Grains and nutrition: a cereal scientist’s perspective: cereal starches, fibers, and gluten

Dr Andrew Ross
Outline

- Full disclosure
- Some basic assertions
- Interactions between cereal and nutrition sciences
- Raw material development
- Primary Processing
- Secondary Processing
- Gluten
Funding

OWC
Oregon Wheat Commission

Agricultural Research Foundation
promoting agricultural research since 1934

IDAHO Barley Commission

USDA
United States Department of Agriculture
National Institute of Food and Agriculture
Some basic assertions…

[Image of cellular structure and grains]

[Diagram illustrating various health effects of dietary fiber, including enzyme inhibition, cholesterol lowering, and antioxidant properties, leading to beneficial physiological effects in humans.]

[Chemical structures of carbohydrates, with formulas presented in a structural format, indicating the repeating unit of carbohydrates.]

[Diagram showing molecular structures with oxygen, carbon, and hydroxyl groups.]
1: Wholegrain consumption leads to health benefits in humans

2: Dietary fiber can be defined

For example: this broadly inclusive definition.

“dietary fiber consists of all carbohydrate components that are non-digestible to mammalian enzymes”

3: More than just fiber

- Fibre
- Niacin & Thiamin
- Iron
- Protein
- Antioxidants
- Bioactives

Aleurone

Bran Layers

- Fibre
- Bioactives
- Antioxidants
- B Vitamins
- Minerals
- Protein

Synergistic effects

Beneficial physiological effects in humans

Agriculture and Agri-Food Canada

HEALTHGRAIN FORUM
4: Whole grain does not = fiber

**Bran**
- Dietary fiber
- Phenolic acids
- Vitamins and minerals

**Endosperm**
- Starch
- Protein
- Some vitamins and minerals

**Germ**
- Unsaturated fats
- Phytosterols
- Tocotrienols
- Sphingolipids
- Protein
- Vitamins and minerals

Photo: Rob’s Red Mill.
Whole grains shall consist of the intact, ground, cracked or flaked kernel after the removal of inedible parts such as the hull and husk. The principal anatomical components - the starchy endosperm, germ and bran - are present in the same relative proportions as they exist in the intact kernel.

Small losses of components - i.e. less than 2% of the grain/10% of the bran - that occur through processing methods consistent with safety and quality are allowed.
Interdisciplinary interactions:

- Nutrition Sciences: **key data**
- Cereal Science and Plant Breeding: **raw materials**
- Cereal and Food Sciences: **processing**
- Nutrition and Dietetics & Culinary Arts: **delivery**

**Improved Public Health Outcomes**
Raw materials

- **Wheat**
  - Multiple species and multiple varieties within species
  - Einkorn (diploid)
  - Emmer, Durum, Kamut (tetraploid)
  - Spelt, Aestivum (hexaploid)

- **Barley**
  - Multiple varieties

- **Rye, oats, sorghum, millets, teff, rice, pseudo-cereals...**

- **Growth environment**
Raw materials: considerations in plant breeding

- Types of fiber: AX vs BG; both; partitioning between soluble and insoluble
- Other nutrients and anti-nutritional factors
- Anatomical locations
- Molecular weight and viscosity building potential of fiber [physiological effects and food texture/mouthfeel]
- Types and accessibility of starches
- Type, digestibility, and quality of proteins
Inertia

Yr 1
- Crossing

Yr 2
- Bulk Testing

Yr 3
- Bulk Testing

Yr 4
- Headrows

Yr 5
- Preliminary

Yr 6
- Advanced

Yr 7
- Elite

Yr 8
- Elite

Yrs 9, 10
- State, Regional Trial

Yr 1
- Generate Double-Haploids

Yr 2
- Headrows
- Some reductions in total starch content
- Analysis in progress:
  - Dietary Fibre
  - Trehalose, Betaine, Cysteine
  - Minerals

Ideal Grain Ingredients:
Breeding Wheat for Health

Dr. Nancy Ames
Agriculture and Agri-Food Canada
Richardson Centre for Functional Foods and Nutraceuticals
September 2013
Raw materials: The OSU food barley experience

- Hulled versus hull-less
  - Interacts with whole-grain definition[s]

- Beta-glucan
  - Variable levels: GxE interactions

- Starches
  - Waxy
  - Normal
  - High amylose [RS]
Raw materials: OSU Food Barley

- Fiber
  - Primarily beta-glucan [BG]
  - Increase arabinoxylan [AX] in endosperm
  - Change AX in hulls [see processing]

- Functionality
  - E.g. hard versus soft
    - Water absorption in flour applications
  - Texture in whole-kernel applications
GI was correlated with total fiber ($r = -0.75, P = 0.002$) but not with measures of starch characteristics...

GI of barley is influenced by cultivar, processing, and food form but is not predicted by its content of amylose or other starch characteristics...
Raw materials: other components

Starchy endosperm (80–85%)
- Starch and proteins (sulfur amino-acids)
- β-Glucans, arabinoxylans
- Carotenoids
- Se
- Thiamin (B₁) and vitamin E
- Flavonoids (anthocyanins)

Germ (3%)
- Lipids (α-linolenic acid)
- Sucrose and monosaccharides
- Sulfur amino acids
- Glutathione
- Insoluble and soluble fibre, raffinose
- Flavonoids
- Vitamin E
- B vitamins
- Minerals and trace elements
- Phytosterols
- Betaine and choline
- Policosanol
- Enzymes
- Myo-inositol

Aleurone layer (6–9%)
- Soluble and insoluble dietary fibre (xylans, β-glucans, raffinose, stachyose, fructans)
- Proteins (sulfur amino acids and glutathione)
- Antioxidants (phenolic acids, carotenoids, lignans, anthocyanins, isoflavonoids)
- Vitamin E
- B vitamins
- Minerals and trace elements
- Phytic acid
- Betaine and choline
- Enzymes

Hyaline layer
- Inner and outer pericarp (4–5%)
- Bran:
  - Policosanol
  - Phytosterols

OCOLOR
Systematic introgression of Himalayan food barley traits
Primary processing

- Effects of milling or other primary processes on composition of the process intermediate [e.g. flour refinement, “pearls”]

- Interactions between raw materials and primary process
  - E.g. hardness and milling & hardness and flaking [e.g. Streaker flakes]

- Effects of milling on particle size distributions of derived flours and downstream processing effects

- Potential partitioning of fiber rich or depleted fractions
  - E.g. conventional milling and separation of endosperm and bran
  - E.g. separation of beta-glucan rich barley endosperm fractions
Streaker Barley

Directions: Use a ratio of 2:1 water to cooked barley, cook for 8 to 10 minutes.

Streaker is a naked (hull-less) winter barley, the first of its type adapted to the Pacific Northwest. Developed by the Oregon State University Barley Project, Streaker is a blend that will be continuously improved by a participatory plant breeding process involving Hunton's Farm and other local farmers. Enjoy!
Atwell 2001
Refined flour becomes universally available
Multistage milling for fine flours

Sieving

Tempering

[emmer can be hard like durum]

Secondary processing/cooking

- Palatability, visual appeal, culinary qualities...

- Fate of fiber components
  - E.g. Changes in extractability [± molecular weight; ± viscosity]

- Changes in digestibility and accessibility of starches
  - Production of RS3 in situ
  - e.g. sourdough and reduced post-prandial insulin response
  - Exploitation of RS1
Sourdough fermentation of wholemeal wheat bread increases solubility of arabinoxylan and protein and decreases postprandial glucose and insulin responses

Jenni Lappi, Emilia Selinheimo, Ursula Schwab, Kati Katina, Pekka Lehtinen, Hannu Mykkänen, Marjukka Kolehmainen, Kaisa Poutanen
Secondary processing/cooking

- Changes in protein digestibility
  - E.g. mixed lactic acid bacteria (LAB) and “wild” yeast fermentations, versus single culture LAB or *Saccharomyces* fermentations

- Changes in mineral availability
  - E.g. phytic acid degradation in cereal soaking or mixed LAB/wild yeast fermentations
BAGUETTE
100% WESTERN WASHINGTON WHEAT, "DIRTY WHITE",
ROLLER MILL, FRESH

PHOSPHATES
M₆p-INOSITOL MONOPHOSPHATE
MINERALS:
Fe²⁺, Zn²⁺, Ca²⁺, etc.
PROTEINS, PEPTIDES,
AND AA

Malted Bread
Western Washington
100% Whole Grains
with Wheat Berries
Gluten

- The emergent property of 2 protein classes...
  - Glutenins (glutelins) also part of “elastomer” superfamily
  - Gliadins (prolamins)

I have no idea what gluten is either. But I’m avoiding it just to be safe.
HMW glutenins

An x-type high molecular weight glutenin

Gliadins

- α-gliadin
- γ-gliadin

Repeats 1 2 3 4 5 6 7 8
Notably, almost all of the immunogenic sequences of α-gliadins map the N-terminal 57-89 region corresponding to the 33-mer peptide.
Celiac disease (CD) is an immune-mediated enteropathy triggered in genetically susceptible individuals by the ingestion of gluten-containing grains (wheat, barley, and rye). The disease is associated with human leukocyte antigen (HLA) DQ2 and DQ8 haplotypes. In the continued presence of gluten, CD is self-perpetuating. Given the undisputed role of gluten in causing inflammation and autoimmunity, CD represents a unique example of an immune-mediated disease for which early serologic diagnosis and dietary treatment can prevent severe, sometimes life-threatening complications.

Prevalence of Celiac Disease in At-Risk and Not-At-Risk Groups in the United States

A Large Multicenter Study

Alessio Fasano, MD; Irene Berli, MD; Tamio Gerarduzzi, MD; Tarcisio Not, MD; Richard B. Colletti, MD; Sandro Diogo, MS; Yvonne Eliseu, MD; Peter H. R. Green, MD; Stefano Guandalini, MD; Iver D. Hill, MD; Michelle Portokal, MD; Alessandro Venturi, MD; Mary Theo, MS; Debbie Kryszak, BS; Fabiola Formanelli, MD; Steven S. Wasserman, PhD; Joseph A. Murray, MD; Kardo Horvath, MD, PhD
Gluten Causes Gastrointestinal Symptoms in Subjects Without Celiac Disease: A Double-Blind Randomized Placebo-Controlled Trial

Jessica R. Biesiekierski, B Appl Sci¹, Evan D. Newnham, MD, FRACP¹, Peter M. Irving, MD, MRCP¹, Jacqueline S. Barrett, PhD, BSc, MND¹, Melissa Haines, MD¹, James D. Doecke, BSc, PhD², Susan J. Shepherd, B Appl Sci, PhD¹, Jane G. Muir, PhD, PGrad Dip(Dietetics)¹ and Peter R. Gibson, MD, FRACP¹

Non-Celiac Wheat Sensitivity Diagnosed by Double-Blind Placebo-Controlled Challenge: Exploring a New Clinical Entity

Antonio Carroccio, Pasquale Mansueto, Giuseppe Iacono, Maurizio Soresi, Alberto D’Alcamo, Francesca Cavataio, Ignazio Brusca, Ada M Florena, Giuseppe Ambrosiano, Aurelio Seidita, Giuseppe Pirrone and Giovanni Battista Rini

CONCLUSIONS:
Our data confirm the existence of non-celiac WS as a distinct clinical condition. We also suggest the existence of two distinct populations of subjects with WS: one with characteristics more similar to CD and the other with characteristics pointing to food allergy.

Colon/Small Bowel


Non-celiac gluten-intolerance
Has gluten fundamentally changed in the modern era?

Conclusions

...One possible explanation is that the selection of wheat varieties with higher gluten content has been a continuous process during the last 10,000 years, with changes dictated more by technological rather than nutritional reasons.
Table 1. Average Percentages of Protein in Spring Wheat Marketed through Minneapolis, MN, by Crop Years (Data Excerpted from Table 42 of Reference 12)

<table>
<thead>
<tr>
<th>crop year</th>
<th>no. of samples</th>
<th>av protein (%)</th>
<th>standard deviation (σ)</th>
<th>av moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925</td>
<td>33246</td>
<td>12.49</td>
<td>1.34</td>
<td></td>
</tr>
<tr>
<td>1926</td>
<td>26145</td>
<td>13.28</td>
<td>1.55</td>
<td>13.7</td>
</tr>
<tr>
<td>1927</td>
<td>63944</td>
<td>11.96</td>
<td>0.78</td>
<td>13.2</td>
</tr>
<tr>
<td>1928</td>
<td>49964</td>
<td>12.42</td>
<td>0.77</td>
<td>13.4</td>
</tr>
<tr>
<td>1929</td>
<td>37202</td>
<td>13.70</td>
<td>1.41</td>
<td>13.4</td>
</tr>
<tr>
<td>1930</td>
<td>52041</td>
<td>14.85</td>
<td>1.47</td>
<td>13.1</td>
</tr>
<tr>
<td>1931</td>
<td>17182</td>
<td>15.00</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td>45027</td>
<td>14.21</td>
<td>0.99</td>
<td>11.7</td>
</tr>
<tr>
<td>1933</td>
<td>28829</td>
<td>15.03</td>
<td>0.89</td>
<td>11.5</td>
</tr>
<tr>
<td>1934</td>
<td>12900</td>
<td>14.80</td>
<td>1.04</td>
<td>11.4</td>
</tr>
<tr>
<td>1935</td>
<td>28544</td>
<td>15.30</td>
<td>1.71</td>
<td>11.8</td>
</tr>
<tr>
<td>1936</td>
<td>16698</td>
<td>15.92</td>
<td>1.64</td>
<td></td>
</tr>
<tr>
<td>1937</td>
<td>12185</td>
<td>14.83</td>
<td>1.28</td>
<td>11.6</td>
</tr>
<tr>
<td>1938</td>
<td>13169</td>
<td>18.78</td>
<td>1.04</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Has gluten content increased?
Table I: Nutritional composition (%) of hulled wheats: einkorn, emmer and spelt compared to common wheat

<table>
<thead>
<tr>
<th></th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spelt&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.3 - 17.5</td>
</tr>
<tr>
<td>Emmer&lt;sup&gt;b&lt;/sup&gt;</td>
<td>13.5 - 19.05</td>
</tr>
<tr>
<td>Einkorn&lt;sup&gt;a,d&lt;/sup&gt;</td>
<td>18.2±1.48</td>
</tr>
<tr>
<td>Common wheat&lt;sup&gt;c,a&lt;/sup&gt;</td>
<td>13.85±0.16</td>
</tr>
</tbody>
</table>

- ~1% increase in protein over Red Fife
- Improvement in strength
- Water absorption
- Loaf volume

Ideal Grain Ingredients: Breeding Wheat for Health

Dr. Nancy Ames
Agriculture and Agri-Food Canada
Richardson Centre for Functional Foods and Nutraceuticals
September 2013
Questions of quality? Is functionality a bad thing?

“In 1793, nothing marked the limits of the Revolution... more powerfully than the fact that for some time [people] have been eating grayish bread of poor quality that smells dusty and gives most people a stomach ache.

*Concern with quality was a matter of ordinary dignity, not a question of luxury or displaced envy.*”

“GOOD BREAD IS BACK: A contemporary history of French bread, the way it is made, and the people who make it.”

Steven L. Kaplan
Cornell
Has gluten changed qualitatively, and therefore,

have wheat breeders been engaged in an epic conspiracy of monumental proportions?

Presence of celiac disease epitopes in modern and old hexaploid wheat varieties: wheat breeding may have contributed to increased prevalence of celiac disease

Hetty C. van den Broeck · Hein C. de Jong · Elma M. J. Salentijn · Liesbeth Dekking · Dirk Bosch · Rob J. Hamer · Ludovicus J. W. J. Gilissen · Ingrid M. van der Meer · Marinus J. M. Smulders
“It's an 18-inch tall plant created by genetic research in the '60s and '70s, this thing has many new features nobody told you about, such as there's a new protein in this thing called gliadin. It's not gluten”. 
Looking back over the last five decades, several trends are apparent in wheat consumption: an increase in wheat consumption per capita (Rubio-Tapia et al. 2009) (http://www.ers.usda.gov/AmberWaves/september08/findings/wheatflour.htm)
After 5 years of declining flour use in the U.S., ERS estimates an increase in per capita wheat flour use to 137.9 pounds in 2007, up 2.3 pounds from a year earlier. The 2007 total is still down 8.9 pounds from its high in 1997. ERS calculates per capita use by dividing the total annual availability by the U.S. population in the same year. These per capita availability estimates provide an indication of trends in Americans’ consumption of various foods over time.

Between 1972 and 1997, U.S. wheat producers and millers could count on rising per capita food use of wheat flour to expand their domestic market. Contributing to this growth was the boom in away-from-home eating, the desire of consumers for greater variety and more convenient food products, promotion of wheat flour and pasta products by industry organizations, and wider recognition of health benefits stemming from eating high-fiber, grain-based foods.

The decades-long growth ended in 1997, as changing consumer preferences, led by the increased adoption of low-carbohydrate diets after 2000, reduced per capita wheat consumption. Per capita flour use dropped rapidly at first and then fell more slowly until reaching a low of 134.2 pounds in 2005. In response, the flour milling industry began to downsize, leading to the closure of some smaller, older, and less efficient mills. From 2000 to early 2006, 12 percent of the 223 mills listed in the industry publication *Grain and Milling Annual* closed, and milling capacity fell by 7 percent.

The baking industry responded by developing products to satisfy these new dietary preferences, particularly the increased demand for higher fiber and protein. According to Datamonitor, 558 wheat-flour products were introduced in 2007—more than a fourfold increase from the 97 new wheat-flour products that hit the shelves in 1997. Eighty-six whole-wheat flour products were introduced in 2007, up from 16 in 1997. These new product introductions appear to be succeeding because per capita use bottomed out and then rose sharply in 2007.

Despite the recent increase in per capita consumption and new recommendation in the 2005 *Dietary Guidelines for Americans* that whole grains should account for half of all grains consumed, Americans still favor refined-wheat flour products over whole-wheat flour products. According to *Milling & Baking News*, whole-wheat flour grew from 2.1 percent of total flour production in 2002-03 to 4.1 percent in 2006-07.

---

*Gary Vocke, gvocke@ers.usda.gov*
*Jean C. Buzby, jbuzby@ers.usda.gov*
*Hodan Farah Wells, hfarah@ers.usda.gov*
Figure 5. U.S. per capita wheat flour use (figure redrawn from ref 18 and data supplied by G. Vocke).
What about lack of exercise?

What about changes in infant feeding practices?

What about processing?

What about gut microbiota?

What about hygiene?

Other components: fructans, amylase-trypsin inhibitors?
Los Angeles. 1900.
Spring St. near 8th.