since it traps the gas produced during the leavening and contributes to the formation of a
123 cellular crumb structure which confers the bread's volume, texture and eating qualities. The
124 addition of the "right" quantity of water is another key factor affecting dough rheology and the
125 development of gluten; too much or too little water means that the right gluten network cannot be
126 properly developed (Cauvain, 2015).

127 Although there are not any standard **sensory sensorial** attributes of wheat bread, they are all
128 considered of maximum importance in the evaluation of the product. **Sensory Sensorial** features
129 affect consumers' preferences and drive their choices towards the different bread typologies
130 proposed by the current bakery market.

131 The flour used in the bread formulation plays a critical role for the product characteristics. Refined
132 bread presents a high loaf volume, a light colour, homogeneous crumb porosity and soft crumb.
133 Refined flour results in a fairly bland **sensory sensorial** attribute with only a slight grain-like flavour
134 or malted note, since most of these sensory contributions come from the WG oils and from the WB
135 particles removed during milling (Callejo et al., 2015; Challacombe, Abdel-Aal, Seetharaman, &
136 Duizer, 2012; Eckardt et al., 2013; Hayakawa, Ukai, Nishida, Kazami, & Kohyama, 2010; Heenan,
137 Dufour, Hamid, Harvey, & Delahunty, 2008; Jensen, Oestdal, Skibsted, Larsen, & Thybo, 2011a;
138 Katina, Heiniö, Autio, & Poutanen, 2006a; Lotong, Edgar-Chambers, & Chambers, 2000). The sensory
139 attributes of refined breads are largely appreciated by consumers, who, despite the proven health
140 benefits of wholewheat consumption, still prefer refined products (Ye, Chacko, Chou, Kugizaki, &
141 Liu, 2012).

142 The distinctive characteristics of UWF breads include a low loaf volume, coarse and hard texture,
143 dark colour and "speckled" appearance. Moreover, they are characterized by a nutty odour,
144 bitter/sour taste, a grain-like, "seedy" flavour, malted note and musty attribute (Curti, Carini,
145 Bonacini, Tribuzio, & Vittadini, 2013; Callejo et al., 2015; Challacombe, Abdel-Aal, Seetharaman, &
146 Duizer, 2012; Eckardt et al., 2013; Heenan, Dufour, Hamid, Harvey, & Delahunty, 2008; Jensen,
147 Oestdal, Skibsted, Larsen, & Thybo, 2011a; Katina, Heiniö, Autio, & Poutanen, 2006a; Katina,
148 Salmenkallio-Marttila, Partanen, Forssell, & Autio, 2006b).

149 The sensory profile of UWF breads is one of the major obstacles to increasing their consumption.
150 The most challenging attribute is probably the bitter taste, associated with the presence of bioactive
151 compounds (such as phenolic compounds, amino acids, small peptides, fatty acids and sugar) which
152 are highly concentrated in the outer layers of the wheat kernel (Heiniö, 2009; Zhou et al., 2014; Van
153 Gemert, 2011; Mattila, Pihlava, & Hellström, 2005); rancid sensory defects could also occur relating
154 to oxidation of the WG oil (Heiniö et al., 2016).

155 The quality characteristics were created for refined breads, but in the literature they are also used
156 for UWF bread. However, well-informed consumers appreciate the better nutritional value of UWF
157 and they have different expectations about the product characteristics.

158 This can lead implicitly to some questions on bread quality. Does the different chemical composition
159 of UWF require new qualitative standards or are the quality criteria of refined flours still suitable for
160 UWF? Is it right to have the same expectations about the characteristics of the final product? It is
161 hard to answer these questions and they require an in-depth discussion from a wide perspective.
162 Besides bread quality criteria, some important methods have also been developed for refined flours.
163 This is the case of the optimum water absorption (WA) of the flour, officially determined as the
164 amount of water required to reach 500BU in the farinographic test. However, it has been reported
165 that 500BU underestimates the absorption capacity of UWF (Hemdane et al., 2016). Improper
166 hydration of the dough could lead to i) the wrong evaluation of UWF bread quality, especially when
167 compared to refined bread, and ii) biased results if a new process setting is desired and the tested
168 variables significantly interact with water. Nevertheless, indications regarding the correct amount
169 of water for UWFs are still missing in the literature.

170

171 **3. Breadmaking process**

172 The literature has shown controversial results regarding breadmaking with UWFs, making it difficult
173 to interpret or compare experimental data in the literature. Indeed, several operating factors have
174 been reported to have a significant effect on bread quality (Table 1):

175 (i) The composition of UWFs is extremely variable; beside the starchy endosperm they
176 include the presence of specific fractions of milling by-products, WG and WB. The
177 different chemical compositions of UWFs produce great variability in the breadmaking
178 performance.

179 (ii) The milling method. It is widely known that the milling method has a marked impact on
180 the technological performance of flour (Jones, Adams, Harriman, Miller, & Van der Kamp,
181 2015). Standard indications about the milling method, and particle size and composition
182 of milling by-products could be useful for a better comprehension of their impacts and
183 could help overcome their adverse effects in breadmaking. It is important to point out
184 that the milling method strongly affects the UWF composition.

185 (iii) Bread formulation. In the literature there is no official bread formula, but different
186 recipes are adopted. Besides the basic components (i.e., flour, water and the leavening
187 agent), other ingredients are often added to the bread dough, such as salt (NaCl), sugar,
188 shortening and oxidizing agents, which affect the flour performance. This variability of
189 recipes could hinder the comparison and understanding of the effects and results.

190 (iv) Breadmaking procedure. Owing to the absence of a standard process in breadmaking,
191 operating conditions cannot be standardized, making it difficult to compare and
192 understand the literature data.

193 The paragraphs below set out to improve the comparability between the different studies in the
194 literature by promoting both a standardization of methods and some technological innovations for
195 UWF processing.

196

197 *3.1 UWF quality and composition*

198 In recent years several studies have reported the nutritional value, technological impact and sensory
199 profile of the milling by-products WG and WB in the breadmaking process (Hemdane et al., 2016;
200 Boukid, Folloni, Ranieri, & Vittadini, 2018; Heiniö et al., 2016).

201 WG (2%-3% of the caryopsis) is composed of the embryo and scutellum, the latter being discarded
202 with the bran during the milling process (Boukid, Folloni, Ranieri, & Vittadini, 2018). It is considered
203 the most nutritious part of the wheat kernel, providing 381 cal/100 g: 54% carbohydrates, 23%
204 proteins and 23% lipids (Boukid, Folloni, Ranieri, & Vittadini, 2018; Nutrition data, 2014).

205 The limited utilization of WG in the bakery industry is primarily due to the high presence of
206 unsaturated fats and hydrolytic and oxidative enzymes (i.e., lipoxygenase and lipase) which favour
207 WG degradation (Boukid, Folloni, Ranieri, & Vittadini, 2018). Several treatments have been
208 developed to improve WG stability while preserving the high nutritional value (Boukid, Folloni,
209 Ranieri, & Vittadini, 2018). The first crucial step is to perform an efficient separation of the WG from
210 the other flour components. Two different approaches have been developed: (i) direct
211 degermination, which is performed before the milling process and (ii) indirect degermination, which
212 is realized through gradual separation phases during the milling process (Boukid, Folloni, Ranieri, &
213 Vittadini, 2018). A high recovery of the WG fraction enables the subsequent adoption of stabilization
214 strategies through the deactivation of the oxidative enzymes or/and removal of the oil fraction.
215 These strategies are based on physical, chemical or biological methods, as extensively revised by
216 Boukid, Folloni, Ranieri, & Vittadini (2018).

217 WB (17% of the caryopsis), together with the aleurone layer and remnants of the starchy endosperm
218 and WG, produces a range of milling by-products which are recovered at different stages in the mill
219 (Hemdane et al., 2016). The bran fractions can be classified as different by-products (i.e., coarse
220 bran, coarse weatings, fine weatings and low-grade flour), which are roughly distinguishable based
221 on two main characteristics: particle size and endosperm content (Hemdane et al., 2016).

222 The bran streams recovered further down the milling process consist of finer bran particles and
223 contain relatively more endosperm (Hemdane et al., 2016). Coarse bran mainly consists of non-
224 starch carbohydrates, with 17%-33% arabinoxylan (AX), 9%-14% cellulose, 3%-4% fructan and 1%-
225 3% mixed-linkage β -D-glucan as major components (Hemdane et al., 2016). In order to study the
226 mechanisms through which bran affects breadmaking, multiple approaches which change bran
227 functionality (physical properties, chemical composition, and/or enzymatic load) have been
228 developed. These strategies (i.e., (i) particle size reduction, (ii) (hydro-)thermal treatments, (iii) pre-
229 soaking, (iv) enzymatic treatment, (v) fermentation, and (vi) chemical treatment, reviewed by
230 Hemdane et al., 2016), treat the bran before its re-addition to the flour, and investigate both bran
231 properties and breadmaking performance.

232 In the literature, great efforts have been made to try to understand the functionality of milling by-
233 products or to develop new strategies to stabilize them. Conversely, far fewer efforts have been
234 made to try to improve the breadmaking with stabilized milling by-products. The combination of
235 stabilizing treatments with roller milling, followed by flour re-combination/re-constitution and/or
236 enrichment, could provide UWFs with a better nutritional and technological quality. Moreover,
237 although it seems that the roller milling method could ensure better preservation of the wheat's
238 nutritional value (Jones, Adams, Harriman, Miller, & Van der Kamp, 2015), the consumer is still
239 highly attracted by the "stone mill" label on flours or baked products, considering this method
240 better than roller milling (Jones, Adams, Harriman, Miller, & Van der Kamp, 2015). This points out
241 that it is pressing to improve the dissemination of scientific knowledge to the final target.

242 The presence of WB and WG significantly changes the chemical composition of flour. Regardless of
243 the amount of milling by-products added, UWFs show a low endosperm fraction and include specific
244 flour constituents, such as fibre, oil, enzymes, reactive components and anti-nutrients. The amount
245 of the above constituents can change markedly, depending on various factors: (i) level of addition,
246 (ii) milling by-product treatment (if any), (iii) milling process, (iv) bran stream fraction (v) wheat
247 species and cultivar, and (vi) environmental conditions.

248 Considering WG, the main constraints associated with its utilization in the baking industry are
249 represented by its poor chemical stability, the presence of reducing compounds (glutathione) that
250 degrade breadmaking ability, and the presence of non-polar lipids which tend to destabilize gas cells
251 (Tebben et al., 2018; Boukid, Folloni, Ranieri, & Vittadini, 2018).

252 On the other hand, flour supplementation at different levels and/or with different bran fractions
253 has shown deleterious impacts on the technological properties of doughs and breads (Hemdane et

254 al., 2016). Overall, flours containing bran produce a poor loaf volume, dark colour, dense and firm
255 texture, and bitter taste (Hemdane et al., 2016). The following reasons account for these negative
256 effects: fibre-gluten interactions, dilution of gluten proteins by non-endosperm proteins, fibre
257 competition for water resulting in insufficient hydration of gluten and starch, physical effects of
258 bran particles and bran constituents on the gluten network and high level of ferulic acid (Tebben et
259 al., 2018).

260

261 3.1.1 Unprocessed UWFs

262 The incorporation of raw milling by-products in flour without introducing some modification of the
263 product formula and/or processing method gives “unprocessed UWF”. It generally shows a poor
264 breadmaking performance. However, some studies have introduced raw milling by-products into
265 the flour while maintaining an acceptable bread quality (Table 2).

266 Banu, Stoenescu, Ionescu, & Aprodu (2012) investigated the addition of bran streams (3%, 5%, 10%,
267 15%, 20%, 25%, 30% expressed on total flour weight) to refined flour on dough rheology and bread
268 quality. Despite the negative effect of ash on the technological rheological properties of flour and
269 on bread quality, the incorporation of 25% bran streams showed the same ash content as UWF, but
270 with an improvement in bread quality dough rheology and bread physical parameters were
271 significantly improved. Therefore, this level can be used to obtain high nutritional quality bread
272 without improvers in the formulation of incorporation can be used to increase the nutritional value
273 of the breads with less damage on the bread quality compared to wholewheat flour.

274 Blandino et al. (2013) tested refined flour enriched with selected fractions of the kernel obtained
275 by sequential pearling of wheat kernels and added at 5 different levels (5%, 10%, 15%, 20%, 25%
276 expressed on total flour weight) on dough rheology, bread quality and nutritional properties. The
277 presence of a 10% pearled fraction enhanced the nutritional value of the bread, revealing only a
278 slightly increase in deoxynivalenol contamination and showing a technological quality comparable
279 to the control.

280 Bagdi et al. (2015) evaluated the breadmaking potential of an aleurone-rich flour (ARF) (40g/100g,
281 75g/100g) in comparison with refined bread. The ARF was suitable for breadmaking without any
282 flour additives. Bread made with aleurone-rich flour showed better nutritional properties than
283 refined bread, but a low technological quality. The optimal blending ratio for the sensory quality
284 resulted 40g/100g since it showed a similar acceptability to the control sample.

285 Sun, Zhang, Hu, Xing, & Zhuo (2015) tested different levels (0%, 3%, 6%, 9%, 12% expressed on total
286 flour weight) of WG flour to improve the quality of Chinese steamed bread (CSB). WG negatively
287 affected both the dough and bread properties, and the steaming performance, in proportion to the
288 level of addition. The incorporation of up to 6% WG showed fewer negative effects and gave CSB
289 with acceptable sensory characteristics, suggesting that this blend could be used for the production
290 of functional breads.

291 Pasqualone et al. (2017) compared the effect on breadmaking ability of two substitution levels
292 (100g/1kg, 200g/1kg) of three different durum wheat milling by-products: i) residuals of the second
293 and third debranning steps (DB), ii) the micronized and air-classified thin fraction from the same
294 residuals (MB), or iii) coarse bran from roller milling of non-debranned durum wheat (B). MB and
295 DB did not alter the textural properties compared to B. Furthermore, the addition of MB (100g/1kg)
296 improved the nutritional value of the bread without reducing its quality. Hence, debranning
297 followed by micronization could represent an interesting strategy for UWF breads from durum
298 wheat.

299

300 3.1.2 Processed UWFs

301 In the literature several treatments have been developed for wheat kernels and milling by-products,
302 namely “processed UWF”. The processing treatments that showed technological improvements for
303 the use of processed UWFs in breadmaking are reported below (Table 3).

304

305 3.1.2.1 Pre-treatment of wheat kernels: germination

306 In recent years, several studies have investigated the impact of the germination process on the
307 technological and nutritional quality of cereals, pseudo-cereals and pulses (Lemmens et al. 2019;
308 Bellaio, Kappeler & Bühler, (2013); Richter, Christiansen, & Guo, 2014; Benincasa, Falcinelli, Lutts,
309 Stagnari, & Galieni, 2019). In fact, by inducing the activation of hydrolytic enzymes for plant growth
310 and development, germination leads to a considerable improvement in the product nutritional
311 value, which makes this process attractive for healthy and functional foods. Applications of the
312 germination process in breadmaking are reported in the literature, but most of these studies used
313 refined wheat flours in the bread formula (Lemmens et al., 2019). The main issue of this approach
314 is optimizing the processing conditions: longer germination times (>72 h) are required to improve
315 the nutritional value of the flour, but they negatively impacted the flour technological performance;
316 on the other hand, only shorter times (20-36 h) or low substitution levels (10%-20%) improved the

317 technological properties of doughs and breads, although they showed lower effects on their
318 nutritional value (Lemmens et al., 2019). These results reflect the different degrees of enzyme
319 activities in wheat kernels as a function of the germination time. Activation of the proper alfa-
320 amylase activity can promote yeast fermentation, carbon dioxide production and gas cell expansion,
321 thus determining a higher oven spring and improving bread volume (Lemmens et al., 2019).
322 Moreover, optimized alfa-amylase activity can also improve the product's shelf life and sensory
323 quality (Lemmens et al., 2019).

324 Marti, Cardone, Nicolodi, Quaglia, & Ambrogina Pagani (2017) proposed the addition of a low
325 amount of germinated wheat flour (1.5%) for a long amount of time (72-90 h) as a natural improver
326 in breadmaking with refined flour. Germinated flour produced similar effects to common improvers
327 (i.e., 0.5% malt or 0.5% enzymatic improver). It could be interesting to test the effect of this natural
328 improver on the technological performance of UWF.

329 Richter, Christiansen, & Guo (2014) developed a 100% germinated white spring wholewheat flour
330 for bread applications. The authors compared 100% white wholewheat flour (control) with 100%
331 germinated white wholewheat flour, including different additions of vital gluten (0%-5%) in the
332 bread formula (Richter, Christiansen, & Guo, 2014). Germinated wholewheat flour significantly
333 increased loaf volume (5%-9%), independently of the presence of gluten (Richter, Christiansen, &
334 Guo, 2014). Moreover, germinated flour significantly improved the sensory quality of the bread,
335 reducing the bitter taste.

336 Zilic et al. (2016) investigated the effect of germination on wholewheat flour proteins. Intensive
337 protein hydrolysis was revealed by an increase in free SH groups and a decrease in albumin +
338 globulin polypeptides with a molecular weight of over 85.94 kDa and between 85.94 and 48.00 kDa.
339 Although this modification affected the dough's viscoelastic properties, germinated wheat flour is
340 proposed as a potential food ingredient owing to the high antioxidant capacity and reduced
341 antigenicity of the glutenin fraction (Zilic et al., 2016).

342 Ding et al. (2018) tested germination time on the functionality of wholewheat doughs. Controlled
343 germination for 5-15 h ($T=28\pm 2^{\circ}\text{C}$ and $\text{RH}=95\pm 3\%$) produced wholewheat flour with improved
344 functionality: enhanced glucose content, reduced starch retrogradation during gelatinizing
345 gelatinization, improved gluten quality, and increased dough stability during mixing (Ding et al.,
346 2018).

347 Johnston et al. (2019) applied controlled germination in the production of wholewheat. Controlled
348 germination ($t=24$ h, $T=21^{\circ}\text{C}$, $\text{FN}=200$ s, excess of water) to increase the activity of α -amylase by

349 decreasing the Falling Number (FN) from 350 s to 200 s reduced dough mixing time and increased
350 bread specific volume (Johnston et al., 2019). Sensory analysis revealed a higher acceptability for
351 germinated wholewheat breads, thanks to their lower degree of bitterness, greater sweetness and
352 moisture (Johnston et al., 2019). Hence, germinating wholewheat flour to an FN value of 200 s
353 proved to be a good strategy to improve flour functionality and consumer preference for
354 wholewheat breads (Johnston et al., 2019).

355 A very recent work by Cardone, Marti, Incecco, & Pagani (2020) showed promising results on the
356 application of a controlled germination to enhance the quality of wholewheat breads. In fact, under
357 the conditions applied in this study (48h, 20°C, 90% relative humidity), although the decrease in
358 dough rheological features, a significant improvement in gluten stretching ability and bread physical
359 properties was obtained.

360 Further studies on the application of germination to improve the UWF breadmaking performance
361 could be an interesting field of research. The substitution of refined flour with UWF may not require
362 additional enhancement of the nutritional quality, since the raw material is naturally characterized
363 by a high nutritional value.

364

365 3.1.2.2 Pre-treatment of milling by-products

366 Over time several pre-treatments have been developed for milling by-products to stabilize their
367 chemical composition and better understand their effects on the breadmaking performance
368 (Hemdane et al., 2016; Boukid, Folloni, Ranieri, & Vittadini, 2018). The present review reports the
369 results of the most promising treatments on technological quality (Table 4).

370 Hemdane et al. (2016) extensively reviewed wheat bran pre-treatments. Chemical treatments did
371 not improve bread quality; very little work has been performed on enzymatic treatments (Santala,
372 Lehtinen, Nordlund, Suortti, & Poutanen, 2011; Messia et al. 2016), while the effects of bran particle
373 size reduction and (hydro)thermal treatments on breadmaking still remain unclear. Pre-soaking
374 appears to be a promising strategy for the incorporation of bran in breadmaking since it generally
375 improved the bread quality (Messia et al. 2016); however, a complete understanding of this
376 approach has yet to be established. In a recent work following the method proposed by Wang et al.
377 (2015a, b), Zhang et al. (2019) developed an arabinoxylan-enriched flour (AXF) (ash content
378 between 39.2%–55.8%) as a fibre supplement (2%, 5%, 10%) for refined bread. AXF pre-soaking
379 positively affected flour functionality, resulting in bread with comparable properties to the control

380 (Zhang et al., 2019). Fermentation treatment has been reported to enhance breadmaking ability: it
381 was effective in improving bread volume and crumb softness.

382 The impact of WG supplementation on breadmaking is reviewed by Boukid, Folloni, Ranieri, &
383 Vittadini (2018). The rheological properties of doughs were affected by the different WG
384 treatments. Fermentation by lactic acid bacteria appeared to be the most promising treatment,
385 showing a significant improvement in the dough properties. In all cases, the addition of more than
386 20% WG severely damages dough quality. Considering bread quality, the addition of up to 5%
387 extruded WG increased bread volume and decreased bread firmness. Sourdough fermentation of
388 WG positively affected bread quality, by decreasing crumb firmness, resilience and fracturability,
389 and enhancing bread shelf life without reducing product acceptability (Boukid, Folloni, Ranieri, &
390 Vittadini, 2018).

391 These results revealed that the use of sourdough fermentation on milling by-products enhanced the
392 performance of UWF in breadmaking. Indeed, Gobbetti, Rizzello, Di Cagno, & De Angelis (2014)
393 extensively reported the positive effects of using this approach for wholegrain products. Pre-
394 fermentation allowed modification of the techno-functionality of the milling by-products, showing
395 improved technological quality in terms of dough retention capacity, loaf volume and crumb
396 softness during storage. In addition, it decreased the anti-nutritive factors and enhanced the
397 sensory properties.

398 Recently, Pontonio et al. (2020) proposed an integrated biotechnological approach, combining LAB
399 fermentation with xylanase treatment on milling by-products (Pontonio et al., 2020). Biochemical
400 and nutritional analysis revealed that fortified breads had higher protein digestibility and a lower
401 glycemic index combined with a better sensory quality (Pontonio et al., 2020). Therefore, a
402 significant improvement could be achieved in UWF breads by applying an integrated approach,
403 suggesting new strategies for the exploitation of UWF.

404

405 The reviewed studies identified effective technological strategies for producing UWF with a high
406 technological quality. The possibility of supplementing bread with even low amounts of milling by-
407 products, without decreasing the bread quality, should be regarded as a technological success.

408

409 *3.2 Bread formulation and improvers for UWF*

410 In the literature the most common solution to improve the breadmaking performance of UWF and,
411 consequently, the quality of UWF breads is to modify the bread formula; the literature results are
412 outlined in Table 5.

413

414 3.2.1 Optimization of water amount for UFW breads

415 Some improvements in breadmaking with UWF can be obtained by optimizing the amount of water
416 in the bread recipe (Table 5). Cappelli et al. (2018) examined the effect of water (70%, 76%, 82%,
417 88%, 94% **expressed as a percentage of the dry weight of the flour**) and degree of flour refinement
418 (refined, brown and wholewheat flour) on the dough rheology. Significant differences in rheological
419 properties were found for refined flour compared to UWF, showing that alveographic analysis
420 cannot be extended to unrefined doughs. Addition of the optimal amount of water, modelled in
421 function of the degree of flour refinement, could be a strategy to optimize the rheological
422 parameters relating to product quality: flour strength “W” and the ratio between tenacity “P” and
423 extensibility “L”, P/L (Cappelli et al., 2018). This approach could improve UWF dough quality,
424 without introducing additional ingredients to the recipe.

425 Similar results were reported in a survey conducted by Guerrini, Parenti, Angeloni, & Zanoni (2019)
426 on the breadmaking process with UWF. The creation of highly hydrated doughs improves the flour
427 workability and bread quality (Guerrini, Parenti, Angeloni, & Zanoni, 2019). Indeed, in the literature
428 it is known that the inclusion of bran significantly affects the water adsorption capacity of the flour
429 and causes a competition for the water uptake with the other flour constituents (Hemdane et al.,
430 2016). High water quantities could allow proper hydration of the gluten matrix even in the presence
431 of bran, resulting in a better P/L balance as well as a higher W.

432 All these results may derive from the wide utilization of the Farinographic test as the official
433 predictor of the water absorption of the flour: this evaluation works well for refined flour, but it is
434 not suitable for UWF (Bruckner et al., 2001; **Schmiele, Jaekel, Patricio, Steel, & Chang, 2012**;
435 Hemdane et al., 2016).

436

437 3.2.2 Modification of the flour for UWF bread

438 In the literature, few process strategies have tested a more “natural approach” to the use of
439 improvers: the addition of UWF flour in a modified form, as reported in Table 5. Parenti et al. (2019)
440 reported an improvement in breadmaking performance with the use of pre-gelatinized brown flour
441 (6%). Pre-gelatinized UWF was obtained by heating some of the bread dough flour to 85°C in water;

442 the product was cooled to room temperature and tested on the dough and bread properties. The
443 addition of the flour in a different physical form increased the water absorption capacity, improved
444 the alveographic parameters, and increased the bread volume, crumb softness and shelf life (Parenti
445 et al., 2019).

446 Hung, Maeda, & Morita (2007) tested the addition of whole waxy flour in order to improve the
447 quality of high-fibre bread. Different levels of whole waxy flour were used to substitute refined flour
448 (10%, 30%, 50% expressed on total flour weight); the resultant flour mixtures were tested on the
449 breadmaking performance of wholewheat flour compared to refined flour. This strategy improved
450 crumb softness during bread storage (Hung, Maeda, & Morita, 2007). It could be interesting to
451 investigate the use of whole waxy flour compared to 100% wholewheat flour for breadmaking, in
452 order to evaluate the impact of this ingredient on the quality of wholewheat bread.

453

454 3.2.3 Improvers for UWF bread

455 The use of improvers in breadmaking with UWF is summarized in Table 5. Tebben et al. (2018)
456 reviewed the effects of common bread improvers, namely enzymes, emulsifiers, hydrocolloids,
457 oxidants and other functional ingredients on the performance of wholewheat flour. A positive role
458 is outlined for some enzymes: (i) by hydrolysing arabinoxylans (AX), xylanase was reported to
459 decrease the water absorption of the flour, increase the concentration of fermentable sugars in the
460 dough, the rate of fermentation and the dough proof height; moreover, xylanase improved the gas
461 retention capacity, loaf volume, crumb softness and crumb staling; (ii) alfa-amylase appeared
462 beneficial under certain conditions; (iii) G4-amylase showed promising effects on loaf volume,
463 crumb hardness and staling (Tebben et al., 2018).

464 Considering hydrocolloids, a general improvement in dough rheology is reported in the literature
465 (Tebben et al., 2018; Farbo et al., 2020). The effects of hydrocolloids change in function of their
466 typology and level of addition. With regard to bread dough, the use of carboxymethylcellulose
467 (CMC) decreased the final proof time and resistance to extension. Guar gum (GG) combined with an
468 emulsifier (diacetyl tartaric esters of monoglycerides, DATEM) was reported to increase the
469 fermentation stability and slightly increased bread volume. However, both CMC and GG reduced
470 the elasticity of wholewheat dough. Hydroxypropyl methylcellulose (HPMC) increased dough
471 elasticity, proof height, and decreased resistance to extension (Tebben et al., 2018).

472 Farbo et al. (2020) studied the effect of methylcellulose (MC), GG, psyllium gum (PG), xanthan gum
473 (XG) and tara gum (TG) on the quality of dough made with old durum wheat. They found that 1% of
474 PG or XG improved dough extensibility, while all hydrocolloids increased gas retention.
475 Considering bread quality, GG was able to increase the specific volume of wholewheat bread.
476 Furthermore, a non-significant effect of HPMC, XG and dextran was reported on bread volume.
477 Conversely, HPMC proved effective in increasing the specific volume of both refined and
478 wholewheat bread, while CMC did not improve the loaf volume of either variety of bread (Tebben
479 et al., 2018).

480 Oxidants are commonly added in breadmaking to increase dough strength by forming disulphide
481 bonds through the oxidation of free sulfhydryl groups on the gluten proteins (Zhou et al., 2014). The
482 presence of reducing compounds in wholewheat flour counteracts the effect of oxidants, which
483 must be added at higher levels (Tebben et al., 2018). Hence, higher amounts of oxidants will also
484 presumably be required for other UWF typologies. Potassium bromate and ascorbic acid improved
485 the dough rheology, dough strength and gas retention ability. The addition of rosehip as a source of
486 ascorbic acid increased the resistance to extension and reduced the extensibility of the wholewheat
487 dough. The best effect on bread volume was reported for ascorbic acid, added at 200 ppm;
488 accordingly, rosehip resulted effective in enhancing bread volume. This latter improver also
489 improved the sensory score of the crumb, increasing the acceptability of the wholewheat bread.
490 Conversely, potassium bromate showed little effect on loaf volume (Tebben et al., 2018).

491 Emulsifiers in breadmaking cause dough strengthening and/or crumb softening (Tebben et al.,
492 2018). The addition of DATEM was reported by some studies to increase the fermentation stability,
493 whereas the opposite effect was observed by others (Tebben et al., 2018). However, these studies
494 are consistent in showing that DATEM improved dough elasticity, a valuable property for the
495 breadmaking performance. Another emulsifier, sodium stearyl lactylate (SSL), improved the
496 handling properties of the wholewheat dough (Tebben et al., 2018).

497 The specific volume of wholewheat bread was generally improved by the addition of emulsifiers
498 (Tebben et al., 2018). DATEM was reported to produce positive effects. Furthermore, the combined
499 addition of DATEM and oxidants improved the gas-holding ability of the dough during the proofing
500 and baking phases. DATEM and SSL had the greatest effect on volume increase, but ethoxylated
501 monoglycerides, succinylated monoglycerides and lecithin significantly increased loaf volume too.
502 On the other hand, polysorbate and monoglycerides did not affect the parameter. Similar results
503 were reported for the inclusion of DATEM, SSL, soy lecithin, polyoxyethylene sorbitan monostearate

504 (polysorbate-60), poly-oxyethylene sorbitan monopalmitate (polysorbate-40) and glycerol-
505 monostearate: all these emulsifiers increased the volume of the wholewheat bread. Conversely, the
506 addition of monoglycerides, DATEM and SSL was not effective in improving wholewheat or refined
507 bread specific volume (Tebben et al., 2018).

508 DATEM and mono- and diglycerides were reported to improve the crumb structure of wholewheat
509 bread; a similar effect was observed with SSL as well as an increase in the eatability score (Tebben
510 et al., 2018).

511 The supplementation of vital gluten is effective in overcoming the multiple problems related to
512 wholewheat bread (Tebben et al., 2018).

513 Parenti, Guerrini, Cavallini, Baldi, & Zanoni, (2020) tested the addition of 7 improvers (i.e., sucrose,
514 sodium chloride, extra virgin olive oil, gelatinized flour, GG, ascorbic acid and ice) to optimize the
515 quality of wholewheat bread. The optimized sample resulted from the combination of sucrose (2%)
516 and extra virgin olive oil (3%), disclosing the interesting role that these improvers can play in the
517 quality of wholewheat bread (Parenti, Guerrini, Cavallini, Baldi, & Zanoni, 2020). Furthermore, the
518 authors proposed a two-step optimization approach for improving the use of UWF in breadmaking:
519 (i) the Screening Design method revealed the most relevant factors affecting bread quality; (ii) the
520 Full Factorial Design gave an in-depth evaluation of the selected variables and allowed identification
521 of the optimized sample (Parenti, Guerrini, Cavallini, Baldi, & Zanoni, 2020).

522 All these results concerned the use of improvers on wholewheat flour. However, due to the very
523 different composition of the raw materials which probably changes the effects of the improvers,
524 they should be further tested before extending these findings to all UWF breads.

525

526 *3.3 The breadmaking process with UWFs*

527 Only a few studies have investigated the possibility of modifying the breadmaking operating
528 conditions. The breadmaking process has been designed to maximize the quality of refined bread.
529 Therefore, the substitution of refined flour with UWF may require an adaptation of the process to
530 the different characteristics of the raw material. Processing conditions, such as the type of mixer,
531 mixing time and speed, resting period etc., may require modifications from the standard procedure.
532 This latter area of research appears poorly investigated in the literature, since the greatest efforts
533 have been made in modifying the bread formulation, while the breadmaking variables were kept
534 almost unchanged. Studies about modifications of the breadmaking process with UWFs are
535 reported in Table 6.

536

537 3.3.1 *Mixing*

538 The mixing is one of the most important phases in the breadmaking process since most of the
539 characteristics of the final product are determined during this phase (Zhou et al., 2014). Considering
540 the different composition of UWF, modification of the mixing variables (type of mixers, mixing
541 speed, mixing time...) could represent a good strategy to be explored, despite being poorly
542 investigated in the current literature.

543 Angioloni & Rosa (2006) tested the effect of mixing time (10-15-20 s) combined with an improver
544 (cysteine, 20 mg/kg) on the rheological properties of refined and wholewheat dough obtained at
545 high-speed revolutions (1600 rpm). Dough viscoelastic behaviour was affected by both cysteine and
546 kneading conditions. Cysteine significantly reduced the mixing time (optimum = 15 s) by decreasing
547 the elastic component of the dough and aiding dough relaxation in both refined and wholewheat
548 flour. Therefore, the use of high-speed mixing combined with cysteine could be useful to improve
549 UWF doughs.

550 Parenti et al. (2013) tested different mixing times on the breadmaking of brown flour. Two trials
551 evaluated different mixing times ((i) 12, 17, 22 min; (ii) 17, 22, 27 min). Mixing time significantly
552 affected loaf increase during proofing: the samples mixed for 17 min showed the highest value in
553 both trials. Furthermore, doughs obtained at the optimum mixing time (17 min) were characterized
554 by a better water retention capacity during storage.

555 The control of the mixing time also proved to be extremely important in the survey by Guerrini,
556 Parenti, Angeloni, & Zanoni (2019); short times, between 10 and 20 min, represented one of the
557 most effective strategies for the breadmaking process with UWF.

558 A recent work by Cappelli, Guerrini, Cini, & Parenti (2019) investigated the delayed addition of bran
559 and middlings during the mixing step. Three bran and middlings **incorporation substitution** levels
560 (10%, 20%, 30% **expressed on refined flour weight**) and five times of addition (0, 2, 3.5, 5, 6.5 min)
561 were tested on the dough rheology and bread quality. The addition of bran and middlings at 2 min
562 into the mixing step improved the dough rheology and increased the bread specific volume.
563 Furthermore, the combination of 10% bran and middlings with time of 2 min produced bread of a
564 better quality than the control bread (i.e., without delayed addition).

565 A specific laboratory test, developed to predict the optimized mixing time, could boost the research
566 on the mixing step, but, to the best of the author's knowledge, no such test currently exists.

567

568 3.3.2 Leavening

569 During leavening, the bread loaf develops its final structure and several modifications of its
570 constituents occur as a function of the different leavening agents used in the recipes. Sourdough
571 fermentation represents one of the oldest biotechnologies in cereal food production; however,
572 when industrial-scale baking was developed in the 19th century, baker's yeast – *Saccharomyces*
573 *cerevisiae* – became the most common leavening agent (Zhou et al., 2014). In recent years, the
574 increasing interest in healthy and functional foods has led to a rediscovery of sourdough bakery
575 products, which are characterized by positive health benefits and unique flavours (Zhou et al., 2014).
576 Chavan & Chavan (2011) made an exhaustive review of this ancient biotechnology. In the present
577 review, only the issues related to the technological performance of UWF are discussed. In the
578 literature it is largely reported that the substrate, mainly flour, used for sourdough production
579 deeply influences its properties (Chavan & Chavan, 2011; Decock, & Cappelle, 2005). The presence
580 of bran, increasing the ash content of wheat flour, promotes the growth of lactic acid bacteria (LAB)
581 and increases the acidification of the sourdough system. LAB are responsible for the production of
582 several organic acids, which are reported to improve the swelling of gluten and increase gas
583 retention, while functioning as natural dough conditioners and reducing bread staling. Furthermore,
584 the acid enhances the solubility of the glutenin fraction, improving the swelling power of the gluten
585 (Chavan & Chavan, 2011). Hence, the use of UWF for sourdough production seems to improve the
586 breadmaking performance, thanks to a better development of the gluten matrix. Studies on UWF
587 performance are reported in Table 6.

588 In the survey by Guerrini, Parenti, Angeloni, & Zanoni (2019), all of the bakers use sourdough as the
589 leavening agent for breadmaking with UWF: they perceive that this method improves the quality of
590 the final product.

591 Komlenić et al. (2010) showed the positive effects of biological acidification on the quality of bread
592 obtained with refined and wholewheat flour. They investigated the effect on dough and bread
593 properties of three different acidifications: chemical (lactic acid) and biological (dry sourdough and
594 *Lactobacillus brevis* pre-ferment) acidification. The bread specific volume was only significantly
595 increased by the biological acidifiers, whereas the acidifier typologies improved the crumb hardness
596 (Komlenić et al., 2010). Therefore, dry sourdough, characterized by a longer shelf life and better
597 stability, could be an interesting strategy for breadmaking with UWF.

598 Taccari et al. (2016) reported the possibility of applying the back-slopping technique to produce
599 type I sourdough from wholewheat flour. Wholewheat sourdough improved the quality of high fibre

600 breads, overcoming the detrimental effect of bran on bread volume. Moreover, sourdough
601 fermentation improved bread texture, flavour, nutritional value and shelf life. The study outlines
602 the suitability of wholewheat flour for sourdough production, encouraging further research for its
603 application in UWF breadmaking.

604 Choi, Kim, Hwang, Kim, & Yoon (2005) evaluated the application of *Leuconostoc citreum* HO12 and
605 *Weissella koreensis* HO20 isolated from kimchi as starter cultures for sourdough wholewheat bread.
606 The sourdoughs fermented with the selected LAB had an optimal Fermentation Quotient (FQ), a
607 criterion for good bread quality. Although no significant improvement was observed on bread
608 specific volume, the LAB reduced crumb hardness on both fresh and stored breads (Choi, Kim,
609 Hwang, Kim, & Yoon, 2005). Hence, the study presented the potential application of LAB isolated
610 from kimchi for the improvement of UWF bread quality.

611 Didar et al. (2011) observed positive effects on bread quality (95% extraction rate) and sensory
612 properties upon performing sourdough fermentation with *Lactobacillus plantarum* (PTCC 1058) and
613 *Lactobacillus reuteri* (PTCC 1655). Different dough yields (DY, 250 and 300) and different levels of
614 sourdough addition (10%, 20%, 30%) were also tested. *Lb. plantarum* sourdough with a DY of 250
615 and 30% addition produced the greatest effect on the overall quality score of the breads (Didar et
616 al., 2011).

617 Katina, Heiniö, Autio, & Poutanen (2006a) studied the influence of sourdough conditions on bread
618 flavour and texture. Ash content (0.6-1.8 g/100 g), fermentation temperature (16-32°C), and
619 fermentation time (6-20 h) were considered independent factors and different starter cultures (i.e.,
620 *Lactobacillus plantarum*, *Lactobacillus brevis*, *Saccharomyces cerevisiae* or a combination of yeast
621 and LAB) were tested. Ash content and lactic acid fermentation were the main factors affecting the
622 intensity of the sensory attributes. The greater the ash content, the higher the intensity of both
623 desired and undesired flavour attributes. An optimization of the process conditions, according to
624 the ash content and the specific LAB strain, improved the sensory quality of UWF breads. However,
625 the improvement of bread volume and texture required different optimized conditions than those
626 required for bread flavour. Hence, an efficient use of sourdough fermentation has to consider its
627 end use in wheat baking (Katina, Heiniö, Autio, & Poutanen, 2006a).

628 The results from the use of sourdough as a leavening agent showed positive effects on UWF bread
629 quality. The drawback of this procedure is primarily represented by the great variability of the
630 sourdough composition, which makes the process difficult to standardize. Further research is

631 needed to find new solutions to combine the use of this leavening agent with a standardization of
632 bread features.

633

634 3.3.3 Baking

635 Baking is the final step in the breadmaking process. The phenomena occurring during this phase
636 include gas evaporation, starch gelatinization, modification of the bread loaf from a sponge-like to
637 a porous structure, and water evaporation. The most significant factors of the baking step are
638 represented by temperature, time and moisture (Zanoni, Peri, & Pierucci, 1993; Zanoni, Pierucci, &
639 Peri, 1994; Zhou et al., 2014).

640 In the literature there appears to be a lack of information on the baking step specifically developed
641 for UWF breads. Guerrini, Parenti, Angeloni, & Zanoni (2019) reported that bakers create high
642 temperatures at the beginning, followed by a temperature decrease, to improve the quality of UWF
643 breads. Moreover, the majority of bakers check the moisture during this step, since it represents
644 another critical factor affecting bread quality. In fact, especially in the first phase of baking, the
645 addition of moisture improves loaf expansion. Therefore, modification of the baking conditions,
646 such as temperature and moisture, in function of the characteristics of the raw material could
647 represent another interesting field of exploration.

648

649 3.4 UWF bread storage

650 The most important phenomena limiting the shelf life of breads are bread staling and microbial
651 growth (Fernandez, Vodovotz, Courtney, & Pascall, 2006). Bread staling is a complex phenomenon,
652 whose mechanism has not been well established yet; however, the most important factors seem to
653 be starch retrogradation, starch-gluten interaction and moisture redistribution (Fadda, Sanguinetti,
654 Del Caro, Collar, & Piga 2014; Curti, Carini, Tribuzio, & Vittadini, 2015). Bread microbial spoilage is
655 generally caused by moulds, bacteria and yeasts (Melini, & Melini, 2018). Different approaches have
656 been developed to reduce bread staling and microbial spoilage, which generally achieve positive
657 effects, allowing the production of breads with a shelf life of up to 4 weeks (Fadda, Sanguinetti, Del
658 Caro, Collar, & Piga 2014; Sargent, 2008). Hence, bread flavour and aroma have become the new
659 limiting factors for bread shelf life.

660

661 3.4.1 Improving the shelf life of UWF bread

662 Different strategies can be applied to extend bread shelf life: (i) direct approach on the food matrix;
663 (ii) indirect approach through packaging systems.

664 Within the direct approaches, Gobbetti, Rizzello, Di Cagno, & De Angelis (2014) reviewed the
665 importance of fermentation of the raw material for wholegrain products. Specifically, the
666 application of this method on milling by-products before their incorporation in the bread formula
667 was reported to improve crumb softness during bread storage.

668 Furthermore, the germination process also showed positive effects on bread storage, linked to the
669 activation of alfa-amylase activity (Lemmens et al., 2019).

670 The supplementation of pre-gelatinized UWF in the bread formula delayed bread staling, in terms
671 of crumb specific volume and texture parameters (Parenti et al., 2019).

672 With regard to improvers, different enzymes reduce the staling of UWF bread: (i) xylanase and (ii)
673 alfa amylase result the most effective enzymes; furthermore, one study has reported that (iii) G4-
674 amylase showed a positive outcome, but further research is necessary to confirm this result (Tebben
675 et al., 2018).

676 The effects of emulsifiers on wholewheat breads were reported by Tebben et al. (2018). DATEM
677 showed anti-staling properties. A reduction in hardness was also reported for wholewheat bread
678 with 0.4% DATEM or 0.6% monoglycerides. Similarly, 0.5% SSL was able to decrease the staling rate
679 of wholewheat bread over 4 days of storage. It is interesting to note that DATEM and SSL only acted
680 as crumb softeners in wholewheat breads but not in refined breads (Tebben et al., 2018).

681 The use of hydrocolloids in UWF breads led to controversial results. Both CMC and GG reduced the
682 staling rate of wholewheat bread; HPMC softened the crumb of both wholewheat bread and refined
683 breads, while another study reported that CMC inclusion was ineffective for both bread typologies.
684 Furthermore, the literature reported that dextran and HPMC produced a non-significant reduction
685 in the initial loaf hardness and delay in bread staling. Hence, further research is necessary to better
686 understand the role of emulsifiers on UWF bread staling (Tebben et al., 2018).

687 Malted wholewheat flour in breadmaking reduced the staling of wholewheat bread (Tebben et al.,
688 2018).

689 Some efforts have been made to increase oxidative stability during the storage of UWF breads,
690 delaying rancidity phenomena.

691 Jensen, Ostdal, Skibsted, & Thybo (2011b) tested three antioxidants, alfa-tocopherol and fat-soluble
692 and water-dispersible rosemary extracts, on the sensory profile and antioxidant capacity of
693 wholewheat bread during storage. These antioxidants did not improve the sensory quality or

694 stability of the wholewheat bread (Jensen, Ostdal, Skibsted, & Thybo, 2011b). Furthermore, alfa-
695 tocopherol produced fresh wholewheat bread with higher concentrations of hydroperoxides and
696 secondary lipid oxidation products, similarly to the stored control sample (Jensen, Ostdal, Skibsted,
697 & Thybo, 2011b). Hence, lipid oxidation is responsible for less favourable sensory notes like a rancid
698 aroma and flavour, bitter taste and astringency, attributes most often associated with low product
699 acceptability (Jensen, Ostdal, Skibsted, & Thybo, 2011b).

700 Ning, Hou, Sun, Wan, & Dubat (2017) tested green tea powder (GTP) on the quality and antioxidant
701 activity of wholewheat dough and bread. Five levels of GTP were tested (0 g, 1 g, 2 g, 3 g, 4 g/100 g
702 flour): the higher the amount of GTP included, the worse the bread quality, while the antioxidant
703 activity showed a reverse trend (Ning, Hou, Sun, Wan, & Dubat, 2017). The best result was obtained
704 with GTP 1 g/100 g, since it did not affect bread quality while enhancing the antioxidant capacity
705 (Ning, Hou, Sun, Wan, & Dubat, 2017). Hence, 1 g/100 g GTP resulted an effective improver in
706 reducing the rate of peroxide accumulation in wholewheat bread during storage (Ning, Hou, Sun,
707 Wan, & Dubat, 2017).

708 Lu, & Norziah (2011) studied the effect of substituting shortening with different levels of
709 microencapsulated n-3 polyunsaturated fatty acid (PUFA) powder (1%, 1.75%, 2.5% of total dough
710 weight) on the sensory and oxidative stability of UWF bread during storage. The flour used was a
711 blend of wholewheat and refined flour (Lu, & Norziah, 2011). Breads containing PUFA were no
712 different to the control containing shortening, revealing that PUFA had a similar effect on bread
713 quality (Lu, & Norziah, 2011). The lowest PUFA addition (1%) resulted in bread with the best sensory
714 acceptability for up to 3 days of storage, suggesting that this improver could be an effective
715 substitute for shortening (Lu, & Norziah, 2011).

716 With regard to the breadmaking process, the most effective variable in enhancing the shelf life of
717 UWF bread was sourdough fermentation (Chavan & Chavan, 2011; Taccari et al., 2016; Choi, Kim,
718 Hwang, Kim, & Yoon, 2005).

719 The evaluation of the sensory profile of wheat bread during shelf life has been little investigated in
720 the literature. Significant changes in the flavour, aroma and taste of refined and wholewheat bread
721 have been reported by Jensen, Oestdal, Skibsted, Larsen, & Thybo (2011a). The sensory
722 characteristics of refined bread and wholewheat bread during storage were studied by measuring
723 volatile and non-volatile compounds and performing a descriptive sensory profiling (Jensen,
724 Oestdal, Skibsted, Larsen, & Thybo, 2011a). Refined and wholewheat bread showed distinctive
725 flavours, revealing two different sensory profiles (Jensen, Oestdal, Skibsted, Larsen, & Thybo,

2011a). Storage time affected 8 out of 13 of the tested attributes of refined bread, while all 14 13 attributes of wholewheat bread were significantly impacted by storage time (Jensen, Oestdal, Skibsted, Larsen, & Thybo, 2011a). The fresh wholewheat samples were characterized by higher concentrations of fermentation products; after one week of storage, dough and bran aroma were the predominant attributes, while breads stored up to 2-3 weeks were defined by rancid and fatty aromas, and a bitter taste (Jensen, Oestdal, Skibsted, Larsen, & Thybo, 2011a). The formation of off-flavours in bread could be related to the formation of secondary lipid oxidation products during storage together with a reduction in compounds from Maillard reactions (Jensen, Oestdal, Skibsted, Larsen, & Thybo, 2011a). Since UWFs are characterized by higher enzymatic activity and lipid and antioxidant contents than refined flours, the development of specific strategies for the control of oxidative reactions represents a key factor for improving bread storage (Doblado-Maldonado, Pike, Sweley, & Rose 2012).

738

3.4.2 Packaging of UWF breads

Several packaging strategies have been developed to preserve bread freshness. The main objectives of these methods are to prevent microbial spoilage and bread staling. Bread packaging has been studied on refined bread, while no techniques have been specifically developed to preserve UWF bread.

Therefore, here we discuss the packaging strategies that appear promising to us for extending the shelf life of UWF breads.

Packaging methods are classified as conventional and active packaging. The former includes traditional packaging methods, aimed at preserving the food from chemical, physical and biological damage without interacting with it. Conversely, active packaging is based on the interaction between the packaging material and the food matrix by absorbing or releasing specific substances (Melini, & Melini, 2018).

WG makes UWF particularly susceptible to lipid oxidation (Boukid, Folloni, Ranieri, & Vittadini, 2018), and the fibre component also impacts the product moisture during storage time (Hemdane et al., 2016). Hence, the critical aspects of UWF storage could be identified as rancidity phenomena and higher moisture retention, linked to microorganism spoilage.

Active Packaging with Antimicrobial Releasing Systems could be useful in preventing UWF bread spoilage. These methods release antimicrobial agents (organic acids, fungicides, alcohols and

757 antibiotics) into the food surface, thus inhibiting or delaying microbial growth and spoilage (Melini,
758 & Melini, 2018).

759 Active Packaging with oxygen absorbers could be even more interesting for UWF (Alhendi &
760 Choudhary, 2013; Melini, & Melini, 2018). In fact, Nielsen, & Rios (2000) observed that oxygen
761 absorbers combined with essential oils prevented microorganism spoilage. Furthermore, Latou,
762 Mexis, Badeka, & Kontominas (2010), by combining oxygen absorbers with an alcohol emitter, and
763 Tian, Decker, & Goddard (2012), using metal chelating carboxylic acids, reported effective
764 prevention against microorganism spoilage and lipid peroxidation.

765 The innovative trend in Active Packaging includes the application of nanotechnology, a fusion of
766 traditional packaging polymers with nanoparticles. These methods are able to extend a product's
767 shelf life, while reducing the addition of preservatives in the food formulation (Melini, & Melini,
768 2018). Being a "natural" approach, nanotechnology could be applied to UWF bread, since it could
769 preserve the high nutritional value of the product. Silver nanoparticles included in polypropylene
770 food containers were reported to keep bread fresher over 3 or 4 times longer and to reduce
771 bacterial growth by 95% compared to conventional food containers (Bumbudsanpharoke et al.,
772 2015). Moreover, nanoencapsulation applied to essential oils, which show potent antimicrobial
773 and/or antioxidant properties, may represent another promising technique for UWF bread. This
774 method protects the compound against chemical reactions and undesirable interaction with the
775 food matrix (Melini, & Melini, 2018). Nanoencapsulated essential oils extend the shelf life and
776 maintain the sensory properties of breads (Otoni, Pontes, Medeiros, & Soares, 2014; Gutiérrez,
777 Batlle, Andújar, Sánchez, & Nerín, 2011; Souza, Goto, Mainardi, Coelho, & Tadini, 2013). However,
778 nanoparticles are not inert materials: they may interact with food, its surroundings and negatively
779 impact human health. Therefore, there is an urgent need to assess the risks of this innovative
780 method (Alhendi & Choudhary 2013; Melini, & Melini, 2018).

781

782 **4. The carbon footprint of UWF bread**

783 Technological innovations sometimes have negative environmental effects, such as the emission of
784 greenhouse gases (GHG) and waste as a result of manufacturing activities. The Carbon Footprint
785 (CFP) is a useful tool to quantify GHG emission during the life cycle of a product/service, allowing an
786 estimation of its environmental impact. The food industry, including food production, preservation
787 and distribution, consumes a considerable amount of energy which contributes to total CO₂
788 emission (Roy et al., 2009). Furthermore, consumers in developed countries require safe foods of a

789 high quality, produced with a minimal impact on the environment (Boer, 2002), showing that
790 sustainability will soon become a primary factor in making food choices a part of food quality criteria
791 (Andersson, Ohlsson, & Olsson, 1994; Pattara, Russo, Antrodicchia, & Cichelli, 2016).

792 In the literature several papers have analysed the CFP associated with the life cycle of wheat bread
793 (Holderbeke, Sanjuán, Geerken, & Vooght, 2003; Braschkat, Patyk, Quirin, & Reinhardt, 2003; Rosing
794 & Nielsen, 2003; Roy et al., 2009; Pattara, Russo, Antrodicchia, & Cichelli, 2016; Meisterling,
795 Samaras, & Schweizer, 2009; Notarnicola, Tassielli, Renzulli, & Monforti, 2017; Laurence, Hartono,
796 & Christiani, 2018). These studies have shown that the main hotspots in the bread supply chain are
797 the agricultural phase, primarily due to the use of pesticides and fertilizers, followed by the baking,
798 mainly performed with an electric source of energy. The consumption of bread, including
799 refrigerated storage or toasting, has an important environmental impact too (Holderbeke, Sanjuán,
800 Geerken, & Vooght, 2003; Rosing & Nielsen, 2003; Meisterling, Samaras, & Schweizer, 2009;
801 Espinoza-Orias, Stichnothe, & Azapagic, 2011; Notarnicola, Tassielli, Renzulli, & Monforti, 2017;
802 Laurence, Hartono, & Christiani, 2018). Conversely, the CFP associated with the phases of packaging
803 and transport still deserve discussion (Roy et al., 2009).

804 To the best of the authors' knowledge, only one paper has considered flour composition as a
805 variable for CFP estimation (Espinoza-Orias, Stichnothe, & Azapagic, 2011). This paper reported the
806 hot spots in the life cycle of packaged sliced breads from refined, brown and wholewheat flours
807 produced and consumed in the UK (Espinoza-Orias, Stichnothe, & Azapagic, 2011). The key findings
808 showed that the CFP of bread ranges from 977 to 1244 g CO₂eq per loaf of bread (defined as 800 g),
809 and that thick-sliced wholewheat bread packaged in plastic bags has the lowest CFP while medium-
810 sliced refined bread in a paper bag has the highest. The degree of refinement of the flour used in
811 the bread recipe made a significant environmental impact: the higher the milling extraction rate,
812 the lower the CFP (Espinoza-Orias, Stichnothe, & Azapagic, 2011). This means that bread with higher
813 degrees of refinement is more ecologically sustainable. However, the reported results could be
814 attributed to UWF breads produced with raw materials not subjected to additional processing. On
815 the other hand, the current literature does not evaluate the environmental impact associated with
816 those techniques designed to increase the technological quality of UWF bread. In our opinion, this
817 topic deserves deeper investigation, considering that environmental impact has becoming an
818 essential quality criterion for a food product (Pattara, Russo, Antrodicchia, & Cichelli, 2016).
819 Therefore, in evaluating the best processing techniques for breadmaking with UWF, computation
820 of the CFP should be included as a quality requirement.

821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850

5. Conclusions

The present review reported the main techniques and technologies that have been specifically developed for the use of UWF in the breadmaking process. Although the consumption of UWF breads characterized the greatest part of human history, the introduction of the roller mill in the 19th century led to the use of refined flour with a better technological performance, longer shelf life and sensory quality largely appreciated by modern consumers. Hence, refined flour has become the standard in the development of the quality tests, bread formulation and processing methods applied in each phase of the breadmaking process.

In recent years, studies about the positive effects of wholegrain consumption have led to a renewed interest in the employment of UWF in breadmaking. However, although the presence of various amounts of wheat bran and/or WG enhances the flour's nutritional value, these supplementations significantly change its composition. As a result, a different raw material, that is, UWF, can be used as a substitute for refined flour in bread production. The following points summarize the main consequences that the re-introduction of UWF have brought:

- i) The standard tests to predict the breadmaking attitude of flour have remained unchanged, often giving an improper evaluation of the potentiality of UWF (i.e., water absorption capacity of the flour).
- ii) The main efforts to improve the quality of UWF bread have been focused on optimizing the bread formula with the inclusion of various improvers.
- iii) Little research has been conducted on modifying the processing variables of the breadmaking phases (i.e., mixing, resting, leavening and baking); practically the same methods developed for refined flours are adopted for the production of UWF bread too.

In our opinion, the different composition of UWF requires specific adaptation of the quality tests, so that this may improve both the technological evaluation and the use of UWF in bread production. Furthermore, new processing methods specifically adapted for the chemical characteristics of UWF may require further investigation as strategies to both preserve the high nutritional value and increase the technological quality of the final products, hence promoting the consumption of healthy foods.

851 **FIGURE CAPTIONS**

852

853 **Fig. 1** Schematic representation of the production of unrefined wheat flours (UWFs): flour enriched
854 with wheat germ, flour enriched with wheat bran, and flour enriched with both wheat germ and
855 bran in the same (i.e., wholewheat flour) or in a different relative proportion to the wheat kernel.

856

857 **Fig. 2** Schematic representation of the main techniques and technologies reported in the literature
858 for the breadmaking process with unrefined wheat flours (UWFs). (i) Treatments on the raw
859 material (i.e., wheat kernels) before the milling step; (ii) treatments on milling by-products (i.e.,
860 wheat germ and bran); (iii) modification of the bread formulation; (iv) modifications of processing
861 variables: mixing, leavening and (v) improvement of bread storage.

862

863

864

865 **References**

866

867 1. Alhendi, A., & Choudhary, R. (2013). Current Practices in Bread Packaging and Possibility of
868 Improving Bread Shelf Life by Nanotechnology. *International Journal of Food Science and*
869 *Nutrition Engineering*, 3, 55–60.

870

871 2. Andersson, K., Ohlsson, T., Olsson, P., 1994. Life cycle assessment (LCA) of food products and
872 production systems. *Trends in Food Science and Technology*, 5, 134–138.

873

874 3. Angioloni, A., & Rosa, M. D. (2006). Effects of cysteine and mixing conditions on white /
875 whole dough rheological properties. *Journal of Food Engineering*, 80, 18–23.

876

877 4. Bagdi, A., Toth, B., Lorincz, R., Szendi, S., Gere, A., Z.Kokai, Sipos, L., Tomoskozi, S. (2016).
878 Effect of aleurone-rich flour on composition, baking, textural, and sensory properties of
879 bread. *LWT - Food Science and Technology*, 65, 762–769.

880

881 5. Banu, I., Stoenescu, G., Ionescu, V. S., & Aprodu I. (2012). Effect of the addition of wheat
882 bran stream on dough rheology and bread quality. *Food Technology*, 36, 39–52.

883

884 6. Bellaio S., Kappeler S., & Bühler, R. Z. E. (2013). Partially Germinated Ingredients for Naturally
885 Healthy and Tasty Products. *Cereal Foods World*, 58, 55–59.

886

887 7. Benincasa, P., Falcinelli, B., Lutts, S., Stagnari, F., & Galieni, A. (2019). Sprouted Grains: A
888 Comprehensive Review. *Nutrients*, 11, 1–29.

889

890 8. Blandino, M., Sovrani, V., Marinaccio, F., Reyneri, A., Rolle, L., Giacosa, S., Locatelli, M.,
891 Bordiga, M., Travaglia, F., Coisson, J. D., Arlorio, M. (2013). Nutritional and technological
892 quality of bread enriched with an intermediated pearled wheat fraction. *Food Chemistry*,
893 141, 2549–2557.

894

- 895 9. Boer, D.I.J.M. (2002). Environmental impact assessment of conventional and organic milk
896 production. *Livestock Production Science*, 80, 69–77.
897
- 898 10. Boukid, F., Folloni, S., Ranieri, R., & Vittadini, E. (2018). A compendium of wheat germ:
899 Separation, stabilization and food applications. *Trends in Food Science & Technology*, 78,
900 120–133.
901
- 902 11. Braschkat, J., Patyk, A., Quirin, M., & Reinhardt, G.A., (2003). Life cycle assessment of bread
903 production – a comparison of eight different scenarios. In: Proceedings of the Fourth
904 International Conference on Life Cycle Assessment in the Agri-Food Sector, Bygholm,
905 Denmark.
906
- 907 12. Bumbudsanpharoke, N., & Ko, S. (2017). Nano-Food Packaging: An Overview of Market,
908 Migration Research, and Safety Regulations. *Journal of Food Science*, 910–923.
909
- 910 13. Callejo, N. J. (2011). Present situation on the descriptive sensory analysis of bread. *Journal*
911 *of Sensory Studies*, 255–268.
912
- 913 14. Cappelli, A., Cini, E., Guerrini, L., Masella, P., Angeloni, G., & Parenti, A. (2018). Predictive
914 models of the rheological properties and optimal water content in doughs: An application to
915 ancient grain flours with different degrees of refining. *Journal of Cereal Science*, 83, 229–
916 235.
917
- 918 15. Cappelli, A., Guerrini, L., Cini, E., & Parenti, A. (2019). Improving whole wheat dough tenacity
919 and extensibility: A new kneading process. *Journal of Cereal Science*, 90, 102852.
920
- 921 16. Cardone, G., Marti, A., Incecco, P. D., & Pagani, M. A. (2020). Sprouting improves the bread-
922 making performance of whole wheat flour (*Triticum aestivum* L.). *Journal of the Science of*
923 *Food and Agriculture*.
924
- 925 17. Cauvain, S. (2015). *Technology of Breadmaking*. Springer Sciences, New York.
926

- 927 18. Challacombe, C. A., Abdel-Aal, E. M., Seetharaman, K., & Duizer, L. M. (2012). Influence of
928 phenolic acid content on sensory perception of bread and crackers made from red or white
929 wheat. *Journal of Cereal Science*, 56, 181–188.
- 930
- 931 19. Chavan, R. S., & Chavan, S. R. (2011). Sourdough Technology-A Traditional Way for
932 Wholesome Foods: A Review. *Comprehensive Reviews in Food Science and Food Safety*, 10,
933 169–182.
- 934
- 935 20. Choi, H., Kim, Y., Hwang, I., Kim, J., & Yoon, S. (2012). Evaluation of *Leuconostoc citreum*
936 HO12 and *Weissella koreensis* HO20 isolated from kimchi as a starter culture for whole
937 wheat sourdough. *Food Chemistry*, 134, 2208–2216.
- 938
- 939 21. Curti, E., Carini, E., Bonacini, G., Tribuzio, G., & Vittadini, E. (2013). Effect of the addition of
940 bran fractions on bread properties. *Journal of Cereal Science*, 57, 325–332.
- 941
- 942 22. Curti, E., Carini, E., Tribuzio, G., & Vittadini, E. (2015). Effect of bran on bread staling: Physico-
943 chemical characterization and molecular mobility. *Journal of Cereal Science*, 65, 25–30.
- 944
- 945 23. Kock, S. De, Taylor, J., & Taylor, J. R. N. (1999). Effect of Heat Treatment and Particle Size of
946 Different Brans on Loaf Volume of Brown Bread. *LWT - Food Science and Technology*, 356,
947 349–356.
- 948
- 949 24. Decock, P., & Cappelle, S. (2005). Bread technology and sourdough technology. *Trends in*
950 *Food Science and Technology*, 16, 113–120.
- 951
- 952 25. Ding, J., Hou, G. G., Nemzer, B. V, Xiong, S., Dubat, A., & Feng, H. (2018). Effects of controlled
953 germination on selected physicochemical and functional properties of whole-wheat flour
954 and enhanced γ -aminobutyric acid accumulation by ultrasonication. *Food Chemistry*, 243,
955 214–221.
- 956
- 957 26. Doblado-Maldonado, A. F., Pike, O. A., Sweley, J. C., & Rose, D. J. (2012). Key issues and
958 challenges in whole wheat flour milling and storage. *Journal of Cereal Science*, 56, 119–126.

959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990

27. Eckardt, J., Ohgren, C., Alp, A., Ekman, S., Astrom, A., Chen, G., Swenson, J., Johansson, D., & Langton, M. (2013). Long-term frozen storage of wheat bread and dough - Effect of time, temperature and fibre on sensory quality, microstructure and state of water. *Journal of Cereal Science*, 57, 125–133.
28. Espinoza-Orias, N., Stichnothe, H., & Azapagic, A. (2011). The carbon footprint of bread. *International Journal of Life Cycle Assessment*, 16, 351–365.
29. Fadda, C., Sanguinetti, A. M., Del Caro, A., Del Collar, C., & Piga, A. (2014). Bread Staling: Updating the View. *Comprehensive Reviews in Food Science and Food Safety*, 13, 473–492.
30. Fernandez, U., Vodovotz, Y., Courtney, P., & Pascall, M. A., (2006). Extended shelf life of soy bread using modified atmosphere packaging. *Journal of Food Protection*, 69, 693–698.
31. Gani, A., SM, W., FA, M., & Hameed, G. (2012). Whole-Grain Cereal Bioactive Compounds and Their Health Benefits: A Review. *Journal of Food Processing & Technology*, 3, 1000146.
32. Gobbetti, M., Rizzello, C. G., Di Cagno, R., Di, & De Angelis, M. De. (2014). How the sourdough may affect the functional features of leavened baked goods. *Food Microbiology*, 37, 30–40.
33. Guerrini, L., Parenti, O., Angeloni, G., & Zanoni, B. (2019). The bread making process of ancient wheat: A semi-structured interview to bakers. *Journal of Cereal Science*, 87, 9–17.
34. Gutiérrez, B. L., Batlle, R., Andújar, S., Sánchez, C., & Nerín, C. (2011). Paper presented at iapri symposium 2011, Berlin. Evaluation of Antimicrobial Active Packaging to Increase Shelf Life of Gluten - Free Sliced Bread, 485–494.
35. Hauner, H., Bechthold, A., Boeing, H., Bronstrup, A., Buyken, A., Leschik-bonnet, E., Linseisen, J., Schulze, M., Strohm, D., Wolfram, G. (2012). Evidence-Based Guideline of the German Nutrition Society: Carbohydrate Intake and Prevention of Nutrition-Related Diseases. *Annals of Nutrition and Metabolism*, 60, 1–58.

- 991
- 992 36. Hayakawa, F., Ukai, N., Nishida, J., Kazami, Y., & Kohyama, K. (2010). Lexicon for the sensory
993 description of French bread in Japan. *Journal of Sensory Studies*, 25, 76–93.
- 994
- 995 37. Heenan, S. P., Dufour, J., Hamid, N., Harvey, W., & Delahunty, C. M. (2008). The sensory
996 quality of fresh bread: descriptive attributes and consumer perceptions. *Food Research
997 International*, 41, 989–997.
- 998
- 999 38. Heiniö, R. L. (2009). Comparison of sensory characteristics of refined and whole grain foods.
1000 *Cereal Foods World*, 54, 12–13.
- 1001
- 1002 39. Heiniö, R. L., Noort, M. W. J., Katina, K., Alam, S. A., Sozer, N., Kock, H. L. De, Hersleth, M.,
1003 Poutanen, K. (2016). Sensory characteristics of wholegrain and bran-rich cereal foods e A
1004 review. *Trends in Food Science & Technology*, 47, 25–38.
- 1005
- 1006 40. Hemdane, S., Jacobs, P. J., Dornez, E., Verspreet, J., Delcour, J. A., & Courtin, C. M. (2016).
1007 Wheat (*Triticum aestivum* L.) Bran in Bread Making: A Critical Review. *Comprehensive
1008 Reviews in Food Science and Food Safety*, 15, 28–42.
- 1009
- 1010 41. Holderbeke, M.V., Sanjuán, N., Geerken, & T., Vooght, D.D. (2003). The history of bread
1011 production: using LCA in the past. In: Proceedings of the Fourth International Conference on
1012 Life Cycle Assessment in the Agri-Food Sector, Bygholm, Denmark.
- 1013
- 1014 42. Hung, P. Van, Maeda, T., & Morita, N. (2007). Dough and bread qualities of flours with whole
1015 waxy wheat flour substitution. *Food Research International*, 40, 273–279.
- 1016
- 1017 43. Jensen, S., Oestdal, H., Skibsted, L. H., Larsen, E., & Thybo, A. K. (2011a). Chemical changes
1018 in wheat pan bread during storage and how it affects the sensory perception of aroma,
1019 flavour, and taste. *Journal of Cereal Science*, 53, 259–268.
- 1020
- 1021 44. Jensen, S., Ostdal, H., Skibsted, L. H., & Thybo, A. K. (2011b). Antioxidants and shelf life of
1022 whole wheat bread. *Journal of Cereal Science*, 53, 291–297.

1023

1024 45. Johnston, R., Martin, J. M., Vetch, J. M., Byker-Shank., C., Finnie, S., & Giroux, M. J. (2019).
1025 Controlled sprouting in wheat increases quality and consumer acceptability of whole - wheat
1026 bread. *Cereal Chemistry*, 96, 866–877.

1027

1028 46. Jones, J. M., Adams, J., Harriman, C., Miller, C., & Van der Kamp, J. W. (2015). Nutritional
1029 Impacts of Different Whole Grain Milling Techniques: A Review of Nutritional Impacts of
1030 Different Whole Grain Milling Techniques: A Review of Milling Practices and Existing Data.
1031 *Cereal Foods World*, 60, 130–139.

1032

1033 47. Katina, K., Heiniö, R. L., Autio, K., & Poutanen, K. (2006a). Optimization of sourdough process
1034 for improved sensory profile and texture of wheat bread. *LWT - Food Science and
1035 Technology*, 39, 1189–1202.

1036

1037 48. Katina, K., Salmenkallio-Marttila, M., Partanen, R., Forssell, P., & Autio, K. (2006b). Effects of
1038 sourdough and enzymes on staling of high-fibre wheat bread. *LWT - Food Science and
1039 Technology*, 39, 479–491.

1040

1041 49. Komlenić, D. K., Ugarčić-Hardi, Ž., Jukić, M., Planinić, M., Bucić-Kojić, A., & Strelec, I. (2010).
1042 Wheat dough rheology and bread quality effected by *Lactobacillus brevis* preferment, dry
1043 sourdough and lactic acid addition. *International Journal of Food Science and Technology*,
1044 45, 1417–1425.

1045

1046 50. Latou, E., Mexis, S. F., Badeka, A. V, & Kontominas, M. G. (2010). Shelf life extension of sliced
1047 wheat bread using either an ethanol emitter or an ethanol emitter combined with an oxygen
1048 absorber as alternatives to chemical preservatives. *Journal of Cereal Science*, 52, 457–465.

1049

1050 51. Laurence, Hartono, N., & Christiani, A. (2018). Case study of life cycle assessment in bread
1051 production process Case study of life cycle assessment in bread production process. IOP
1052 Conf. Series: Earth and Environmental Science, 195, 012043.

1053

- 1054 52. Lemmens, E., Moroni, A. V, Pagand, J., Heirbaut, P., Ritala, A., Karlen, Y., Le, Kim-anne, Van,
1055 H. C., Broeck, D., Brouns, F. J. P. H., Brier, N. De, Delcour, J. A. (2019). Impact of Cereal Seed
1056 Sprouting on Its Nutritional and Technological Properties: A Critical Review. *Comprehensive*
1057 *Reviews in Food Science and Food Safety*, 18, 305–328.
- 1058
- 1059 53. Lotong, V., Edgar-Chambers, I., & Chambers, D. H. (2000). Determination of the sensory
1060 attributes of wheat sourdough bread. *Journal of Sensory Studies*, 15, 309–326.
- 1061
- 1062 54. Lu, F. S. H., & Norziah, M. H. (2011). Contribution of microencapsulated n-3 pufa powder
1063 toward sensory and oxidative stability of bread. *Journal of Food Processing and Preservation*,
1064 604, 596–604.
- 1065
- 1066 55. Maningat, C. C., Bassi, S. D., & Hesser, J. M. (1994). Wheat gluten in food and non-food
1067 systems, Vol. 16. *American Institute of Baking Technical Bulletin*.
- 1068
- 1069 56. Marti, A., Cardone, G., Nicolodi, A., Quaglia, L., & Pagani Ambrogina, M. A. (2017). Sprouted
1070 wheat as an alternative to conventional flour improvers. *LWT - Food Science and Technology*,
1071 80, 230–236.
- 1072
- 1073 57. Mattila, P., Pihlava, J., & Hellström, J. (2005). Contents of phenolic acids, alkyl-and
1074 alkenylresorcinols, and avenanthramides in commercial grain products. *Journal of*
1075 *Agricultural and Food Chemistry*, 53, 8290–8295.
- 1076
- 1077 58. Meisterling, K., Samaras, C., & Schweizer, V. (2009). Decisions to reduce greenhouse gases
1078 from agriculture and product transport: LCA case study of organic and conventional wheat.
1079 *Journal of Cleaner Production*, 17, 222–230.
- 1080
- 1081 59. Messia, M. C., Reale, A., Maiuro, L., Candigliota, T., Sorrentino, E., & Marconi, E. (2016).
1082 Effects of pre-fermented wheat bran on dough and bread characteristics. *Journal of Cereal*
1083 *Science*, 69, 138–144.
- 1084

- 1085 60. Melini, V., & Melini, F. (2018). Strategies to Extend Bread and GF Bread Shelf-Life: From
1086 Sourdough to Antimicrobial Active Packaging and Nanotechnology. *Fermentation*, 4, 1–18.
1087 Pagine?
1088
- 1089 61. Nielsen, P. V, & Rios, R. (2000). Inhibition of fungal growth on bread by volatile components
1090 from spices and herbs, and the possible application in active packaging, with special
1091 emphasis on mustard essential oil. *International Journal of Food Microbiology*, 60, 219–229.
1092
- 1093 62. Ning, J., Hou, G. G., Sun, J., Wan, X., & Dubat, A. (2017). Effect of green tea powder on the
1094 quality attributes and antioxidant activity of whole-wheat flour pan bread. *LWT - Food
1095 Science and Technology*, 79, 342–348.
1096
- 1097 63. Notarnicola, B., Tassielli, G., Renzulli, P. A., & Monforti, F. (2017). Energy flows and
1098 greenhouses gases of EU (European Union) national breads using an LCA (Life Cycle
1099 Assessment) approach. *Journal of Cleaner Production*, 140, 455–469.
1100
- 1101 64. Nutrition data (2014). Food composition databases show foods list. Retrieved March 4, 2018,
1102 from <https://ndb.nal.usda.gov/ndb/search/list>.
1103
- 1104 65. Otoni, C. G., Pontes, S. F. O., Medeiros, E. A. A., & Soares, N. de F. F. (2014). Edible Films from
1105 Methylcellulose and Nanoemulsions of Clove Bud (*Syzygium aromaticum*) and Oregano
1106 (*Origanum vulgare*) Essential Oils as Shelf Life Extenders for Sliced Bread. *Journal of
1107 Agricultural and Food Chemistry*, 62, 5214–5219.
1108
- 1109 66. Parenti, A., Guerrini, L., Granchi, L., Venturi, M., Benedettelli, S., & Nistri, F. (2013). Control
1110 of mixing step in the bread production with weak wheat flour and sourdough. *Journal of
1111 Agricultural Engineering*, 44, 10–13.
1112
- 1113 67. Parenti, O., Guerrini, L., Canuti, V., Angeloni, G., Masella, P., & Zanoni, B. (2019). The effect
1114 of the addition of gelatinized flour on dough rheology and quality of bread made from brown
1115 wheat flour. *LWT - Food Science and Technology*, 106, 240–246.
1116

- 1117 68. Parenti, O., Guerrini, L., Cavallini, B., Baldi, F., & Zanoni, B. (2020). Breadmaking with an old
1118 wholewheat flour: Optimization of ingredients to improve bread quality. *LWT - Food Science
1119 and Technology*, 121, 108980.
1120
- 1121 69. Pasqualone, A., Laddomada, B., Centomani, I., Paradiso, V. M., Minervini, D., Caponio, F., &
1122 Summo, C. (2017). Bread making aptitude of mixtures of re-milled semolina and selected
1123 durum wheat milling by-products. *LWT - Food Science and Technology*, 78, 151-159.
1124
- 1125 70. Pattara, C., Russo, C., Antrodocchia, V., & Cichelli, A. (2016). Carbon footprint as an
1126 instrument for enhancing food quality: overview of the wine, olive oil and cereals sectors.
1127 *Journal of the Science of Food and Agriculture*, 97, 396-410.
1128
- 1129 71. Pontonio, E., Dingo, C., Di Cagno, R., Blandino, M., Gobbetti, M., & Giuseppe, C. (2020).
1130 Brans from hull-less barley, emmer and pigmented wheat varieties: From by - products to
1131 bread nutritional improvers using selected lactic acid bacteria and xylanase. *International
1132 Journal of Food Microbiology*, 313, 108384.
1133
- 1134 72. Richter, K., Christiansen, K., & Guo, G. (2014). Wheat Sprouting Enhances Bread Baking
1135 Performance. *Cereal Foods World*, 59, 231-233.
1136
- 1137 73. Rosing, L., & Nielsen, A.M., (2003). When a hole matters - the story of the hole in a bread
1138 fro French hotdog. In: *Proceedings of the Fourth International Conference on Life Cycle
1139 Assessment in the Agri-Food Sector*, Bygholm, Denmark.
1140
- 1141 74. Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., & Shiina, T. (2009). A Review
1142 of Life Cycle Assessment (LCA) on Some Food Products. *Journal of Food Engineering*, 90, 1-
1143 10.
1144
- 1145 75. Santala, O., Lehtinen, P., Nordlund, E., Suortti, T., & Poutanen, K. (2011). Impact of water
1146 content on the solubilisation of arabinoxylan during xylanase treatment of wheat bran.
1147 *Journal of Cereal Science*, 54, 187-194.
1148

- 1149 76. Sargent, K., (2008). A “softer” approach to improving the quality of refrigerated bakery
1150 products. *Cereal Foods World*, 53, 301–305.
1151
- 1152 77. Schmiele, M., Jaekel, L. Z., Patricio, S. M. C., Steel, C. J., & Chang, Y. K. (2012). Rheological
1153 properties of wheat flour and quality characteristics of pan bread as modified by partial
1154 additions of wheat bran or whole grain wheat flour. *International Journal of Food Science
1155 and Technology*, 47, 2141–2150.
1156
- 1157 78. Souza, A. C., Goto, G. E. O., Mainardi, J. A., Coelho, A. C. V., & Tadini, C. C. (2013). Cassava
1158 starch composite films incorporated with cinnamon essential oil: Antimicrobial activity,
1159 microstructure, mechanical and barrier properties. *LWT - Food Science and Technology*, 54,
1160 346–352.
1161
- 1162 79. Sovrani, V., Blandino, M., Scarpino, V., Reyneri, A., Daniel, J., Travaglia, F., Locatelli, M.,
1163 Bordiga, M., Montella, R., Arlorio, M. (2012). Bioactive compound content, antioxidant
1164 activity, deoxynivalenol and heavy metal contamination of pearled wheat fractions. *Food
1165 Chemistry*, 135, 39–46.
1166
- 1167 80. Sun, R., Zhang, Z., Hu, X., Xing, Q., & Zhuo, W. (2015). Effect of wheat germ flour addition on
1168 wheat flour, dough and Chinese steamed bread properties. *Journal of Cereal Science*, 64,
1169 153–158.
1170
- 1171 81. Taccari, M., Aquilanti, L., Polverigiani, S., Osimani, A., Garofalo, C., Milanovic, V. & Clementi,
1172 F. (2016). Microbial Diversity of Type I Sourdoughs Prepared and Back-Slopped with
1173 Wholemeal and Refined Soft (*Triticum aestivum*) Wheat Flours. *Journal of Food Science*, 81,
1174 1996–2005.
1175
- 1176 82. Tebben, L., Shen, Y., & Li, Y. (2018). Improvers and functional ingredients in whole wheat
1177 bread: A review of their effects on dough properties and bread quality. *Trends in Food
1178 Science & Technology*, 81, 10–24.
1179

- 1180 83. Tian, F., Decker, E. A., & Goddard, J. M. (2012). Development of an Iron Chelating
1181 Polyethylene Film for Active Packaging Applications. *Journal of Agricultural and Food*
1182 *Chemistry*, 60, 2046–2052.
- 1183
- 1184 84. Van Gemert, L. J. (2011). Odour thresholds. Compilations of odour threshold values in air,
1185 water and other media (pp. 11–80). *Utrecht: Oliemans Punter & Partners BV*.
- 1186
- 1187 85. Wang, J., De Wit, M., Boom, R.M., & Schutyser, M.A.I., (2015a). Charging and separation
1188 behaviour of gluten-starch mixtures assessed with a custom-built electrostatic separator.
1189 *Separation Purification Technology*, 152, 164–171.
- 1190
- 1191 86. Wang, J., Smits, E., Boom, R. M., & Schutyser, M. A. I. (2015b). Arabinoxylans concentrates
1192 from wheat bran by electrostatic separation. *Journal of Food Engineering*, 155, 29–36.
- 1193
- 1194 87. Ye, E., Chacko, S., Chou, E., Kugizaki, M., & Liu, S. (2012). Greater whole-grain intake is
1195 associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *The*
1196 *Journal of Nutrition*, 142, 1304–1313.
- 1197
- 1198 88. Zanoni, B., Peri, C., & Pierucci, S. (1993). A study of the bread-baking process. I: A
1199 phenomenological model. *Journal of Food Engineering*, 19, 389–398.
- 1200
- 1201 89. Zanoni, B., Pierucci, S. & Peri, C. (1994). Study of the bread baking process - II. Mathematical
1202 modelling. *Journal of Food Engineering*, 23, 321–336.
- 1203
- 1204 90. Zhang, L., Boven, A. Van, Mulder, J., Grandia, J., Chen, X. D., Boom, R. M., & Schutyser, M. A.
1205 I. (2019). Arabinoxylans-enriched fractions: From dry fractionation of wheat bran to the
1206 investigation on bread baking performance Arabinoxylans-enriched fractions: From dry
1207 fractionation of wheat bran to the investigation on bread baking performance. *Journal of*
1208 *Cereal Science*, 87, 1–8.
- 1209
- 1210 91. Zhou, “W”., Therdthai, N., & Hui, Y. H. (2014). *Bakery products science and technology*,
1211 Blackwell.

1212

1213 92. Zilic, S., Jankovic, M., Barac, M., Pesic, M., Konic-Ristic, A., & Sukalovic, V. H. (2016). Effects
1214 of enzyme activities during steeping and sprouting on the solubility and composition of
1215 proteins, their bioactivity and relationship with the bread making quality of wheat flour.

1216 *Food a*

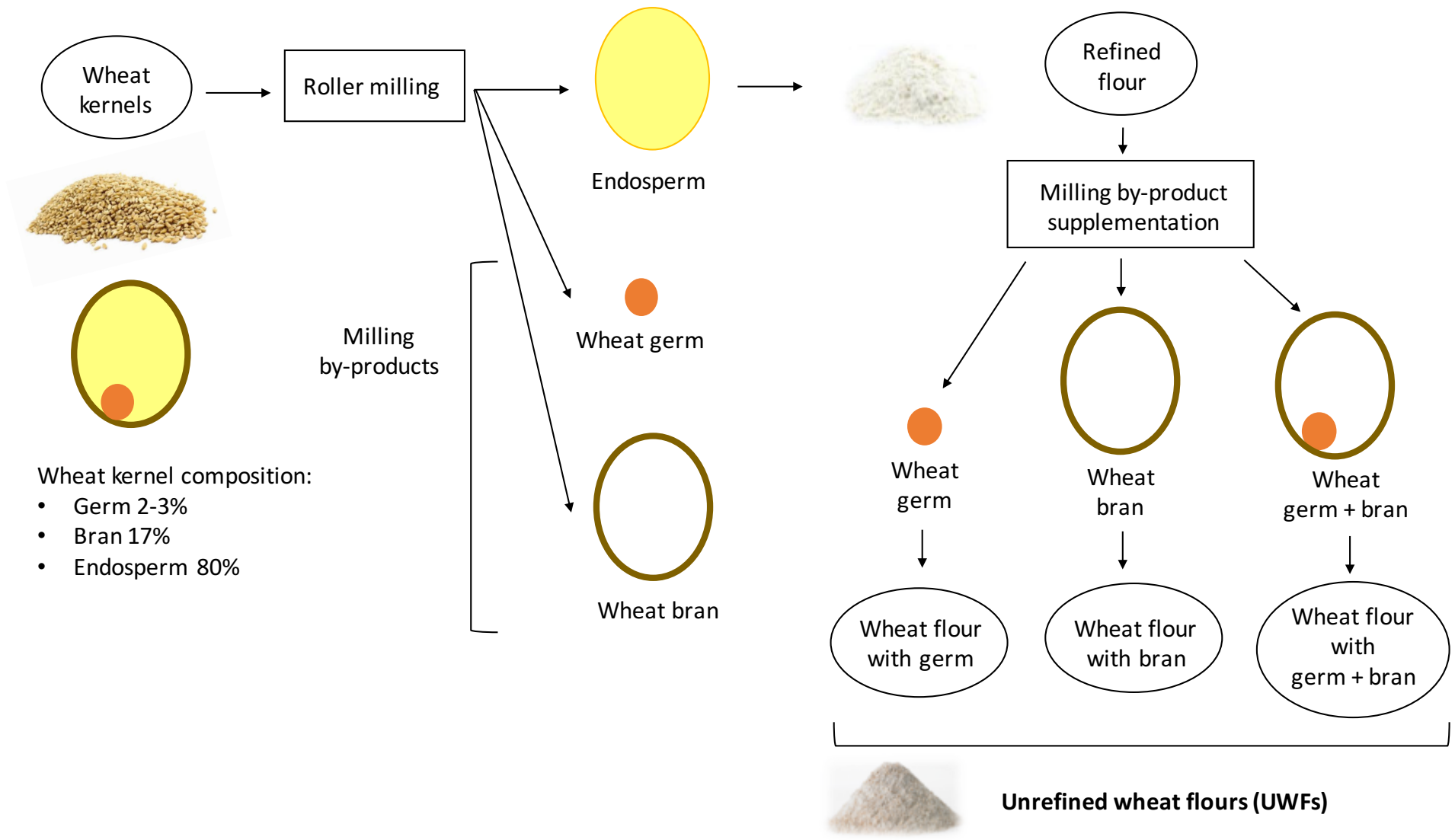


Fig.1

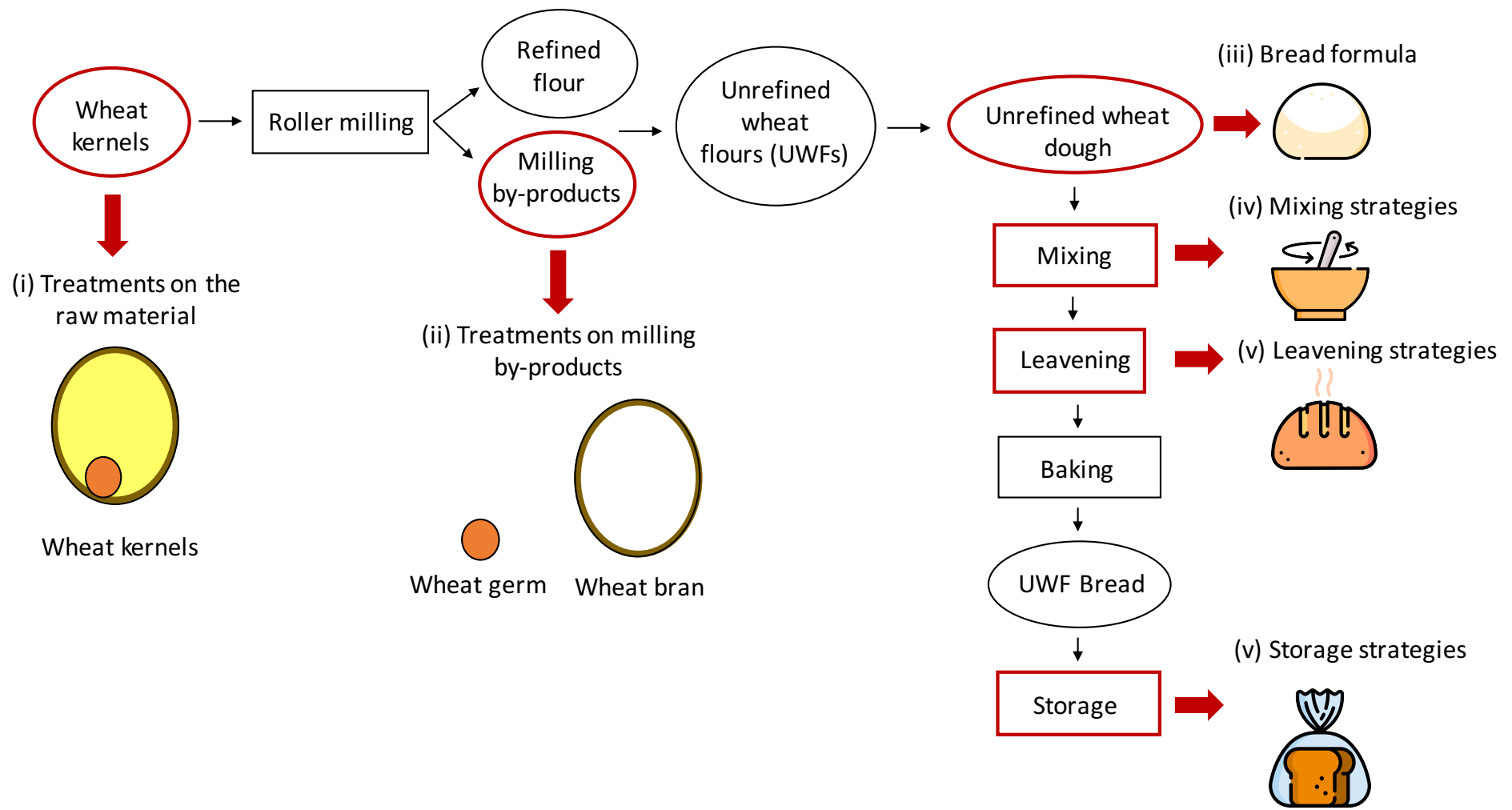


Fig.2

Food matrix/ Process step	Processing strategy
Wheat kernels	Germination
Milling	Bran pre-soaking
by-products	Bran/germ fermentation
Bread dough	Bread formulation
	-Optimization of water amount
	-Addition of modified flour
	<ul style="list-style-type: none"> • Pre-gelatinized flour • Waxy wholewheat flour
	-Addition of improvers
	<ul style="list-style-type: none"> • Enzymes (<i>xylanase, alfa-amylase, G4 amylase</i>) • Hydrocolloids (<i>carboxymethylcellulose CMC, guar gum GG, hydroxypropyl methylcellulose HPMC, methylcellulose MC, psyllium gum PG, xanthan gum XG, tara gum TG</i>) • Oxidants (<i>ascorbic acid, rosehip, potassium bromate</i>) • Emulsifiers (<i>diacetyl tartaric esters of monoglycerides DATEM, sodium stearoyl lactylate SSL, ethoxylated monoglycerides, succinylated monoglycerides, lecithin, polyoxyethylene sorbitan monostearate, polyoxyethylene sorbitan monopalmitate, glycerol-monostearate</i>) • Vital gluten
Mixing	Mixing time
	Delayed addition of milling by-products
Leavening	Sourdough fermentation
Bread storage	Treatments on milling by-products (fermentation)
	Bread formulation
	-Addition of modified ingredients
	<ul style="list-style-type: none"> • Pre-gelatinized flour
	-Addition of improvers
	<ul style="list-style-type: none"> • Enzymes (<i>xylanase, alfa-amylase, G4 amylase</i>) • Emulsifiers (<i>diacetyl tartaric esters of monoglycerides DATEM, sodium stearoyl lactylate SSL, monoglycerides</i>) • Hydrocolloids (<i>carboxymethylcellulose CMC, guar gum GG, hydroxypropyl methylcellulose HPMC, dextran</i>) • Malted flour • Anti-oxidants (<i>alfa-tocopherol, rosemary extract, green tea powder, microencapsulated n-3 polyunsaturated fatty acids PUFA powder</i>)

Table 1. The main processing strategies for breadmaking with unrefined wheat flours (UWFs).

Literature reference	Wheat flour	Milling by-product supplement	Supplementation with good bread technological and sensory quality
Banu et al. (2012)	Refined flour	Bran streams (3%, 5%, 10%, 15%, 20%, 25%, 30% expressed on total flour weight)	25% bran stream
Blandino et al. (2013)	Refined flour	Pearled fractions (5%, 10%, 15%, 20%, 25% expressed on total flour weight)	10% pearled fraction
Bagdi et al. (2015)	Refined flour	Aleurone (40%, 75% expressed as percentages of refined flour)	40% (only on sensory profile)
Sun et al. (2015)	Refined flour	Wheat germ (0%, 3%, 6%, 9%, 12% expressed on total flour weight)	6% wheat germ
Pasqualone et al. (2017)	Refined flour (re-milled semolina)	3 fractions of durum wheat milling by-products (10%, 20% expressed as percentages of refined flour): i) bran obtained from non-debranned wheat ii) second and third debranning fractions mixed together iii) thin subfraction obtained by micronization and air classification of the second and third debranning fraction mix	10% second and third debranning step

Table 2. The use of unprocessed unrefined wheat flours (UWFs) for breadmaking. Reporting literature reference, wheat flour, type of milling by-products used for supplementation and level of supplementation that gave good bread technological and sensory quality.

Literature reference	Treatment	Tested variables	Measurements	Main results
Ding et al. (2018)	Germination	Germination time	Hagberg falling number (FN) Rapid Visco Analyser (RVA) Starch pasting properties Mixolab mixing properties Physicochemical analysis γ -aminobutyric acid (GABA) content	Controlled germination (t=5-15 h, T=28±2°C, RH=95±3%) improved wholewheat flour functionality
Ritcher et al. (2014)	Germination	Germinated wholewheat flour + vital gluten (0%, 3%, 4%, 5%) for breadmaking	Farinographic test Proof time Loaf volume Sensory analysis	100% germinated wholewheat bread showed better technological and sensory quality than control; Vital gluten did not improve bread quality
Zilic et al. (2016)	Germination	Germination effect on wholewheat protein functionality	Total and free sulfhydryl (-SH) groups Lipoxygenase (LOX) and peroxidase (POX) activity SDS-PAGE gel electrophoresis Total antioxidant capacity of albumin+globulin proteins Gliadin and glutenin immunogenicity Analysis of pasting viscosity	Total protein content did not change with germination Intensive protein hydrolysis Increased antioxidant capacity of albumin + globulin fraction and reduced glutenin antigenicity Potential health positive effects
Johnston et al. (2019)	Germination	Germination effect on wholewheat flour functionality and flavour	Kernel hardness Hagberg falling number (FN) Sodium dodecyl sulphate sedimentation analysis (SDS) Starch content Total dietary fibre Alfa-amylase activity Metabolite analysis Mixograph analysis Sensory analysis	Controlled germination (t=24 h, T=21°C, FN=200 s, excess of water) increased wholewheat bread volume and flavour

Table 3. References concerning the use of processed unrefined wheat flours (UWFs) produced through treatments on the raw material, i.e., wheat kernels. Outlining type of treatment, tested variables, measurements made and main results.

Literature reference	Milling by-product	Treatments	Best results on bread quality	Interpretation of results
Hemdane et al. (2016)	Wheat bran	Pre-soaking Particle size reduction	14% pre-soaked bran 22% pre-soaked, fine-ground bran	Reduction of bran water uptake during mixing
Hemdane et al. (2016)	Wheat shorts	Pre-soaking	Bread specific volume	Activation of endogenous lipoxygenase
Hemdane et al. (2016)	Wheat bran	Pre-soaking (limited/excess water)	Good bread quality	A complete understanding has not been established yet. Some hypotheses proposed: -Saturating bran with water before mixing prevent the detrimental effects on dough/bread quality; -Activation of endogenous lipoxygenase oxidize components detrimental to bread quality -Washout effect when pre-soaking in excess of water
Messia et al. (2016)	Wheat bran	Pre-soaking Enzyme addition (xylanase, amylase, cellulase)	Improved dough rheology and bread physical properties	Modification of arabinoxylan solubility allowing a better redistribution of water
Zhang et al. (2019)	Arabinoxylan flour from wheat bran	Pre-soaking Enzyme addition (xylanase)	Up to 10% pre-soaked arabinoxylan flour	The positive effects associated to the pre-soaking of arabinoxylan flour was not explained
Hemdane et al. (2016)	Wheat bran (native bran and bran from peeled kernel)	Fermentation (20 h, yeast starter)	20% fermented bran from peeled kernel	Solubilization of arabinoxylans Reduction of endogenous xylanase activity
Hemdane et al. (2016)	Wheat bran	Fermentation (8 h, lactic acid bacteria and yeast strain) Particle size reduction	15% 160 um bran fermented 8 h	Lactic acid fermentation (<i>Lactobacillus brevis</i>)
Boukid et al. (2018)	Wheat germ	Sourdough fermentation (bacteria and yeast)	Up to 20% sourdough fermented wheatgerm	Reduction of enzymatic activities (lipase, lipoxygenase) Reduction of glutathione content
Boukid et al. (2018)	Wheat germ	Sourdough fermentation (<i>Lactobacillus plantarum</i> LB1, <i>Lactobacillus rossiae</i> LB5)	Better nutritional, chemical and stabilization properties	Reduction of pH Reduction of enzymatic activities (lipase, lipoxygenase) Higher total amino acids Higher protein digestibility Inactivation of anti-nutritional factors Higher antioxidant activity
Boukid et al. (2018)	Wheat germ	Sourdough fermentation (<i>Lactobacillus plantarum</i> LB1, <i>Lactobacillus rossiae</i> LB5)	4% sourdough fermented wheat germ	Reduction of enzymatic activities (lipase, lipoxygenase) Reduction of glutathione content
Boukid et al. (2018)	Wheat germ	Sourdough fermentation (<i>Lactobacillus plantarum</i> LB1, <i>Lactobacillus rossiae</i> LB5)	4% sourdough fermented wheat germ bread shelf life	Antifungal activity of sourdough fermented wheat germ (phenolic acids, organic acids) Lower pH values

Table 4. References concerning the use of processed UWF produced through treatments on the raw material, i.e., milling by-products (wheat bran and wheat germ). Summarizing milling by-product, type of treatment, best results on bread quality and interpretation of the main results.

Literature reference	Process strategy	Tested variables	Wheat flour	Improvement of bread quality
Cappelli et al. (2019)	Optimization of water amount	Water amount (70%, 76%, 82%, 88%, and 94%) Flour refinement degree (refined, brown, wholewheat)	Refined, brown and wholewheat flour	Optimal water addition as a function of degree of flour refinement
Guerrini et al. (2019)	Optimization of water amount	Different variables used by bakers	Brown and wholewheat flour	Higher water amount
Parenti et al. (2019)	Modification of the flour	Water amount (59%, 70%, 80%) Pre-gelatinized flour (0%, 6%)	Brown flour	6% pre-gelatinized flour + high water amount
Hung et al. (2007)	Modification of the flour	Waxy wholewheat flour (0%, 10%, 30%, 50%)	Wholewheat flour and waxy wholewheat flour	Waxy wholewheat breads showed softer crumb during storage
Tebben et al. (2018)	Improver	Enzyme, xylanase	Wholewheat flour	Optimization of xylanase usage level
Tebben et al. (2018)	Improver	Enzyme, alfa-amylase	Wholewheat flour, blends of refined and wholewheat flours	Optimization of amylase usage level
Tebben et al. (2018)	Improver	Enzyme, G4-amylase	Wholewheat flour	Optimization of G4-amylase usage level
Tebben et al. (2018)	Improver	Hydrocolloids (carboxymethylcellulose, CMC; guar gum, GG; methylcellulose, MC; psyllium gum, PG; xanthan gum, XG; tara gum, TG)	Wholewheat flour	0.5%-1% hydrocolloids
Tebben et al. (2018)	Improver	Oxidants (potassium bromate, ascorbic acid, rosehip as a source of ascorbic acid)	Wholewheat flour	Optimum amount of antioxidants corresponds to higher quantities than refined flour; best results with 200 ppm
Tebben et al. (2018)	Improver	Emulsifiers (diacetyl tartaric esters of monoglycerides, DATEM; sodium stearoyl lactylate, SSL; ethoxylated monoglycerides, succinylated monoglycerides, lecithin, polyoxyethylene sorbitan monostearate, poly-oxyethylene sorbitan monopalmitate, glycerol-monostearate, mono- and diglycerides)	Wholewheat flour	Usage level 0.4%-0.5% Positive results emulsifiers combined with oxidants
Tebben et al. (2018)	Improver	Vital gluten	Wholewheat flour	Usage level 2%-2.5%

Table 5. Literature references about the modification of unrefined wheat flours (UWFs) bread formula to improve breadmaking performance. Reporting the main process strategies (i.e., optimization of water amount, modification of flour and addition of improvers), tested variables, type of UWF and strategies that improved bread quality. Percentages relate to flour base (ingredient/total flour %).

Literature reference	Breadmaking step	Tested variable	Wheat flour	Processing strategy
Angioloni et al. (2006)	Mixing	Mixing time (10, 15, 20 min) Cysteine (20 mg/kg)	Refined and wholewheat flour (<i>T. aestivum</i> L.)	Combination of high-speed mixer and cysteine addition
Parenti et al. (2013)	Mixing	Mixing time (12, 17, 22, 27 min)	Brown flour (<i>T. aestivum</i> L.)	Optimized mixing time (17 min)
Guerrini et al. (2019)	Mixing	Different variables used by bakers	Brown and wholewheat flour (<i>T. aestivum</i> L., <i>T. durum</i>)	Short mixing time (10-20 min)
Cappelli et al. (2019)	Mixing	Time for addition of bran and middlings during mixing (0, 2, 3.5, 5, 6.5 min) Levels of bran and middlings (10%, 20%, 30%)	Refined flour enriched with bran and middlings (<i>T. aestivum</i> L.)	10% bran and middlings added at t=2 min
Kolmenic et al. (2010)	Leavening	Biological acidification (dry sourdough, <i>Lactobacillus brevis</i> preferment) Chemical acidification (lactic acid)	Refined flour Wholewheat flour (commercial blends)	Biological acidification (dry form)
Taccari et al. (2016)	Leavening	Back-slopping technique for type I sourdough	Wholewheat flour (<i>T. aestivum</i> L.)	Application of back-slopping techniques for sourdough fermentation
Choi et al. (2005)	Leavening	Selected LAB isolated from kimchi as starter cultures (<i>Leuconostoc citreum</i> HO12 and <i>Weissella koreensis</i> HO20)	Wholewheat flour (<i>T. aestivum</i> L.)	Applicability of selected LAB (<i>Leuconostoc citreum</i> HO12 and <i>Weissella koreensis</i> HO20)
Didar et al. (2011)	Leavening	Sourdough fermentation with <i>Lactobacillus plantarum</i> (PTCC 1058) and <i>Lactobacillus reuteri</i> (PTCC 1655) Level of sourdough addition (10%, 20%, 30%) Dough yield (250 and 300)	Flour with 95% extraction rate (cv Alvand wheat)	30% <i>Lb. plantarum</i> sourdough with DY 250
Katina et al. (2006a)	Leavening	Sourdough time = 6-20 h Sourdough temperature = 16-32°C LAB and yeast for sourdough fermentation (<i>Lactobacillus plantarum</i> , <i>Lactobacillus brevis</i> , <i>Saccharomyces cerevisiae</i> or a combination of yeast and LAB) Flour ash content (0.6-1.8 g/100 g)	Flours with different ash content (0.6-1.8 g/100 g) (commercial flours)	Different flour ash contents required different optimization strategies

Table 6. Literature references about processing strategies for breadmaking with unrefined wheat flour (UWF). Outlining breadmaking step, tested variable, types of UWF used and process strategy.