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Review

Challenges and Opportunities in Wheat Flour, Pasta, Bread, and Bakery Product Production Chains: A Systematic Review of Innovations and Improvement Strategies to Increase Sustainability, Productivity, and Product Quality

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Abstract: Pasta, bread, and bakery products are considered worldwide as essential foods for human nutrition. In particular, ancient wheats and whole wheat flours, despite being able to provide health benefits via bioactive compounds, present significant technological problems related to poorer dough rheological properties and final product characteristics. Moreover, both the food industry and consumers are increasingly sensitive to environmental impacts, highlighting the urgent need for sustainable innovations and improvement strategies, from cradle to grave, for the entire production chains, thus motivating this review. The aim of this review is to provide technological innovations and improvement strategies to increase the sustainability, productivity, and quality of flours, pasta, bread, and bakery products. This review is focused on the main operations of the production chains (i.e., wheat cultivation, wheat milling, dough processing, and, finally, the manufacturing of pasta, bread, and bakery products). To achieve this goal, the use of life-cycle assessment (LCA) analysis proved to be an effective tool that can be used, from early stages, for the development of eco-friendly improvement strategies. The correct management of the wheat cultivation stage was found to be essential since it represents the most impacting phase for the environment. Successively, particular attention needs to be paid to the milling process, the kneading phase, to breadmaking, and, finally, to the manufacturing of pasta. In this review, several specifically developed solutions for these essential phases were suggested. In conclusion, despite further investigations being necessary, this review provided several innovations and improvement strategies, using an approach "from cradle to grave", able to increase the sustainability, productivity, and final quality of flour, semolina, pasta, bread, and bakery products.

Keywords: optimization of wheat cultivation; wheat milling; dough kneading; bread baking; life-cycle assessment; environmental sustainability; innovations in agriculture; sustainable food productions; breadmaking; circular economy

1. Introduction

Wheat flour, pasta, bread, and bakery products are considered worldwide as essential for human nutrition since they are an important source of macronutrients (mainly carbohydrates and protein), micronutrients (vitamins and minerals), dietary fiber, and antioxidants [1,2]. Recently, a significant increase has been observed in consumer interest for bakery products able to provide health benefits via bioactive compounds [3,4]. This trend has led to the rediscovery of ancient wheats and to an increase in the use of whole wheat flours in the food industry [4–6]. With respect to ancient wheats, the revival of cultivation and use of several ancient local varieties has increased the sustainability of wheat cultivation and contributed to biodiversity protection [3,7,8]. Furthermore, it has permitted the development of a local micro-economy (continuously growing) which allows the local producers to differentiate their products and increase their remuneration using drivers which are easily recognized by consumers (e.g., “from local production” or “from circular economy”) [5]. Despite a more suitable nutritional profile [3], the ancient wheats are characterized by worse technological characteristics (e.g., poorer rheological properties of doughs and lower bread volume), compared to modern wheat cultivars.

Whole wheat flours, doughs, and bread are characterized, as the ancient wheats, by an improved nutritional content, poor dough rheological properties, and lower bread volume [6]. This is mainly due to the negative effects of bran and middlings, which introduce important rheological problems in doughs, in particular regarding the formation of the gluten network [6,9]. This negative effect is related to the capacity of arabinoxylans, inulin, and β-glucans (which are the principal non-starch polysaccharides present in wheat bran) to hold and bind water which should be destined to gluten forming proteins (i.e., gliadin and glutenin) [6,9]. The result is not fully hydrated gluten with excessive tenacity and low extensibility [4,6,9]. Li et al. (2014) [9] demonstrated the migration of water from the gluten network to arabinoxylans in whole wheat doughs through nuclear magnetic resonance, highlighting a significant reduction in water absorption, a deficit in gluten network formation, and, finally, a lower gas-retention capacity.

The literature review highlighted that the most noteworthy rheological problems related to the presence of bran, middlings, and germ in whole wheat dough are: a significant increase in dough tenacity (P) and viscosity [4,6]; a decrease in dough extensibility (L) [4,6]; a reduction of dough strength (W) [4,6]; and, finally, a significant rise in the curve configuration ratio (P/L) [4,6]. These negative effects are not limited to whole wheat dough. In fact, bread produced with whole wheat flour showed lower volume [6,10], higher crumb density [6,11], and increased crumb moisture [6,11]. Consequently, strategies to limit the negative effects of bran, middlings, and germ addition in whole wheat dough and bread and to improve the performance of ancient wheats are indispensable. However, these innovations and improvements must not only be effective and efficient. Given that our planet is in dreadful condition, exacerbated by the continuous increase of environmental pressures, these ameliorations need to be also eco-friendly and sustainable. In this direction, the literature review highlighted that the life-cycle assessment (LCA) seems to be a powerful tool able to improve and guide both innovations development and food industry ameliorations, with positive returns for the environment [5].

This highlights an urgent need for sustainable technological innovations and improvements, from cradle to grave, for the entire production chain, thus motivating this review. The aim of this review is to provide technological innovations and improvement strategies, to increase the sustainability, productivity, and quality of flours, pasta, bread, and bakery products. In order to provide technical solutions and significant ameliorations for farmers, food producers, and food industry, these improvements need to be focused on the main operations of the production chains (i.e., wheat cultivation, wheat milling, dough processing, and finally, the manufacturing of pasta, bread, and bakery products), considering the environmental advantages related to the use of alternative sources of protein and to the use of the powerful tool of life-cycle assessment (LCA).

2. What Is Meant by the Term Ancient Wheats?

Nowadays, the term ancient wheats divides the scientific world about several aspects, in particular regarding what is meant by this term. If a literal definition of the term was used, only ancestral or very old wheats might be included in the ancient wheats category. In this way, the only one that can be definable as “ancient” would be the *Triticum monococcum*, which was the first domesticated and cultivated species of the genus *Triticum* [12]. Furthermore, in various scientific publications, additional terms like “old wheat varieties” can be found. This might generate further confusion in both readers and researchers. However, does all this make sense? Does it make sense to define ancient wheats according to a temporal basis constructed on such an ancestral watershed? Definitely not [2,4,6,12]. In fact, highlighting the lack in the literature of an unambiguous definition of ancient wheats, with a clear and unequivocal meaning, an additional aim of this review is to provide a clarification on this important topic.

Some authors tried to define the boundary that separates ancient and modern wheats. In the literature, it is possible to find several proposals. The most "curious" classifications are based on historical dates and events; for example, in one of these, ancient wheats were defined as those varieties existing before the First World War, and modern wheats, instead, were those varieties developed after the First World War. These authors chose the First World War as the watershed as if it had been the First World War to produce the most significant changes in wheat. Based on what is reported in the literature, we can only disagree.

However, it is essential to correctly define what is meant with the term "ancient" through the definition of a specific temporal cut-off that has an unambiguous sense [2,4,6,12]. In particular, it is necessary to select the watershed that has determined the most significant changes in wheat characteristics. These changes must be so deep and significant to justify that after that moment the wheat will be completely different than before. It seems obvious that the most suitable cut-off is the green revolution [12]. Why the most suitable? Because the American plant breeders' approach of the 20th century has determined the most significant changes in wheat.

Precisely, before this approach, the large-sized varieties were considered as the most suitable and the ones capable of guaranteeing higher productivity, after which, instead, the most productive varieties became the semi-dwarf ones [12]. Before the green revolution, the varieties were characterized by higher adaptability and therefore by reduced input of fertilizers and chemicals [12]. Successively, on the contrary, the wheat varieties were characterized by lower adaptability and by the need for high inputs of fertilizers and chemicals [12]. Another important difference is related to the grain and straw yields, which ex-ante were high for straw (which, for example, had a great economic value in Italian agriculture) and good for grain, while ex-post became low for the straw and from high to very high for the grain [12]. Not to mention the significant differences in terms of "genetic erosion" and biodiversity protection between ancient and modern wheats (i.e., between plant breeding approaches prior and after the green revolution) [12,13]. In conclusion, all these aspects highlight that the deepest changes in the characteristics and in the techniques of wheat cultivation are due to the green revolution [12,13].

Therefore, which might be the correct definition of ancient wheats? Bordes et al. (2008) [7] provided a definition of modern wheats by defining them as those cultivars developed after 1960. Unlike these authors, who use this date as the watershed that divides ancient and modern varieties, it is preferable to use the year 1961, since it corresponds to the release date of the first wheat cultivar definable as semi-dwarf (i.e., Gaines 61) released by Orville Vogel [12]. This clarification, which may appear to be punctilious, allows instead to include in the ancient wheats category all the varieties released in the year 1960, such as the Italian cultivar *Sieve*, which otherwise would risk the exclusion from this classification.

In conclusion, a proper definition of ancient wheats might be "the term ancient wheats refers to all those wheat varieties (genus *Triticum*) not subjected to intensive genetic improvement programs and characterized by an origin prior to the year 1961" [12]. This new and precise definition includes spelt (*Triticum spelta*, *Triticum monococcum*, and *Triticum dicoccum*) in ancient wheats. Nonetheless, pseudocereals like amaranth, buckwheat, quinoa, and many others are obviously not included in the ancient wheats category, since they are not part of the genus *Triticum*. This new definition is supported by several authors in literature [3,7,8,14–16] and by earlier work [2,4,6,12,13,16]. Finally, particularly in crisis situations like the actual COVID-19 pandemic, the revival of the cultivation and use of ancient wheats and the strengthening of short food supply chains and local productions might be essential to take a step forward in the safeguarding of the right of access to healthy and sustainable food [13,17].

3. Search Strategy

The literature review used one search strings to explore three databases: Science Direct, PubMed, and the Web of Science. The search string used was as follows:

- (bakery products OR pasta) AND sustainability

The literature review was performed between December 2020 and January 2021. No language, time, or publication status restrictions were imposed, and duplicates were excluded from the final obtained results. The initial results were screened by reading the title and abstract (the articles that only consisted of an abstract and/or index, were excluded at this point), and successively by a full-text reading. All the articles concerning innovations and improvement strategies able to improve the sustainability, productivity, and quality of wheat, flours, semolina, pasta, bread, and bakery products were included in this review, while those that were not relevant, since they did not mainly focus on advance in sustainability, were discarded. For each type of database, a flow chart was produced to summarize the obtained results (Figure 1).

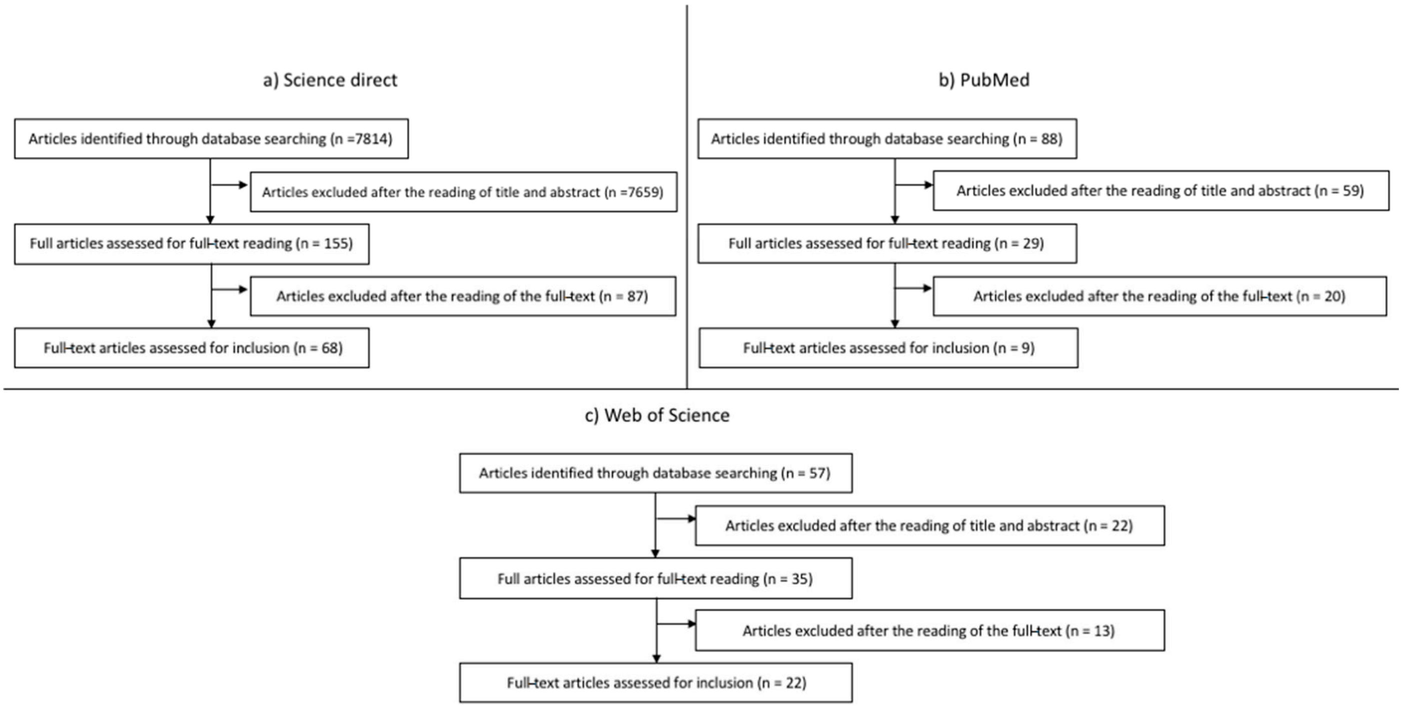

Figure 1. Flow charts pertaining to the selection process of papers on Science direct (**a**), PubMed (**b**), and the Web of Science (**c**), summarizing the obtained results of the systematic literature review.

4. Main Findings

Results of the Systematic Review

A total of 7959 initial items were obtained. Following the application of the selection criteria described in the search strategy (Section 3), after abstracts and full-text reading, 99 texts were selected. Duplicates that had been included twice (or thrice), because they resulted from the three databases, were also removed, leaving a final total of 87 items. Figure 1 summarizes, in the form of flow charts, the selection process, which is consistent with the PRISMA statement [18]. Figure 1a–c show the results for Science Direct, PubMed, and the Web of Science, respectively.

5. Wheat Cultivation and Sustainable Agriculture

Innovations and Improvements in Wheat Cultivation

The correct management of the wheat cultivation stage is essential to obtain wheat flour or wheat semolina, pasta, bread, and bakery products with suitable characteristics. The growing need for increased yield, protein and gluten content, and remunerations, has led to the rise, to an unsustainable level for the environment, of the use of chemical fertilizers, pesticides, and fungicides. This intensification of agronomical treatments is producing good results on the final quality of the products but detrimental effects on the environment. In fact, according to several authors [17,19,20], wheat cultivation is the most impacting phase in the production chains of pasta, bread, and bakery products. For this reason, the innovations and improvement strategies to improve the wheat cultivation stage must be not only effective but also environmentally friendly and sustainable.

With respect to fungicides, Gao et al. (2020) [21] proposed an interesting strategy to substitute chemical fungicides to prevent *Fusarium* head blight (caused by the fungal pathogen *Fusarium graminearum*) with a natural fungicide, obtained from wheat straw pyrolysis, named wheat straw vinegar. Since chemical fungicides have significant environmental impacts and, moreover, are becoming less effective, the use of wheat straw vinegar seems to be a more effective, low-cost, and natural solution [21]. The results of Gao et al. (2020) [21] showed that the application of wheat straw vinegar, diluted 200-fold, significantly decreased the wheat infection rate and deoxynivalenol content by 66% and 69%, respectively. This natural fungicide, given its effectiveness, seems to be very interesting since it is an eco-friendly product that may additionally increase farmers' income by reducing the fungicide costs [21].

Regarding chemical fertilizers, some authors have suggested interesting improvement strategies to significantly reduce the environmental impact by replacing them with manure [22] or with natural fertilizers obtained from by-products of other production chains [23,24]. The use of manure, and the total or partial replacement of fertilizer with it, is a traditional approach that is recently back to the fore. Li et al. (2020) [22] highlighted the potentiality of substituting 50% of mineral-N with liquid and solid manure from an LCA point of view. In particular, [22] highlighted that the economic analysis showed a profit increase of 17.2% and 19.1% using solid and liquid manure, respectively. Moreover, the environmental impacts at the endpoint level decreased by 24.6% and 37.9% using solid and liquid manure, respectively.

However, despite that the partial or total replacement of chemical fertilizers with manure or with natural fertilizers obtained from by-products seems a very interesting strategy, it is not applicable in very large production organizations with an intensive character. In these cases, in order to obtain both a significant reduction of environmental impacts and the improvement of wheat quality, it is necessary to follow the improvement strategies suggested by Recchia et al. (2019) [17]. In particular, it is essential to identify the minimum amount of fertilizers that guarantees suitable yields, flour and semolina quality, and suitable pasta, bread, and bakery product characteristics. Moreover, where applicable, the partial or total conversion to organic farming could be an interesting additional improvement strategy.

In this direction, Guerrini et al. (2020) [16] assessed the effect of seeding density and of nitrogen and sulfur fertilization on wheat kernel composition, flour quality, dough rheology, and bread characteristics. In particular, two seeding densities (90 and 180 kg seed/hectare), three nitrogen fertilization levels (35, 80, and 135 kg nitrogen/hectare), and two sulfur fertilization treatments (0 and 6.4 kg sulfur/hectare) were tested for three ancient wheat cultivars, namely *Andriolo*, *Sieve*, and *Verna* [16]. Kernel yield was significantly and positively related to nitrogen fertilization [16]. However, differences were found to be related to N135, while no significant differences were found for N35 and N80 [16]. On the contrary, seeding density and sulfur treatment did not significantly affect the kernel yield. Kernel nitrogen content was significantly increased by N135, while no significant differences were found for the other fertilization levels [16]. Moreover, results also indicate a positive interaction between sulfur and nitrogen fertilization in increasing the nitrogen accumulation in the kernel [16]. A significant increase in kernel total protein content was found by the authors in the case of nitrogen fertilization with 135 kg of nitrogen/hectare [16].

On the contrary, the nitrogen fertilization levels had little effect on the protein composition of the tested ancient wheat cultivars [16]. Nitrogen fertilization significantly affected albumin content, which increased slightly (from 1.81% to 2.2%) but only with the N135 treatment [16]. Furthermore, N fertilization significantly affected total gluten, which increased by 18.2% passing from N35 to N135 [16]. Results also indicate that the sulfur treatment deeply changed the protein composition [16]. In particular, the sulfur treatment significantly decreased albumin, globulin, and gliadin fractions, while it significantly increased glutenin (from 4.23% to 6.07%) [16]. Moreover, total gluten significantly increased by about 12.3% [16]. The positive effect of sulfur treatment is mainly due to its capacity to enhance the activity of enzymes such as nitrate reductase and glutamine synthetase in flag leaves, thereby affecting the protein pattern composition [16].

Agronomical treatments significantly affected dough rheology and, particularly, dough tenacity (P), dough extensibility (L), and deformation energy (W) [16]. P increased slightly with sulfur and nitrogen fertilization, while L was increased by nitrogen fertilization [16]. W increased by 34% with nitrogen fertilization (from N35 to N135), compared to roughly 14% with the sulfur treatment [16]. This improvement in dough rheological parameters, especially for the weak flours from ancient wheats, must be considered very helpful for the breadmaking process. In particular, nitrogen fertilization increased the *Verna* W values from 48 to 67 $\times$ 10^{-4} J, the *Andriolo* W values from 49 to 54 $\times$ 10^{-4} J, and the *Sieve* W values from 78 to 111 $\times$ 10^{-4} J [16]. Moreover, both W and glutenin were found to be significantly affected by the sulfur treatment [16].

Finally, with respect to bread quality, nitrogen fertilization produced a significant decrease in bread crumb density [16]. Furthermore, nitrogen fertilization also affected crumb texture. In particular, it increased crumb springiness and crumb cohesiveness by 17% and 32%, respectively, in the case of N135 [16]. Nitrogen fertilization seems to be able to improve both these parameters, resulting in an improvement of bread crumb texture [16]. Despite sulfur treatment proving to be able to affect the gluten quantity, it did not significantly affect bread characteristics [16]. This is probably linked to the observed decrease in the gliadin fraction and also to the fact that a proper ratio between gliadins and glutenins is needed to obtain optimal bread [16]. In conclusion, Guerrini et al. (2020) [16] highlighted that it is possible to improve wheat kernels, flours, dough rheological properties, and bread characteristics via the correct management of agronomical treatments, in particular, using a lower amount of nitrogen fertilizers (N135) with respect to those currently used in agriculture (up to 250–300 kg nitrogen/hectare).

6. Innovations and Improvements in Wheat Milling

6.1. The Importance of Wheat Conditioning before Milling

The wheat milling process significantly affects flour quality and bread characteristics [25–27]. For this reason, the correct management of this unit operation is essential to obtain final products with suitable characteristics [25–27]. In this direction, for optimal conservation of wheat kernels during storage, in the post-harvesting phase, it is necessary to reduce significantly the moisture to a very low content (lower than 10%) [28]. In order to optimize the milling process, after storage, it is necessary to rehydrate the wheat kernels to the optimal level using a process called conditioning [29]. The final moisture content of the conditioned wheat kernels could vary according to the type of wheat (differences between *Triticum aestivum* or *durum* and based on the specific cultivar) and according to the type of product [29]. However, the correct management of wheat conditioning and milling could both improve flour, semolina, dough, pasta, and bread quality and reduce the environmental impacts related to energy and water consumption [17].

Cappelli et al. (2020) [29] assessed differences in flour yield, flour particle size, milling efficiency, dough rheology, and bread characteristics as a function of four moisture levels used in the wheat conditioning stage (i.e., 11%, 13%, 15%, and 17%) for an ancient *Triticum aestivum* cultivar named Verna. The results clearly show that wheat conditioning is a powerful tool for the improvement of breadmaking and the milling process, respectively [29]. Conditioning affected almost all of the tested variables (mill operative parameters and consumption, flour particle size, dough rheology, and bread characteristics) [29]. In particular, the decrease in the P/L index found for the tested weak flours with the increase of wheat moisture is very interesting [29]. The results of rheological and breadmaking tests carried out by Cappelli et al. (2020) [29] clearly highlight that the best performance was obtained by flours milled between 13% and 15% of wheat moisture. Therefore, although flours obtained from wheat kernels at 15% moisture had lower P/L values and slightly higher bread volume compared to 13% moisture, the latter percentage seems to be the best compromise between milling optimization (higher yields and lower consumption) and dough and bread performance [29]. At 13%, dough stability and dough strength (W) were higher, while bread volume and P/L were very similar to 15% [29]. At the same time, using wheat kernels conditioned at 13% of moisture (instead of 15%) allows one, referring to large production scales, to save large amounts of water and energy, highlighting a significant reduction of the environmental impacts related to conditioning and milling phases, with potential benefit on LCA assessment [17,19,20]. In conclusion, the correct management of the wheat conditioning stage seems to be a very interesting eco-friendly improvement strategy.

6.2. Innovations and Improvements in Stone Milling

Stone mill is the oldest and the most traditional form of attrition mill used to produce flour [27]. Moreover, it is the easiest way to produce whole wheat flour [27]. This type of mill is still preferred by many millers, bakers, organic food producers, and consumers due to the widespread opinion that stone-milled flours have a better nutritional profile compared to roller-milled flours [27,30]. Furthermore, the use of a stone mill to produce wheat flours (in particular for unrefined flours) ensures a marketing advantage and the perception, by consumers, of more traditional products [27,30]. These advantages have led to a significant increase in the use of whole wheat flours in both the food industry and retail markets [4–6,27,30]. Moreover, the increased use of whole wheat flours produced positive effects on consumer health and on the environment due to the reuse of the by-products of the milling process like bran and middlings, which are rich in healthy nutritional compounds [17,19,20]. Despite these advantages, the stone mill needs innovations and improvement strategies aimed to improve the efficacy, efficiency, and sustainability of this traditional milling machine.

The most interesting and eco-friendly improvement strategies for the stone mill are focused on the reduction of the specific grinding energy via wheat crushing before milling [31], the rediscovery and modernization of traditional stone watermills [30], and last but not least, the correct management of wheat conditioning before milling, described in Section 6.1. With respect to the improvement strategy proposed by Dziki (2008) [31], it seems very interesting to reduce the milling energy consumption by crushing the wheat kernels before milling. The results suggest that crushing considerably decreased the grinding energy requirements for both soft and hard cultivars, with a reduction in the average particle size distribution of the grounded material in soft wheat [27,31]. Moreover, this strategy could reduce significantly the impacts related to the consumption in the milling phase, with potential benefit for the environment and for the production costs [17,19,20].

Another interesting strategy for improving stone milling is linked to the rediscovery and modernization of traditional stone watermills [27,30]. Di Silvestro et al. (2014) [30] highlighted that stone-milled flours obtained using a traditional watermill, keeping the temperature under 30 °C, differs significantly from the flour obtained using a modern stone mill (at a temperature of around 60 °C). In particular, the authors highlighted that the content of total starch, polyphenols, and flavonoids was significantly higher in the flour obtained from the traditional stone watermill [30]. These results confirm the potentialities of rediscovering and modernizing traditional stone watermills as a way to increase nutraceutical content in flours and bakery products [27,30]. Moreover, this strategy shows additional advantages like lower environmental impacts (due to the use of green energy) [27], improvements to the landscape and attractiveness of rural areas [27], and a potential marketing advantage related to the promotion of tradition and craftsmanship [27].

6.3. Innovations and Improvements in Roller Milling

According to the literature and to the evolution in milling techniques, the roller mill clearly appears as the most advanced milling technology for wheat kernel processing [27]. The literature review confirms several advantages of the roller mill like higher efficiency and flexibility [27], lower heat generation compared to the stone mill (due to the presence of cooling systems) [27], and the capability to separate bran and middlings at the end of the milling process, extending the shelf life of whole wheat flours without influencing the flour's functional properties [27]. However, even a machine as technologically advanced as the roller mill needs innovations and improvement strategies to improve its efficacy, efficiency, and sustainability.

In this sense, the most interesting environment-friendly improvement strategies reported in the literature are wheat debranning before milling combined with the stabilization of bran, middlings, and germ [27,32–37]; development and improvement of automatic and adaptive mill plants [27,38]; use of the break, sizing, and reduction systems of the roller mill for improving milling technology, flour differentiation, and reducing the impacts [39]; and the correct management of wheat conditioning before milling, as described in Section 6.1.

With respect to wheat debranning before milling, the literature review demonstrates that this process, both in *aestivum* and *durum* wheat milling, is able to increase milling capacity and yields [27,32–34], improve semolina quality [27,32–34], facilitates the separation of bran, middlings, and germ in the first break enhancing flour quality [27,32–34], and increase the nutritional content of by-products (in particular regarding mineral, vitamin, and polyphenol content) which are even more promising in the applications as novel food ingredients [27,32–34]. Debranning became even more interesting in the case of bran, middlings, and germ stabilization using new technologies like light steam treatments [35], microwaves [36], and infrared radiation [37], before its reinsertion into the refined flour, increasing whole wheat flour storage time and the nutritional characteristics of whole wheat bread [27]. In conclusion, the combination of debranning and stabilization of non-endospermic components using eco-friendly and innovative technologies, like infrared radiation, is able to increase the health benefits associated with whole wheat products and to extend the whole wheat flour shelf life via enzyme inhibition, leading to an increase in the reuse of by-products in the wheat flour production chain, with positive effects on productivity, remunerations, and the environment.

Another interesting strategy to improve roller milling, from both a productivity and sustainability point of view, regards the development and improvement of automatic and adaptive mill plants [27]. In particular, with respect to large industrial scale mills, the development and use of specific programmable logic controllers, automation units, and adaptive machines able to change, case-by-case, several parameters like the correct amount of water provided during the conditioning stage, differential ratios, wheat feed rate, the distance between rollers, and other essential milling parameters could lead to increased productivity, higher flour and semolina quality, lower energy demand, and to the reduction of by-products and consumption, with an additional benefit for the environment [27]. In this direction, particular attention should be paid to the development of usable machines in the whole mill plant [38] in order to avoid problems related to reliability, productivity, and product quality.

Last but not least, Cappelli et al. (2020) [39] suggested an improvement strategy for the roller mill based on the use of the break, sizing, and reduction systems for the flour differentiation and the reduction of the impacts [39]. The roller mill is divided into three systems: the break system, which separates endosperm from bran and germ by opening and scraping off the bran from the kernel [27]; the sizing system, which continues the removal action of bran, middlings, and germ, cleaning the endosperm before further processing [27]; and, finally, the reduction system, which uses smooth and larger rolls to mill the endosperm into flour (meeting defined refinement standards established upstream) [27]. Therefore, the improvement strategy proposed by Cappelli et al. (2020) [39] assessed if flours recovered from the break system, and from the sizing and reduction systems, differ between them and from the control flour (obtained at the end of the complete standard milling process). The authors tested two *Triticum aestivum* cultivars: an ancient wheat (*Conte Marzotto*) and a modern wheat (*Nogal*).

The results reported by Cappelli et al. (2020) [39] highlighted that the different roller mill systems are able to significantly influence flour composition, dough rheological properties, and bread characteristics. In particular, break system flours had lower total dietary fiber content and higher starch content [39]. In contrast, flours recovered by the sizing and reduction systems were characterized by higher fiber and phenolic content and lower starch content [39]. With respect to dough rheological properties, break system flours showed higher dough stability compared to the control, highlighting improved rheological properties [39]. Furthermore, in the case of the *Nogal* cultivar, higher bread specific volume was found using the break system flour [39].

The findings reported by Cappelli et al. (2020) [39] clearly show that flours obtained by the break system have improved rheological performances and bread characteristics. On the other hand, flours recovered from the sizing and reduction systems have a more interesting nutritional profile (higher fiber and phenolic content) [39]. In conclusion, the suggested strategy makes it possible, starting from the same batch of wheat, to use the milling process to modulate the characteristics of the obtained flours, which might be destined to different markets, with no additional expenditure, no lengthening of milling time, better product differentiation, and the expansion of the potential clientele [39]. Finally, this improvement strategy allows to produce two different flours using one single milling process, highlighting important reduction of energy consumption and the environmental impacts.

7. Progress in Dough Kneading and Breadmaking

7.1. Innovations and Improvements in Dough Kneading

In addition to the milling process, which, according to the literature, is the most impacting phase on flour quality, dough rheology, and bread characteristics [25–27,29,32,39], the kneading phase plays a key role in ensuring suitable dough rheology and bread characteristics [40]. The current progress in dough kneading was carefully summarized in earlier work [40]. As highlighted by Cappelli et al. (2020) [40], in order to correctly manage the kneading phase, it is necessary to start from the correct management of the following key parameters: kneading time, which must be identified precisely in order to avoid over- and under-mixing [40]; dough temperature and mixing speed, which need to be managed carefully to avoid dough warming and excessive weakening [40]; water temperature, water absorption, and water content, in order to obtain the optimal dough rheology and consistency, avoiding undesired softening [40]; and last but not least, the dough aeration, to ensure proper oven spring during baking and optimal characteristics of the bread crumb [40].

As highlighted for the milling process in Section 6, the kneading process needs innovations and improvement strategies that must never lose sight of the essential aspect of environmental sustainability. In this direction, the most interesting eco-friendly improvement strategies for the kneading phase are controlling the dough temperature during kneading using alternative, eco-sustainable, refrigerants [40–42]; use of organic acids, recovered from by-products, to improve dough rheology and bread characteristics [40,43]; correct management of the water addition during kneading [4,40]; and, finally, development of automatic and adaptive kneading machines able to optimize the kneading process [40,44].

With respect to the control of dough temperature during kneading, it is essential to keep the dough temperature under 27 °C, above which the dough becomes sticky, with detrimental effects also on bread characteristics [40]. Moreover, Quayson et al. (2016) [41] found that keeping a low dough temperature (lower than 27 °C) increase and strengthen noncovalent interactions, improving protein network formation and bread characteristics. However, keeping a low temperature during kneading is an expensive technique both in terms of cost/energy consumption and from the environmental point of view. Nowadays, water jackets and refrigerants are used to maintain a low dough temperature during kneading, without particular attention to consumption and the environment [40,41]. Cappelli et al. (2020) [42], instead, proposed a more sustainable strategy to manage dough temperature based on carbonic snow addition during kneading. The authors tested the addition of six levels (from 0% to 10%) of carbonic snow to dough during kneading, as an alternative refrigerant [42]. The results show the effectiveness of the technique for dough thermoregulation (rapidly decreased dough temperature, in both rheological and bread-making tests) and for improving bread characteristics (increased bread specific volume and loaf height) [42]. Further advantages include minimal additional expenditure, higher cooling power (compared to other refrigerants), no increase in total water content, and no chemical or toxic residuals, with positive effects also on the environment [42].

The addition of organic acids during kneading proved to be another interesting improvement strategy, in particular in the case of their production from by-products and waste substrates [40,43]. Su et al. (2019) [43] tested the addition of several organic acids during kneading in order to extend the shelf life and improve bread characteristics. The improvement strategy suggested by Su et al. (2019) [43] proved to be effective (in particular with the addition of 0.3% of citric acid) in increasing dough elasticity and bread specific volume, decreasing moisture content, pH, and textural hardness, enhancing yeast activity, extending bread shelf life, and delaying starch retrogradation. However, excessive acid concentrations might overly weaken the gluten network, impairing its gas retention capability [40,43].

The correct and responsible management of water in bread and bakery product production chains is essential both for obtaining optimal characteristics in the final products and for safeguarding the environment. Water is a precious resource that needs to be used responsibly, avoiding waste. Moreover, it is well known, both from theory and in everyday practice, that adding too much water during kneading generates a soft and sticky dough [4,40]. At the same time, dough with moisture content below the optimal water absorption of the flour will be harder to knead and require more work in the production line [4,40]. This observation is supported by the results of Cappelli et al. (2018) [4], which highlight that increasing the total water content in dough increases dough extensibility (L) and the index of swelling (G). Moreover, it decreases dough tenacity (P), deformation energy (W), and the curve configuration ratio (P/L) [4]. On the contrary, a poorly hydrated dough shows increases in P, W, and P/L, and a decrease in G and L [4]. In conclusion, the correct dosage of water is essential to obtain products with optimal characteristics and to reduce environmental pressure related to water and energy consumption. Moreover, a further interesting improvement strategy, which needs additional investigations, might regard the optimal modality of water addition during kneading [40].

Last but not least, the development of automatic and adaptive kneading machines, able to measure kneading progress in real time, could significantly improve either dough rheology or bread characteristics, reducing the energy demand and the environmental pressures [40,44]. The first step in this direction was taken by Aljaafreh, (2017) [44] who proposed a novel design for an intelligent process controller to automate the kneading process. The design is based on current sensing, and on-line learning through reinforcement, using operator input [40,44]. The system developed by the author might represent a low-cost solution to automating production equipment that currently is managed manually. Moreover, it might be considered as a first step toward the development, in the future, of more efficient and structured automatic and adaptive kneading machines. In particular, these innovative kneading machines could optimize kneading parameters (i.e., kneading time, kneading speed, dough temperature, etc.), reducing energy consumption and environmental impacts.

7.2. Use of Alternative Sources of Protein in Breadmaking

Another interesting improvement strategy, able to boost dough rheology, bread characteristics, and environmental protection, regards the use, in the breadmaking process, of alternative sources of protein [2,40]. To this effect, several authors have tested the addition of conventional protein from vegetal sources, like soya and potato, and from animal founts, e.g., egg albumen, dairy products, and many others, to improve dough rheology and bread characteristics, with interesting results [45–47]. Nevertheless, these protein sources do not show a significant reduction of environmental pressures. Both the food industry and consumers are increasingly sensitive to environmental impacts [2]. This has increased significantly the research efforts for alternative, cheaper, and more sustainable sources of protein. In this context, insects and legumes seem to be the best opportunities in breadmaking [48–56].

Legumes are an interesting source of protein that has been widely examined in the literature. They contain high amounts of essential amino acids such as lysine, threonine, valine, and tryptophan [48–51]. Unlike legumes, cereals are rich in sulfur amino acids, and their combination creates protein with high biological value [48–51]. In particular, chickpeas are rich in omega-3 and lecithin, highlighting positive effects on human health [50]. Moreover, chickpea cultivation reduces the use of nitrogen fertilizers due to their nitrogen-fixing capacity, with positive impacts on sustainable agriculture and on subsequent crops [50]. In relation to the use of chickpea in breadmaking, the literature review did not highlight only positive effects on the environment. Galli et al. (2020) [51] highlighted the interesting capacity of indigenous *Weissella confusa*, isolated from chickpea sourdough, to produce, in situ, bacterial exopolysaccharides. Moreover, Cappelli et al. (2020) [50] found that the substitution with 5% of chickpea flour proved to be an excellent technological improver for ancient wheat flour. In particular, this substitution significantly increased dough stability and extensibility, reduced P/L, and, finally, significantly increased bread specific volume compared to the control (100% wheat) [50].

Nowadays, between the alternative sources of protein, insects are one of the most investigated founts for potential application in the food industry. The introduction of insect-based food could lead to several positive advantages: first, a significant increase in high-quality protein and nutrients [50,52–56]; second, higher feed conversion efficiency and reduced rearing costs [50,54]; third, higher reproduction rate [50,54]; and, finally, a significant reduction of water consumption and Greenhouse gases (GHG) emissions [50,54]. Despite these promising benefits, neophobia, disgust, and non-acceptance represent the major obstacles for the consumption of insects as food in countries that are not familiar with entomophagy. However, these barriers could be broken by inserting insects into products in an invisible form, such as flour [50,52–56].

Several authors have investigated the use of insect flours for the production of bread [50,53,56] and snacks [52,55]. In both products, the use of insect flours seems to significantly improve the nutritional composition (in particular increased protein and mineral content) and, in some cases, to improve dough rheology [50,52–56]. However, not significant improvements, from a technological point of view, were underlined by the authors on the final product characteristics, highlighting that insects cannot be considered as technological improvers. In particular, it seems that the improvement effects linked to the addition or substitution with insect flours in breadmaking are limited to nutritional content, dough rheology, and the environment. Moreover, the use of insect flours introduces new and significant safety risks in the wheat flour and bakery product production chains. Regarding the safety aspects of insect flours, the microbiological, chemical, physical, and allergenic risks were summarized in earlier work [54]. Despite *Salmonella* spp. and *Listeria* monocytogenes were not detected in the studies examined in the earlier literature review [54], insects are not safe and free from these pathogens, and therefore particular attention needs to be paid to the microbiological risk. In conclusion, notwithstanding that chemical, physical, and allergenic risks are hazardous too, insects seem to represent one of the most interesting alternative protein sources, which obviously needs further investigation.

7.3. Use of Life-Cycle Assessment to Increase the Sustainability of Pasta, Bread, and Bakery Products

As highlighted in Section 5, the tool of LCA could be very powerful in identifying the most impacting phases in the production chains of pasta, bread, and bakery products. Moreover, LCA could drive the development of eco-friendly innovations and improvement strategies for these production chains [17]. As reported by Recchia et al. (2019) [17], wheat cultivation is the most impacting phase, in terms of CO_2 eq emissions in the pasta production chain. A strategy able to reduce such emissions is represented by the organic farming approach, with the additional opportunity of using by-products as fertilizers [17]. These findings are supported by other authors for the bread and bakery product production chains [19,57–62]. In particular, Chiriacò et al. (2017) [57] highlighted a significant reduction of CO_2 eq emissions in the case of organic farming for bread and bakery product production chains, with a significant reduction of environmental pressures. Moreover, the emissions related to wheat cultivation could be even more lowered if by-products (from other production chains) were used as fertilizers, using the allocation method in the LCA assessment.

Unfortunately, sometimes, organic farming is not applicable. In this case, in order to obtain both a significant reduction of environmental impacts and the improvement of wheat quality, it is necessary to identify the minimum amount of fertilizers that guarantees suitable yields, flour and semolina quality, and suitable pasta, bread, and bakery product characteristics. Considering the subsequent production phases in pasta, bread, and bakery product manufacturing (i.e., dough kneading, bread baking, and pasta production), the introduction of new technologies, such as microwaves, infrared radiations, and pulsed electric fields, and the use of sustainable energy in food production and transportation, seems to be the most interesting and sustainable improvement strategies [17,59,61]. With respect to the high-quality pasta production process, the drying phase is the most critical in terms of energy consumption, environmental impacts, and expenditure, since Italian traditional high-quality pasta production is based on a low-temperature long-time (LTLT) drying process, which is recognized as a quality parameter by consumers [17]. Particularly in this case, the introduction of new technologies and the use of sustainable energy sources in food production and transportation appear to be particularly needed [17,59,61].

In order to propose improvement strategies able to increase the quality of traditional pasta, bread, and bakery products, reducing significantly the environmental impacts of these local productions, it is essential that small production companies are independent, carrying out in-house cultivation, milling, and production of pasta, bread, and bakery products. This is essential to be competitive, to ensure the quality of final products, and finally, to avoid additional (and worthless) environmental impacts related to distant transports from field to mill (for wheat kernels) and from mill to the production plant (for flour). Last but not least, the emissions related to the cooking of pasta are discussed. In this direction, Fusi et al. (2016) [63] highlighted that the use of pasta cookers in restaurants allows to save up to 60% of energy and 38% of water, with positive effects on the environment. For the home cooking of pasta, the most interesting and eco-friendly improvement strategy was proposed by Cimini and Moresi (2017) [64]. A substantial reduction of carbon footprint and operating costs in the domestic cooking of pasta can be obtained by using an induction hob and a pan covered by a lid: the power rate should be initially set to the maximum level to make the cooking water boil faster, and then to the minimum level necessary to keep the water temperature constant, allowing starch gelatinization [64]. This strategy led to a carbon footprint reduction of up to 670 g CO_2 eq emissions and to a reduction of operating cost of EUR 0.47 per kg of pasta [64].

8. Conclusions and Future Trends

This review highlighted several innovations and improvement strategies to increase the sustainability, productivity, and quality of flour, semolina, pasta, bread, and bakery products. Additionally, Section 2 provided a definition of ancient wheats which is lacking in the literature. In order to suggest technical solutions and significant ameliorations for farmers, food producers, and food industry, this review focused on the main operations of the production chains (i.e., wheat cultivation, wheat milling, dough processing, and finally, the manufacturing of pasta, bread, and bakery products), considering the effectiveness of the suggested improvement strategies in reducing the environmental pressures. To achieve this goal, the use of LCA analysis, using experimentally collected data for describing extensively the specific case study, seems to be a fundamental tool that needs to be used as a starting point for the development of all improvement strategies.

First, it is necessary to correctly manage the wheat cultivation stage, since it represents the most impacting phase for the environment. Wheat cultivation could be optimized by avoiding (or significantly reducing) the use of pesticides, replacing chemical fungicides with natural ones (like the wheat straw vinegar), using organic farming, and, finally, identifying the minimum amount of fertilizers that guarantees a significant reduction of environmental pressures ensuring suitable yields, flour and semolina quality, and suitable pasta, bread, and bakery product characteristics. Successively, particular attention needs to be paid to the milling process. For both stone and roller mills, the correct management of wheat conditioning showed promising results in improving flour suitability to breadmaking and in reducing water and energy consumption, with positive effects on the environment. Wheat crushing before milling and the rediscovery and modernization of traditional stone watermills are the most interesting, eco-friendly improvement strategies for the stone mill. On the other hand, wheat debranning before milling combined with the stabilization of bran, middlings, and germ, the development and improvement of automatic and adaptive mill plants, and the use of the break, sizing, and reduction systems for flour differentiation seems to be the most interesting improvement strategy for the roller mill.

With respect to kneading and breadmaking, the control of the dough temperature during mixing using alternative, eco-sustainable refrigerants, the correct management of the water addition, the development of automatic and adaptive kneading machines, and the use of sustainable alternative protein sources, like insects and legumes, showed very promising results in improving the final quality of the products and in reducing environmental impacts. In particular, substitutions with 5% of chickpea flours proved to be an excellent technological improver for ancient wheat flour. This is not the case for insect flours, which were able to reduce environmental pressures and improve the nutritional content and, in some cases, the dough rheology but not the final bread characteristics (in particular bread specific volume). However, Carcea (2020) highlighted very interesting results for the technological improvement of *durum* wheat pasta using cricket flours [65]. Other interesting improvement strategies in the pasta production process, able to reduce environmental pressures, are linked to the introduction of new technologies in the drying process of pasta and to the use of sustainable energy sources.

In conclusion, despite further investigations being necessary, this review provided several innovations and improvement strategies, using the "from cradle to grave" approach, which proved to be able to increase the sustainability, productivity, and final quality of flour, semolina, pasta, bread, and bakery products.

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Abbreviations

P, dough tenacity; L, dough extensibility; W, deformation energy; P/L, curve configuration ratio; LCA, life-cycle assessment.

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