**Supplementary Table 1** Summary of wheat flour substitutes and their influences on dough rheological and bread properties

| Source material | Formulation type | Replacement level (% flour weight) | Influences on dough properties | Influences on sensory and nutritional attributes of bread | References |
|-----------------|------------------|-----------------------------------|-------------------------------|----------------------------------------------------------|------------|
| **Legume-based** |                  |                                   |                               |                                                          |            |
| Chickpea        | Flour            | 5−30%                             | -Increased water absorption and dough development time.  
                 |                  |                                   | -Decreased dough extensibility and resistance to deformation.  
                 |                  |                                   | -Above 10% replacement leading to sticky dough, higher onset and peak gelatinization temperatures, and higher elastic and loss moduli. | -Increased protein digestibility and improved amino acid profiles compared to wheat control.  
                 |                  |                                   |                               | -Above 10% substitution leading to reduced specific volume and increased hardness, higher densities, and darker crumb.  
                 |                  |                                   |                               | -Textural quality of chickpea-wheat bread improved by adding 1% emulsifier. | Cappelli et al. 2020;  
                 |                  |                                   |                               |                                                           | Guardado-Félix et al. 2020;  
                 |                  |                                   |                               |                                                           | Kotsiou et al. 2022;  
                 |                  |                                   |                               |                                                           | Mohammed et al. 2012;  
                 |                  |                                   |                               |                                                           | Yamsaengsung et al. 2010 |
| Chickpea        | Protein concentrate | 20−30%                           | -Increased dough mixing time. | -Decreased bread specific volume and denser crumb structure.  
                 |                  |                                   |                               | -Fermentation leading to reduced raffinose, stachyose, and verbascose contents by 75.4%, 97.6%, and 90.0%. | Xing et al. 2021 |
| Lentil          | Flour            | 5−24%                             | -Reduced dough tenacity, extensibility and strength. | -Increased contents of lysine-rich proteins, dietary fiber, and phenolic compounds.  
                 |                  |                                   |                               | -Enhanced antioxidant potential compared to wheat control.  
                 |                  |                                   |                               | -Above 10% substitution reducing specific volume with increased density.  
                 |                  |                                   |                               | -Aroma profile and specific volume improved and crumb hardness decreased by fermentation with in situ dextran production. | Gallo et al. 2022;  
                 |                  |                                   |                               |                                                           | Perri et al. 2021;  
                 |                  |                                   |                               |                                                           | Turfani et al. 2017 |
| Faba bean       | Flour            | 25−40%                            | Reduced dough consistency, gluten strength value, resistance to extension and dough strength. | -Increased contents of proteins, minerals, ash, total phenolic compounds, condensed tannins, and antioxidant potential. | Coda et al. 2017;  
                 |                  |                                   |                               |                                                           | Benayad et al. 2021;  
                 |                  |                                   |                               |                                                           | Wang et al. 2018 |
| Ingredient          | Type                  | Range (%) | Changes                                                                 | References                                                                 | Notes |
|---------------------|-----------------------|-----------|-------------------------------------------------------------------------|---------------------------------------------------------------------------|-------|
| Lupin               | Flour                 | 3–20%     | - Protein digestibility and free amino acid profile increased, and predicted glycemic index decreased by fermentation. | Atudorei et al. 2022; Klupsaite et al. 2017; Villarino et al. 2015; Yaver and Bilgiçi 2021 |       |
|                     |                       |           | - Specific volume and crumb softness increased by fermentation with in situ dextran production. |                                                                           |       |
|                     |                       |           | - Increased protein, dietary fiber, phenolic, and carotenoid contents, and higher antioxidant potential. |                                                                           |       |
|                     |                       |           | - Increased protein digestibility and improved amino acid profile. |                                                                           |       |
|                     |                       |           | - Decreased in vitro glycemic index. |                                                                           |       |
|                     |                       |           | - Above 10% addition decreasing specific volume. |                                                                           |       |
|                     |                       |           | - Intensive color, flavor, and acidity of the bread by (excessive) fermentation. |                                                                           |       |
|                     |                       |           | - Higher specific volume and sensory scores by adding 15% germinated lupin flour. |                                                                           |       |
| Lupin               | Protein isolate       | 5–10%     | - Increased water absorption, dough development time, and stability. | Paraskevopoulou et al. 2010, 2012 |   |
|                     | and concentrate       |           | - Reduced specific volume and increased hardness compared to wheat control. |                                                                           |       |
|                     |                       |           | - Lupin addition leading to green, earthy, malty, buttery and roasted aromas of wheat bread. |                                                                           |       |
| Pea                 | Flour                 | 10–30%    | - Increased water absorption. | Millar et al. 2019; Mondor et al. 2014 |   |
|                     |                       |           | - Reduced dough stability. |                                                                           |       |
| Pea                 | Protein isolate and concentrate | 5–15% | - Increased water absorption. | Belc et al. 2021; Marchais et al. 2011 |   |
|                     |                       |           | - Dough stability unaffected. |                                                                           |       |
| Red kidney bean     | Flour                 | 10–30%    | - Doubled protein content. | Bhol and Bosco 2014 |   |
| Soy                 | Flour                 | 5–18.5%   | - Increased water absorption. | Lazo-Velez et al. 2015; Huang et al. 2019; Wang et al., 2022c |   |
|                     |                       |           | - Decreased specific volume. |                                                                           |       |
|                     |                       |           | - Higher specific volume and crumb softness by fermentation compared to wheat control. |                                                                           |       |
| Crop                  | Component & Quantity | Properties                                                                 | References                                      |
|-----------------------|-----------------------|-----------------------------------------------------------------------------|-------------------------------------------------|
| Cowpea                | Flour 5−20%           | -Increased water absorption, increased protein, crude fiber and ash contents. | Hallén et al. 2004; Olapade and Oluwole 2013     |
|                       |                       | -Above 10% addition leading to reduced specific volume and denser structure, and decreased sensory scores for taste and acceptability. |                                                 |
| Mung bean             | Flour 20%             | -Increased water absorption, elastic modulus and viscous modulus.           | Meng et al. 2019                                |
|                       |                       | -Decreased dough stability.                                                 |                                                 |
| Jack bean             | Flour and protein concentrate 10−20% | -Increased protein, crude fiber, fat, and ash contents.                      | Ugwuona and Suwaba 2013                         |
|                       |                       | -Decreased carbohydrate content.                                            |                                                 |
|                       |                       | -Comparable specific volume and sensory properties compared to control wheat bread. |                                                 |
| Cereal side-streams   |                       |                                                                             |                                                 |
| Wheat bran            | Protein isolate 12.2% | -Recognized for “high in protein” claim.                                    | Arte et al. 2019                                |
|                       |                       | -Decreased specific volume and increased crumb hardness, and darker crumb compared to wheat control. |                                                 |
| Rice bran             | Protein concentrate 1−15% | -Reduced peak viscosity and increased pasting temperature.                  | Chinma et al. 2015; Jiamyangyuen et al. 2005     |
|                       |                       | -Decreased elastic and viscous moduli values.                               |                                                 |
|                       |                       | -Increase bread protein, fiber, and total amino acid contents and higher radical scavenging activity. |                                                 |
|                       |                       | -Reduced bread specific volume.                                             |                                                 |
|                       |                       | -Above 1% addition lowering the liking scores of color, taste, odor, texture, and overall liking. |                                                 |
| Oilseed side-streams  |                       |                                                                             |                                                 |
| Ingredient                          | Description                      | Effects                                                                                                           | Reference(s)                        |
|------------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| Hemp seed cake Flour               | 5–20%                            | - Decreased water absorption. - Above 10% addition reducing dough stability, dough strength, and dough consistency. - Reduced specific volume and increased crumb hardness with increasing levels of hemp cake flour. - Darker crumb and crust compared to wheat control. | Pojić et al. 2015                   |
| Sunflower cake Protein Isolate     | 1–9%                             | - Decreased specific volume and increased hardness. - Increased protein and amino acid content with unpleasant taste and lower acceptability at the 9% addition level. | Mohammed et al. 2018                |
| Flaxseed cake Flour                | 5–10%                            | - Increased monounsaturated and polyunsaturated fatty acids, phenolic content, and antioxidant activity. - 10% substitution leading to negative sensory properties (flavor and texture). | Sanmartin et al. 2020               |
| Rapeseed cake Protein concentrate and isolate | 10–20% | - Recognized for ‘high in protein’ claim. - Reduced loaf specific volume and increased crumb hardness. - Improved specific volume and softness, and nutritional quality (free amino acids and protein digestibility) by fermentation with in situ dextran production compared to wheat control. | Wang et al. 2022a                   |
| Minor cereals                      | Sorghum Flour 10–50%             | - Increased water absorption. - Decreased the dough stability and elasticity. - Increased dietary fiber content, total phenolic compounds, and antioxidant activity. - Reduced specific volume and increased crumb hardness. - Improved bread texture quality and sensory properties i.e., reduced off-flavors such as bitter taste and aftertaste by fermentation with in situ dextran production. | Angioloni and Collar 2012; Jafari et al. 2017; Wang et al. 2020; Wu et al. 2018 |
| Crop Type     | Flour Type | Replacement Range | Changes                                                                                                                                   | References                          |
|--------------|------------|-------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|
| Foxtail      | Flour      | 20−50%            | -Increased acceptability of sorghum-enriched bread by high hydrostatic pressure treatment                                                | Das et al. 2021                     |
| Finger Millet| Flour      | 10−30%            | -Decreased glycemic index with foxtail addition.  
   -Increased sensory quality of foxtail bread by adding guar gum.                                                                  | Muda et al. 2021;  
   Onyango et al. 2020;  
   Patil et al. 2016 |
| Tef           | Flour      | 10−40%            | -Tef addition resulting in higher levels of extractable polyphenols and anti-radical activity.  
   -Above 30% replacement leading to a decrease in specific volume and increase in crumb hardness.                                | Ronda et al. 2015                 |
| Proso Millet  | Flour      | 10−50%            | -Lower bread volume, firmer crumb and altered crumb pore structure.  
   -Improved texture with acceptable quality for as high as 50% replacement by adding emulsifier (DATEM and distilled monoglycerides) and enzymes (xylanase and transglutaminase). | Schoenlechner et al. 2013          |
| Millets (finger,  
   foxtail,  
   barnyard, kodo,  
   little, proso) | Flour      | 25%               | -Decreased water absorption and dough stability.  
   -Increased starch gelatinization temperature and peak viscosity values.                                                             | Sharma et al. 2019                 |
| Barnyard Millet| Flour      | 61.8%             | -Textural quality of composite bread is comparable to wheat control by adding 6.8% gluten.                                               | Singh et al. 2012                  |
| Grain   | Product     | Percentage | Effects                                                                 | References                                      |
|---------|-------------|------------|------------------------------------------------------------------------|------------------------------------------------|
| Pearl millet | Flour | 50%        | -Reduced water absorption and dough extensional properties, and increased dough stickiness. -Decreased specific volume and increased crumb hardness. -Increased specific volume and softness and delayed stalling rate by fermentation with in situ dextran production. -Reduced starch digestibility and improved protein digestibility in vitro by fermentation. | Wang et al. 2019 |
| Barley | Flour | 40−60%      | -Increased water absorption. -Reduced dough stability and extensibility. | -Increased contents of fiber, total phenolic compounds, and antioxidant capacity. -Decreased bread specific volume and increased crumb firmness, and lower sensory scores in taste compared to wheat control. -Bread textural quality unaffected by fermentation. -Decreased average Mw of β-glucan by fermentation. | Rieder et al. 2012; Robles-Ramírez et al. 2020 |
| Barley | Middlings | 15−60%      | -Increased dough firmness. -Decreased resistance to extension and dough elasticity. | -Increased contents of fiber and β-glucan. -Lower loaf specific volume and negative textural properties above 30% addition. | Sullivan et al. 2011 |
| Barley | β-glucan concentrate | 2.5−10%    | -Increased mixing time, dough stability and water absorption, and decreased dough extensibility above 5% replacement. | | Ahmed 2015 |
| Oat | Bran | 5−40%        | -Increased water absorption. -Reduced dough stability, maximum resistance to extension, dough extensibility, and energy value. | -Increased contents of dietary fiber, the phenolic content, and antioxidant activity. -Reduced specific volume and increased crumb hardness compared to wheat control. -Bread quality unaffected by fermentation. -Decreased β-glucan Mw by fermentation. | Rieder et al. 2012; Gamel et al. 2015; Saka et al. 2021 |
| Ingredient | Component | Content | Observations |
|------------|-----------|---------|--------------|
| Oat        | Flour     | 51%     | -High levels of β-glucan (1.4−1.6 g/100 g fresh bread).  
-Slight degradation (lower Mw) of β-glucan during proofing and baking.  
-Content and Mw of oat β-glucan unaffected by fermentation.  
-Bread volume and crumb properties mainly affected by gluten and water contents. | Flander et al. 2007, 2011 |
| Oat        | Soluble fiber | 10−14% | -Lower specific volume and porosity, darker color, higher hardness, and lower springiness and cohesiveness compared to wheat control.  
-The negative effects effectively counteracted by optimizing the water content in bread formulas. | Erive et al. 2020 |
| Pseudocereals | Quinoa Flour | 5−40% | -Decreased water absorption.  
-Gluten secondary structure changed and gluten network disrupted.  
-Above 10% addition resulting in smaller specific volume, increased crumb hardness and coarse porosity.  
-Higher antioxidant activity and reduced in vitro starch digestibility with lower estimated glycemic index due to higher contents of slowly digestible starch and resistant starch.  
-Aroma and taste improved by 10-20% quinoa addition.  
-Chemical, textural, and sensory features improved by fermentation.  
-Increased antioxidant activity.  
-Lower specific volume but improved flavor and mouth feel compared to wheat bread. | Gostin 2019; Rizzello et al. 2016; Stikic et al. 2012; Wang et al. 2021; Xu et al. 2019 |
| Buckwheat  | Flour     | 15%     | -Increased antioxidant activity.  
-Lower specific volume but improved flavor and mouth feel compared to wheat bread. | Lin et al. 2009 |
| Crop                  | Flour      | Percentage | Effects                                                                 | References                                      |
|----------------------|------------|------------|-------------------------------------------------------------------------|------------------------------------------------|
| Amaranth             | Flour      | 25%        | -Increased protein, lipid, fiber, ash, and phytate contents compared to control wheat bread.  
|                      |            |            | -Up to 25% replacement providing bread with comparable specific volume and crumb softness to wheat control. | Miranda-Ramos et al. 2019; Sanz-Penella et al. 2013 |
| Root and tuber crops|            |            |                                                                                           |                                                |
| Yam                  | Flour      | 5−75%      | -Increased water absorption and decreased dough stability.  
|                      |            |            | -Gluten network structure destroyed and contents of α-helix and β-sheet in gluten proteins reduced. | Amandikwa et al. 2015; Li et al. 2020 |
| Yam (purple)         | Flour      | 10−50%     | -Decreased contents of rapidly digestible starch and slowly digestible starch. | Liu et al. 2019 |
| Cassava              | Flour      | 10−50%     | -Reduced water absorption, dough stability, and dough viscoelasticity.  
|                      |            |            | -Decreased specific volume and increased crumb at or above 20% addition levels.  
|                      |            |            | -Improved specific volume and reduced crumb hardness by dry-heat-moisture treatment. | Dudu et al. 2020; Jensen et al. 2015 |
| Orange fleshed sweet potato (OFSP) | Flour | 10−60% | -Decreased water absorption and increased dough development time.  
|                      |            |            | -Decreased pasting temperature, peak viscosities, peak time, and dough stability. | Chikpah et al. 2021; Edun et al. 2019; Nzamwita et al. 2017 |

**Waste valorization**
| Ingredient                          | Component         | Concentration | Effect                                                                 |
|------------------------------------|-------------------|---------------|----------------------------------------------------------------------|
| Surplus bread                      | Bread-water       | 4.5–12.5%     | - Decreased specific volume and increased hardness.                   |
|                                   | slurry or         |               | - Improved specific volume and softness and increased microbial       |
|                                   | hydrolysate       |               | safety by fermentation with exopolysaccharide production.            |
|                                   |                   |               | - Enzymatic hydrolysis of starch in surplus bread hydrolysate with    |
|                                   |                   |               | high-malto-oligosaccharides resulting in increased specific volume    |
|                                   |                   |               | and reduced crumb hardness and staling rate compared to non-treated   |
|                                   |                   |               | control.                                                           |
| Brewers’ spent grain (BSG)         | Flour             | 5–20%         | - Decreased specific volume.                                         |
|                                   |                   |               | - Increased volume, preferrable aroma and taste traits and overall   |
|                                   |                   |               | quality by fermentation of BSG (up to 10%).                          |
|                                   |                   |               | - Adding fermented BSG at above 10% leading to reduced taste quality.|
|                                   |                   |               | - Enzyme treatment leading to larger specific volume and softer       |
|                                   |                   |               | crumb than extrusion treatment.                                      |

Immonen et al. 2020, 2021

Plessas et al. 2007
Steinmacher et al. 2012; Vriesekoop et al. 2021