The physiology of grain fill and how the environment impacts kernel characteristics

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Acknowledgement

• Many slides used from Marina Dobrydina, student working with Frank Manthey, Department of Plant Sciences
2011 was a tough year for wheat

- Late planting
- Excess water
- Difficulties in managing N
- Hot weather during key developmental stages
- Plenty of disease pressure
- Yields were lower than expected
  - 50 bu straw and 25 bu harvest
  - Protein percent was higher than the bu/a
- Protein was high
Yield trends in ND 1998-2011

\[ y = 0.6536x + 29.769 \]

\[ R^2 = 0.2797 \]
Significant delay in planting

Strong relationship between delayed planting and its impact on yield components
Daily Maximum Air Temperature
(2011-05-01 - 2011-10-01)
North Dakota Agricultural Weather Network (NDAWN)


Slafer & Rawson (1994)
Miralles & Slafer (1999)
Effect of maximum daily temperature during the 4-5.5 leaf stage on spikelets per spike.
Key points during early REPRODUCTIVE STA

Flowering:
  • Pollination/fertilization

Stress: reduces number of kernels/spike (yield)

Embryo/endosperm development:
  • Rapid cell division.

Stress: reduces cell number in the endosperm (kernel size).
Key points during the VEGETATIVE STAGE

Stem elongation:

• Spike develops as it moves up the stem.

• N from the soil converted to amino acids/ storage proteins in stem and leaves.

Stress: affects spike development (yield).

affects amount of N stored in the plant.

reduces potential protein content of kernel.

80% of N in grain protein is stored in plant during vegetative sta
How did the environment impact kernel development?

- Stresses reduce the rate of photosynthesis
  - Excessive heat
  - Drought
  - Warm night temperatures
  - Nutrient deficiencies

- Lower rates of photosynthesis means less starch to fill the kernel and less yield at harvest

- Other processes are impacted by temperature
Plants’ response to environmental stress

Environmental stress

- Severity
- Duration
- Number of exposures
- Combination of stresses

Stage of Development

Genotype

Organ or tissue

Tolerance

Susceptibility
Grain development

Prior to anthesis, environment mainly affects formation and therefore number of spikelets.

At anthesis high temperature can cause floral abortion, thereby impacting grain number.

After anthesis, environmental conditions primarily affect kernel size and composition (DuPont and Altenbach, 2003)

* DAA – Days After Anthesis
Grain development under high temperatures

High temperatures shortens the time of grain development, resulting in a lower kernel weight.

Fresh weight (■), dry weight (●), and water content (▲) of developing kernels

Altenbach et al. (2003)
Departure from Normal Daily Maximum Air Temperature

(2011-05-01 - 2011-10-01)

North Dakota Agricultural Weather Network (NDAWN)
Rate of Grain Filling as Affected by High Temperature

<table>
<thead>
<tr>
<th>Rate (mg/day)</th>
<th>Duration (day)</th>
<th>Kernel weight (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18/13°C</td>
<td>1.89</td>
<td>35.6</td>
</tr>
<tr>
<td>24/19°C</td>
<td>2.35</td>
<td>22.6</td>
</tr>
<tr>
<td>30/25°C</td>
<td>2.65</td>
<td>15.9</td>
</tr>
</tbody>
</table>

There is an increase in the rate of grain filling at the temperature up to 30°C (86°F).

Increase in the rate of grain filling does not compensate for the shortened duration.

Wardlae and Moncur (1995)
Composition of Wheat Kernel

Endosperm – about 83% of the kernel

Endosperm is 65-80% \textit{starch} and around 8-20% \textit{protein}

Grain filling responses to high temperatures are largely attributed to effects on the deposition of starch.

Hoseney (2003)
Starch Deposition Under High Temperature

High temperature reduced starch content by shortening the duration of starch accumulation.

The effect was more pronounced when high nighttime temperatures increased.

Altenbach et al. (2003)
Effect of High Temperatures on the Rate of Starch Deposition

Rate of starch deposition increases with the temperature up to 86°F and decreases above this temperature.

High temperature influences activity of enzymes in the pathway of starch synthesis.

Jenner (1994)
Effect of Temperature on Starch Biosynthesis

Starch contains two classes of molecules:

**AMYLOSE (20-35%)**

**AMYLOPECTIN (65-80%).**
Starch Granule Polymorph Distribution

Amylose and Amylopectin form Starch Granules:

“A” – type granules: Large
“B” – type granules: Small

A-type granules contain 5-10% more amylose than B-type granules (Peng, et al., 2001)

Zihua and Jane (2007)
Starch composition as affected by high temperatures

Number of A-granules increases whereas number of B-granules decreases with high temperature.

Therefore
Amylose-to-Amylopectin ratio increases

Increased ratio reduces dough elasticity (Hung et al 2005).

(□)24/17°C, (■)37/17°C, (■) 37/28°C

Hurkman et al. (2003)
Protein Deposition Under High Temperature

Deposition of protein appeared relatively unaffected by high daytime temperature.

Altenbach et al. (2003)
Protein Composition

**Low Molecular Weight**
- Extremely sticky
- Little resistance to extension

**VISCOUS PROPERTIES**

**High Molecular Weight**
- Elastic properties
- Resistant to extension

**ELASTIC PROPERTIES**

Gluten gives elasticity to dough, helping it to rise and to keep its shape, and often giving the final product a chewy texture.

www.aaccnet.org
Effect of Heat Stress on Protein Composition

- General heat-shock response
- Activation of heat-shock elements
  - Synthesis of heat-shock proteins for gliadin
  - Increase synthesis of gliadin
- Increase in gliadin:glutenin ratio

Blumental et al. (1993)
Effect of the Heat Stress on Quality of End-use Products

- Grain size - **Reduced Extraction rate**

- Gliadin:Glutenin Ratio – **Low Bread Loaf Volume and soft pasta/noodles products**

Take Home Message

For later planted crop, warmer than optimum temperature reduced tillering and spike size.

For early planted crop, spike numbers were nearly normal, but excessive heat impacted number of kernels per spike and size of the kernel.

Higher than normal night temperatures may have been especially detrimental to yield development.
Take Home Message

The effect of high temperature on grain size and weight is mainly due to a reduction in the duration of grain filling, rather than rate of grain filling.

Warmer than optimum temperatures increased grain protein percentage through a reduction in starch deposition.

High temperature may have affected the functional protein composition by increasing gliadin to glutenin ratio, therefore reducing gluten strength.