Indirect Continuous Heat Treatment of Wheat Grain and Whole Wheat Flour

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Heat treatment of wheat flour

- The concept of thermal processing of foodstuff has been used extensively since Bigelow and Ball developed the first scientific basis for safe sterilization process in 1920.
  - preserving and extending the shelf-life (via microbial reduction and enzyme inactivation),
  - improving quality and functionality.
- Heat treatment of wheat flour become an important consideration relatively recently.
  - In 2009 the CDC released a report of an *E. Coli* outbreak resulting from consumers eating raw refrigerated cookie dough which brought attention to heat treatment of flours and powders.
  - Chlorination of wheat flour has been replaced by heat treated flour.
- By applying heat treatment, it is possible to modify the physical and rheological properties.
  - Relationship between heat energy input, thermal properties of food, heating medium and the performance of the heat treated products

Scope

Developing an indirect, rapid and continuous thermal processing technique for treating whole wheat flour and whole grain.

Improving the flour functionality for targeted applications.

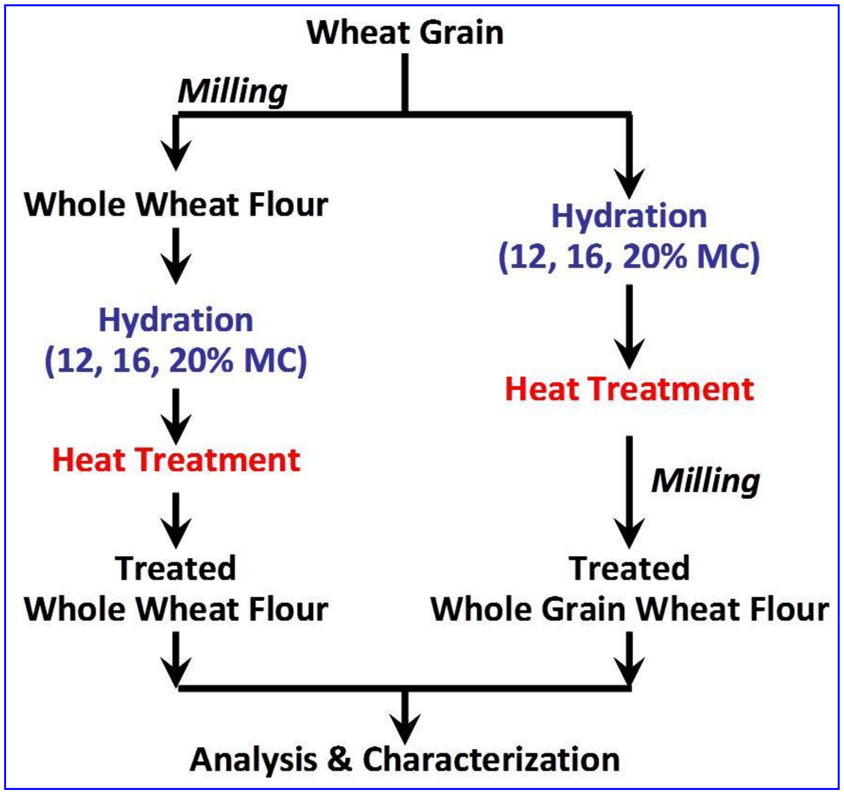
Rationale:

- Demand for specialty flours with targeted quality and end-use.
- Increased consumer interest in clean label naturally functional products.
- Need for developing continuous and rapid techniques for treating of whole grain products.
- Provide equipment and process guidelines for grain industry
  - Systematic study on cause and effect relationships,
  - Identify relevant process parameters to serve as predictors of desired quality for specific end-use.

Experimental Approach

A - Milling ⇨ Heat treatment ⇨ Characterization

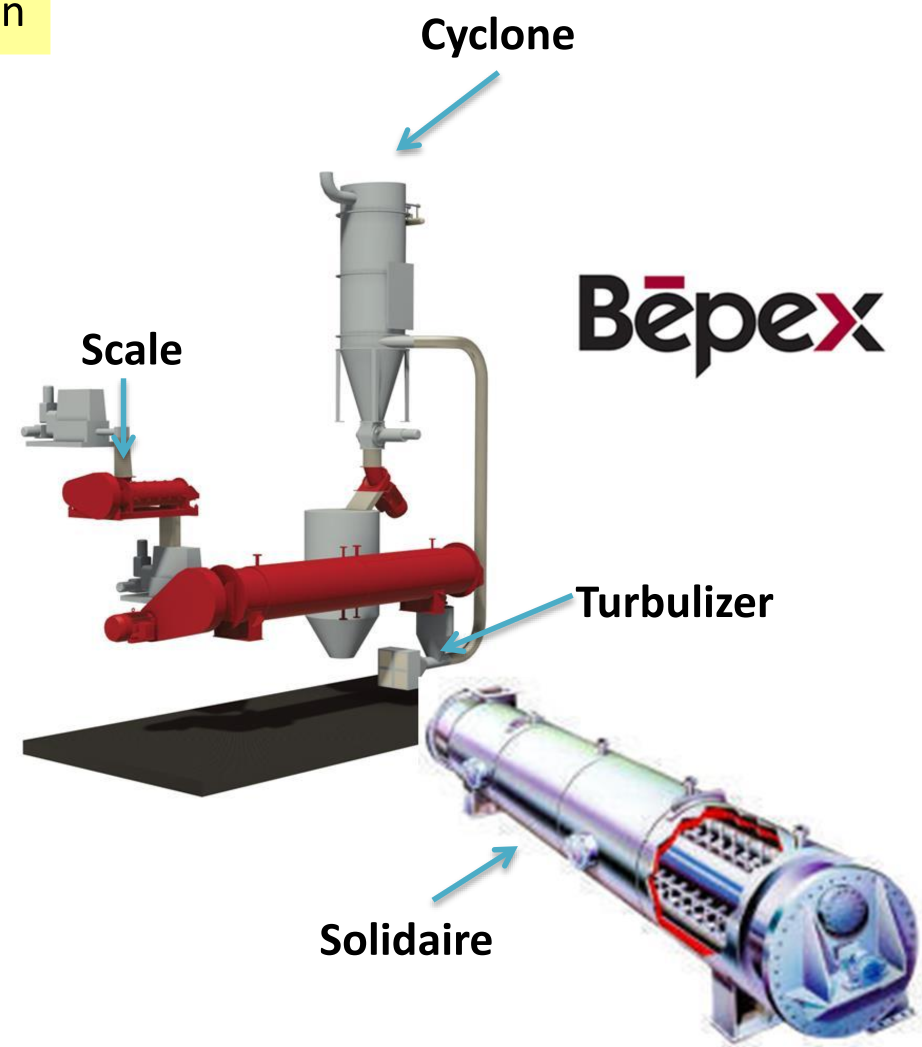
B - Heat treatment ⇨ Milling ⇨ Characterization



RSM – Box Behnken design:

Moisture (%) : 12, 16, 20
Temperature (◦C) : 75, 85, 95
Residence time (s) : 30, 60, 90

Processing Units



Milling process

Before heat treatment

Hal Ross Flour Mill,
Whole wheat milling protocol

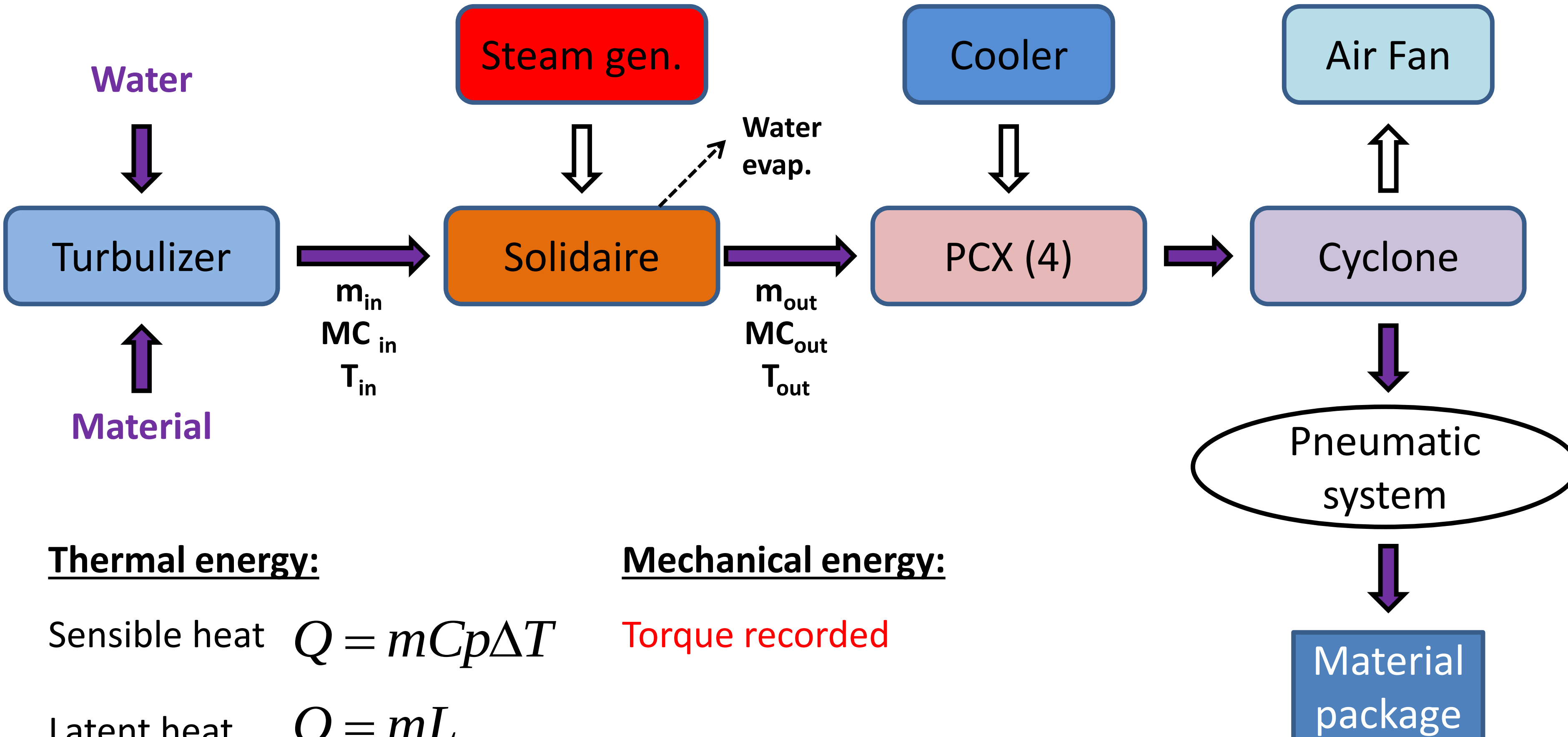
After heat treatment

Buhler 202
Experimental mill

Comminutor FitzMill®

Thermal and mechanical energy input

Schematic of the processing steps



Thermal energy:

Sensible heat $Q = mCp\Delta T$

Latent heat $Q = mL_{evap}$

Mechanical energy:

Torque recorded

Product Characterization

- **Kernel morphology**
  - Single Kernel Characterization Systems (SKCS) AACC Method 55-31.01 (Model 4100-Perten Instruments, Springfield, IL)
- **Microbial load**
  - Aerobic plate count (APC) carried out at Medallion for total yeast, mold and coliform (cfu/g)
- **Composition**
  - AOAC Methods (925.05, 992.23, and 923.02) for moisture, protein, and ash
- **Color**
  - Minolta color meter (Minolta CR-310, Tokyo Japan)
- **Particle size**
  - Light scattering single wavelength laser diffraction particle size analyzer (LS 13 320) using the Tornado dry powder system (Beckman-Coulter Inc.)

Product Characterization

- **Solvent retention capacity (SRC)**
  - AACC Approved Method 56-11.02
- **Swelling power and solubility**

  1% slurry incubated @ 60, 70, 80 or 90°C for 30 min

$$WSI = \frac{W_1}{Sample\ weight} \times 100$$

$$SP = \frac{W_s}{\left[Sample\ weight \times \left(100\% - WSI\right)\right]} \times 100$$

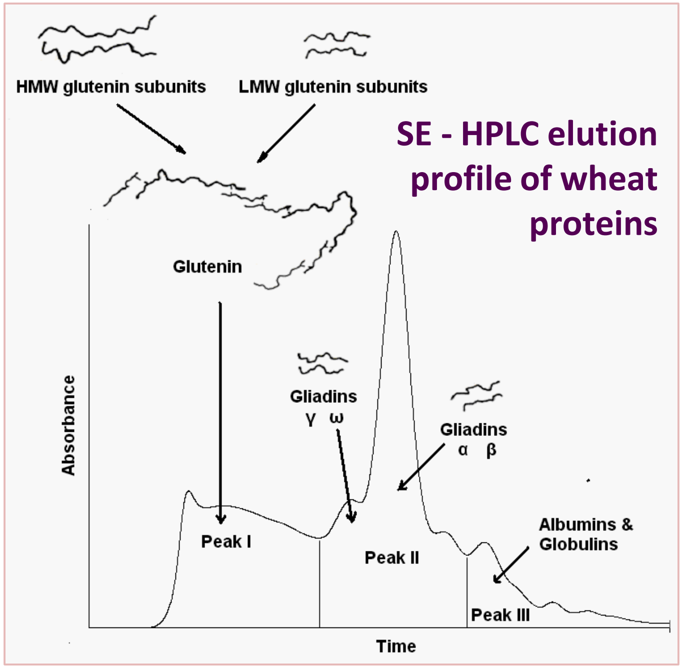
W_s : weight of sediment
W_1 : weight of dry sediment dried

- **Mixing and pasting**
  - Limited water - MixoLab Copin+ protocol, at constant water absorption
  - Excess water - AACC method 76-21 (RVA-4 Perten Instruments)
- **Degree of gelatinization**
  - Using DSC, 1:2 solid:water ratio, 10°C to 100°C @ 2°C/min heating rate

Product Characterization

- **Relative Crystallinity**
  - X-ray diffraction (Rigaku X ray diffractometer)
  - Change in X-ray diffraction patterns and relative crystallinity
- **FT-IR**
  - Perkin Elmer® Spectrum™ 100 FT-IR spectrometer equipped with single reflection diamond attenuated total reflectance (ATR) cell
  - Change in the secondary structure of proteins (shift in frequencies of amide I, II or III band in FTIR spectrum)
- **Protein quality**
  - Size Exclusion HPLC (Bean, Lookhart 2001)

Individual classes, sums and ratios	Description
IPP	Insoluble glutenin polymers of the highest Mw having a greater HMW/LMW subunit ratio than SPP
EP	All proteins soluble in 50% 1-propanol (SPP, Gli, AG)
SPP	Soluble glutenin polymers with a continuous range of molecular sizes and a lower average Mw than IPP, having also a lower HMW/LMW subunit ratio
Gli	Monomers of lower Mw than SPP
AG	Metabolic proteins (non-gluten proteins) of lower Mw than Gli



Before and after heat treatment

Kernel morphology

Significant diff	Moisture cont.	11.3 - 16.2%
Slight decreases	Hardness index	55 - 75
No significant diff	Weight	25.1 - 28.9 mg
	Diameter	2.43 - 2.58 mm

Composition (proximate analysis)

Protein and ash content remained fairly constant, as expected.
Moisture content varied significantly in treated flours due to their large surface area, while the moisture content of treated grain varied minimally.

Color

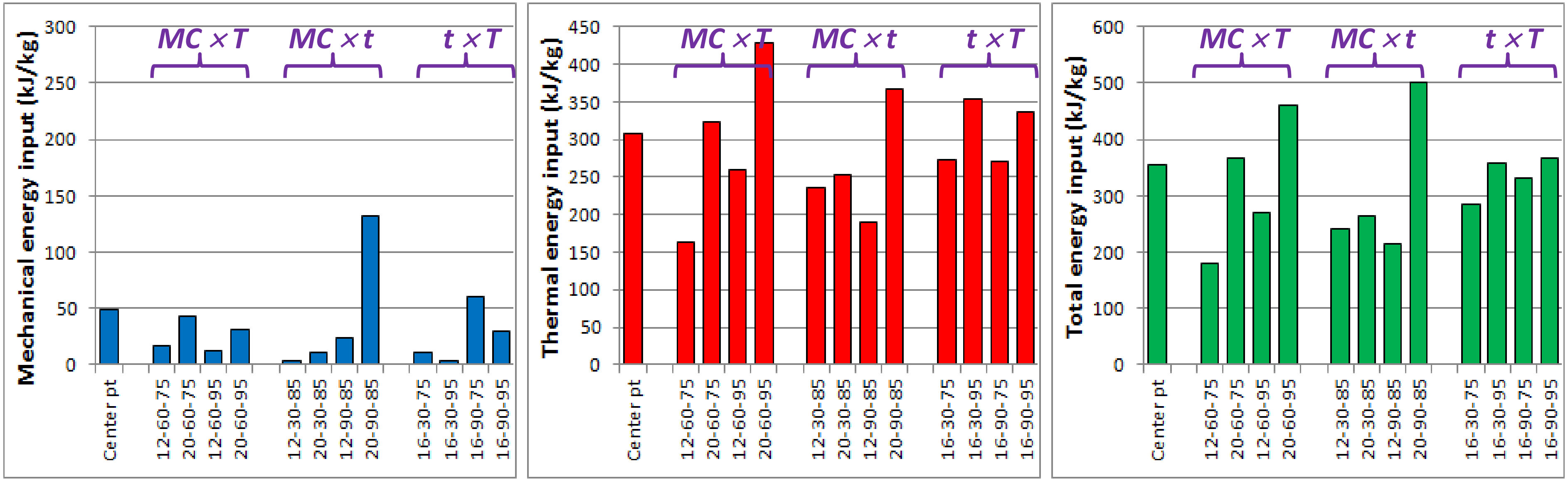
Slight decrease in whiteness of treated whole wheat flour (TWWF) (81.5 versus 76.3 – 79.8)
Slight improvement in whiteness of treated grain whole wheat flour (TGWWF) (77.2 versus 77.6 – 79.3)

Milling performance

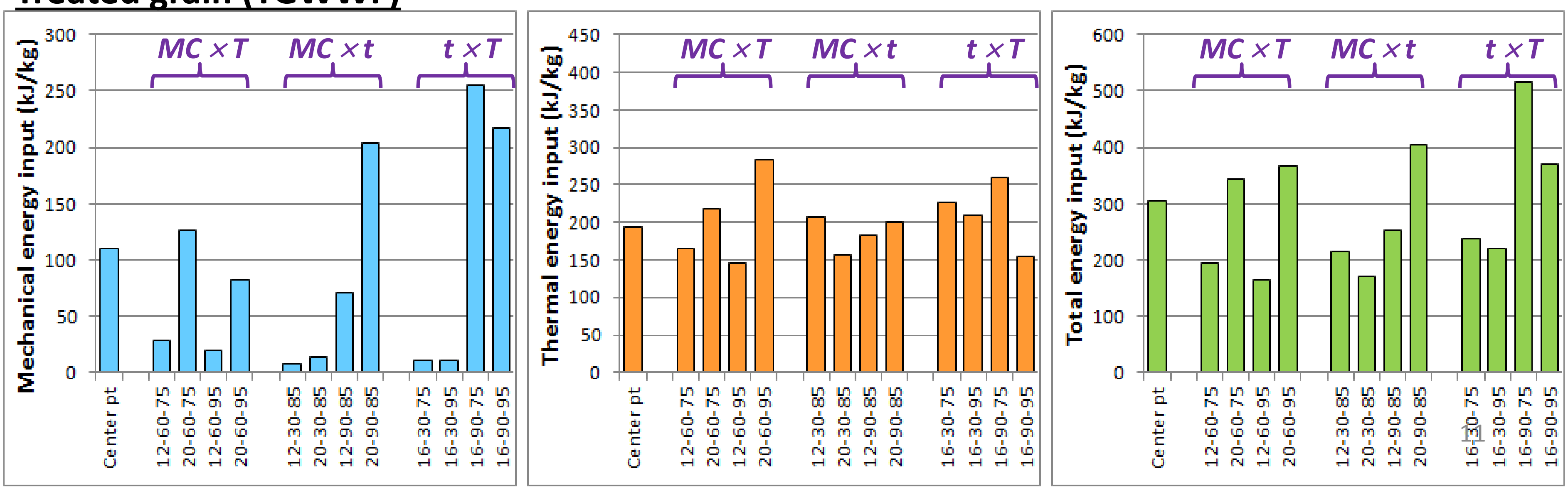
Straight grade flour extraction rate : 69.4 - 74.0%
Milling efficiency for all treatments : 94.8 - 98.6%

Energy input

Treated flour (TWWF)

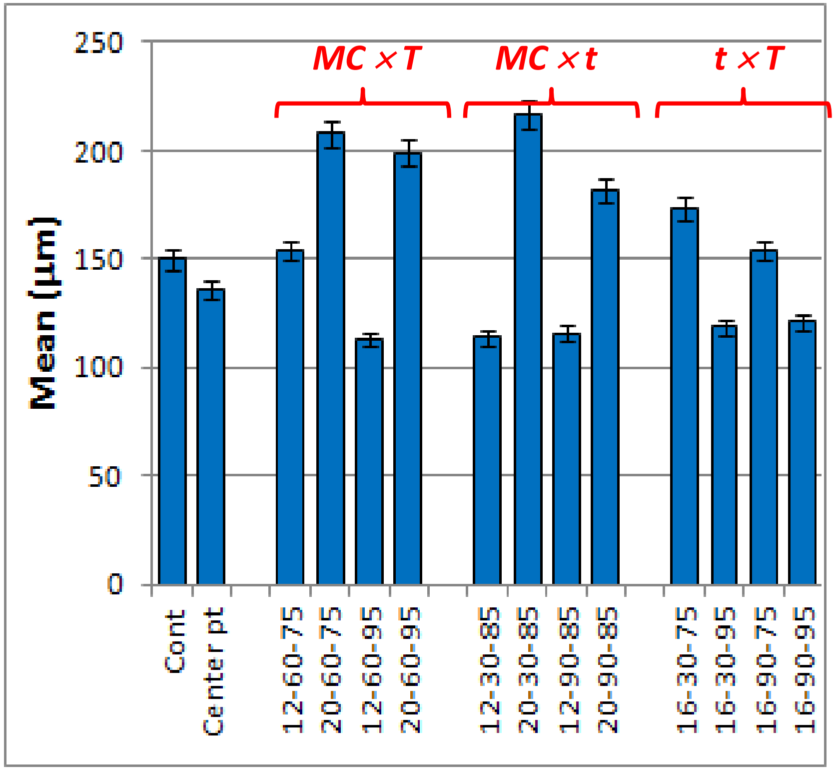


Treated grain (TGWWF)

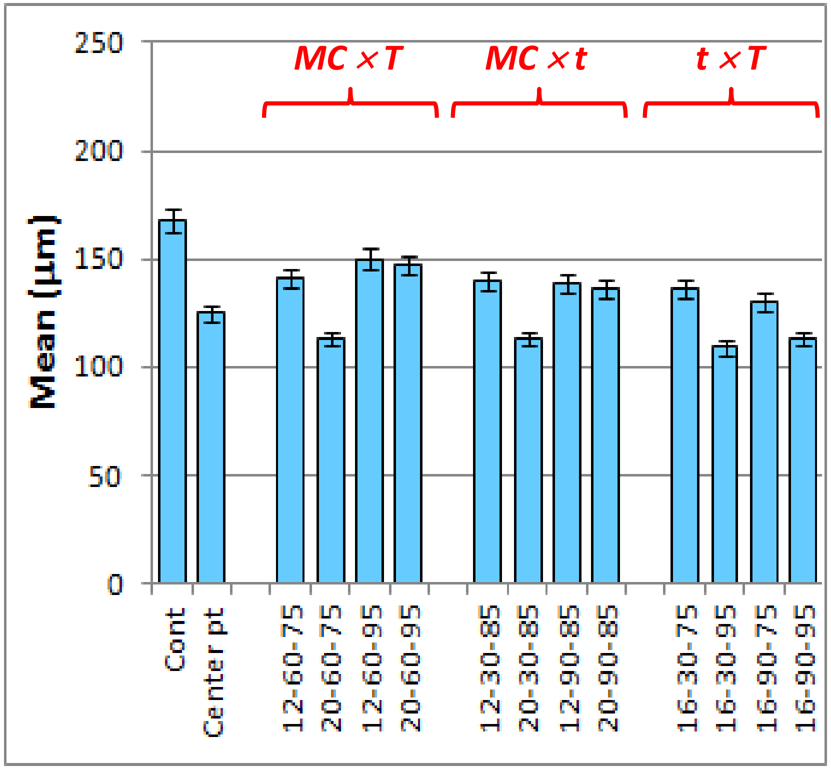


Particle Size Distribution

Treated flour

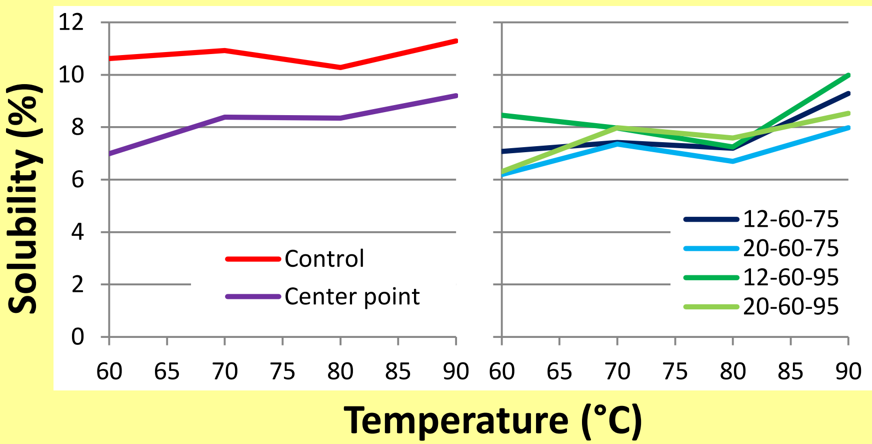


Treated grain

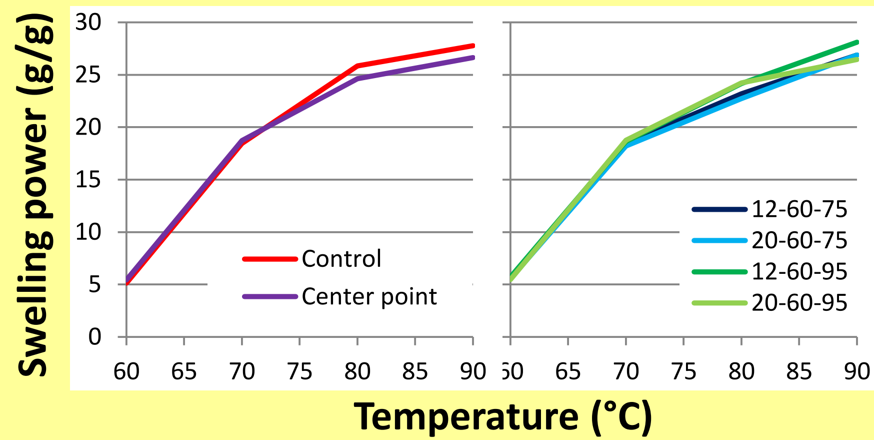


Solubility   *Swelling power*

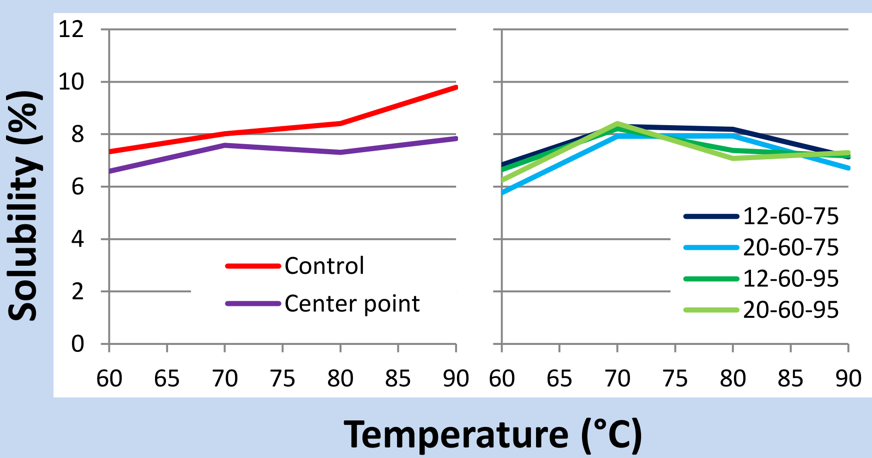
TWWF



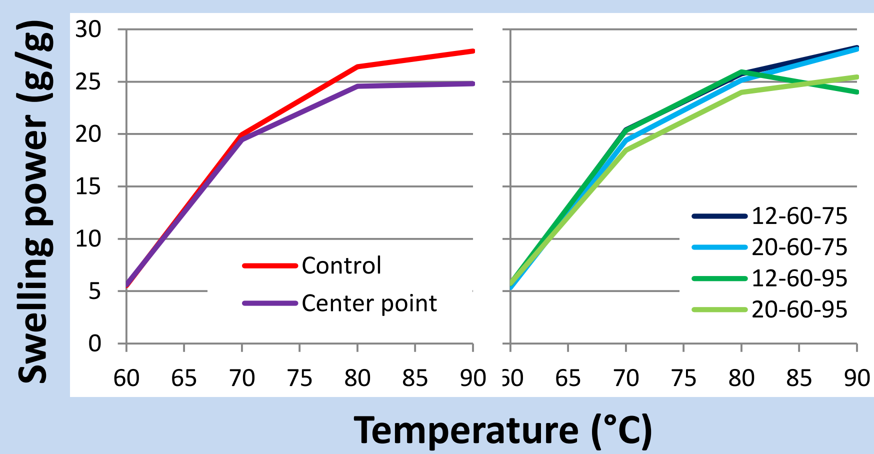
TWWF



TGWWF

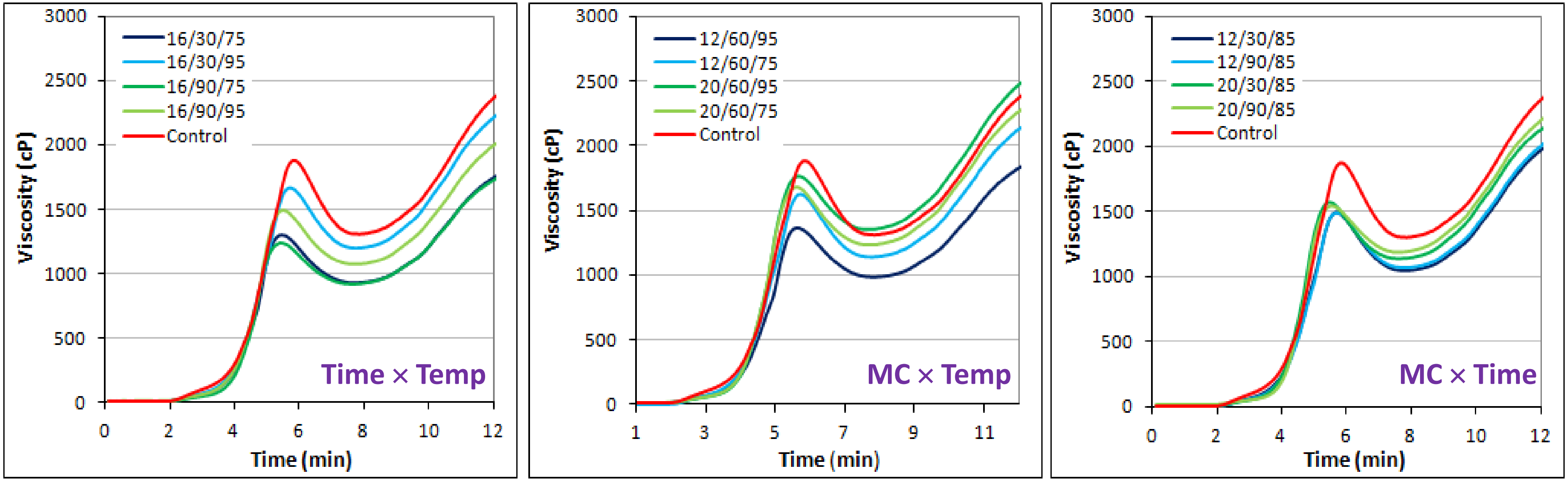


TGWWF

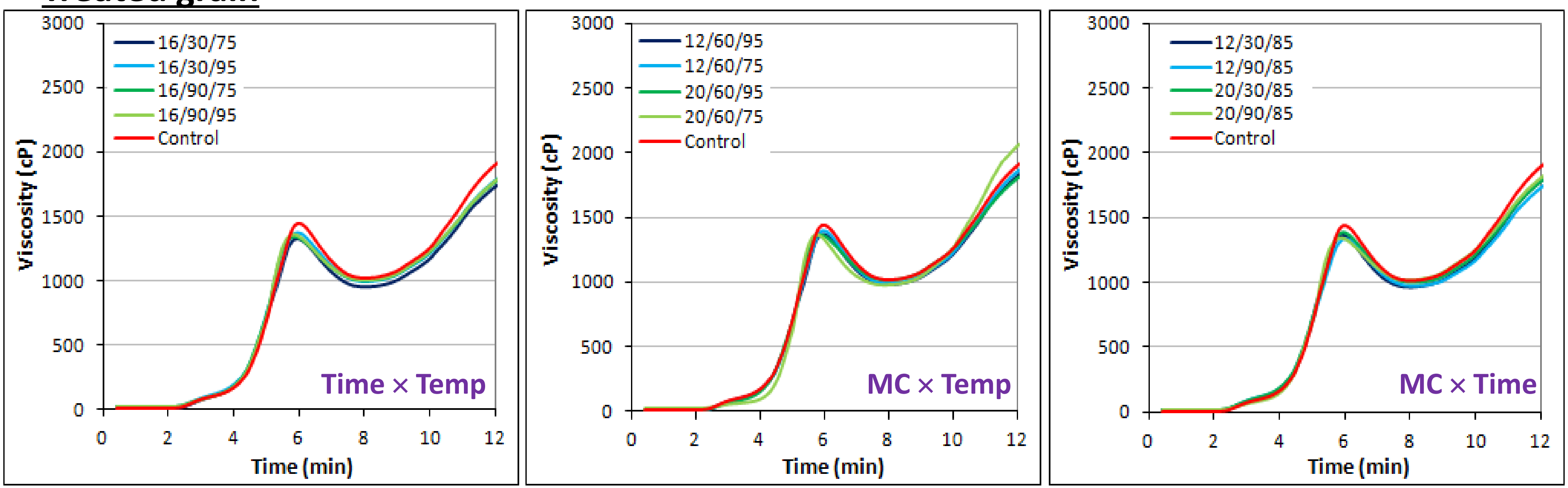


RVA Pasting Profiles

Treated flour

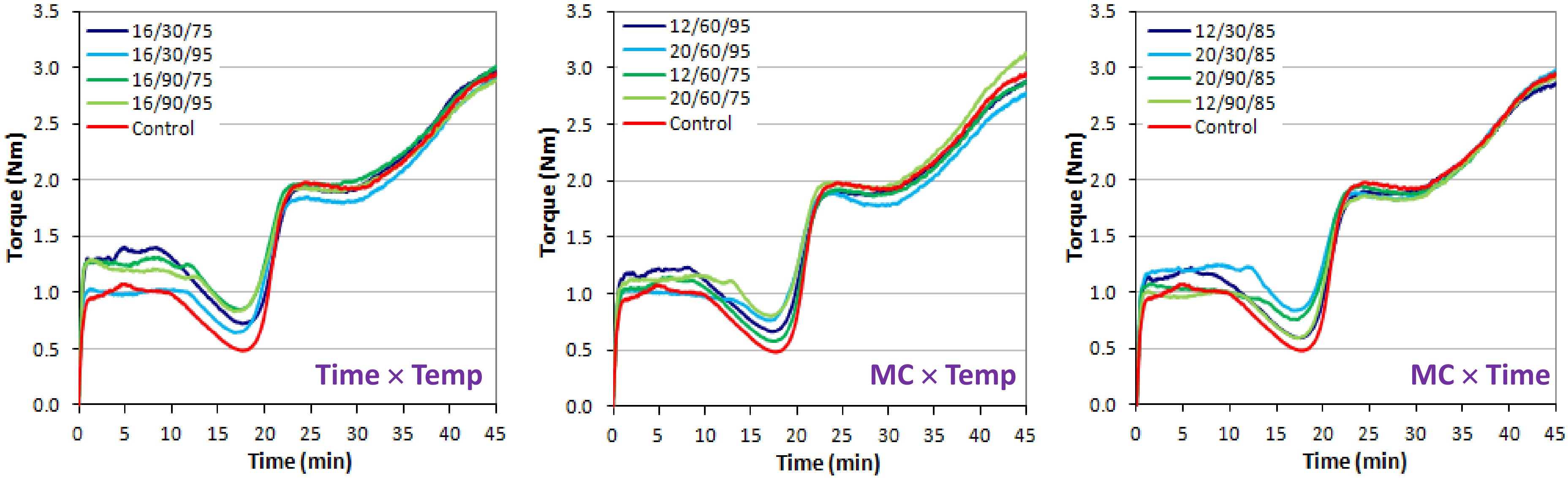


Treated grain

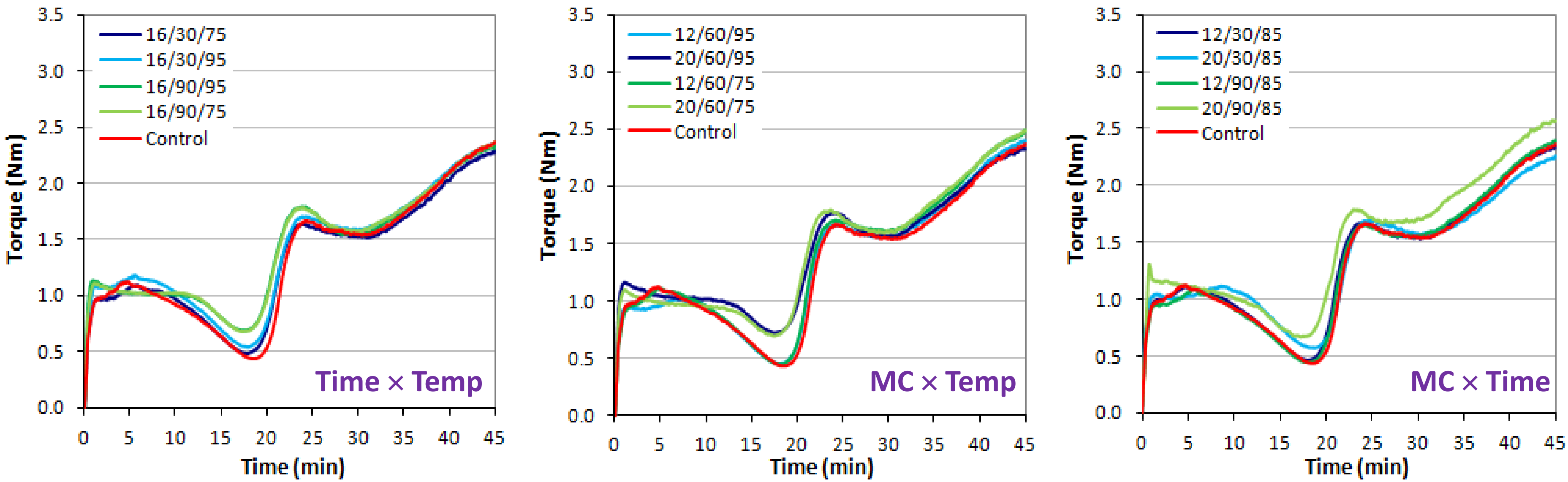


MixoLab Profiles

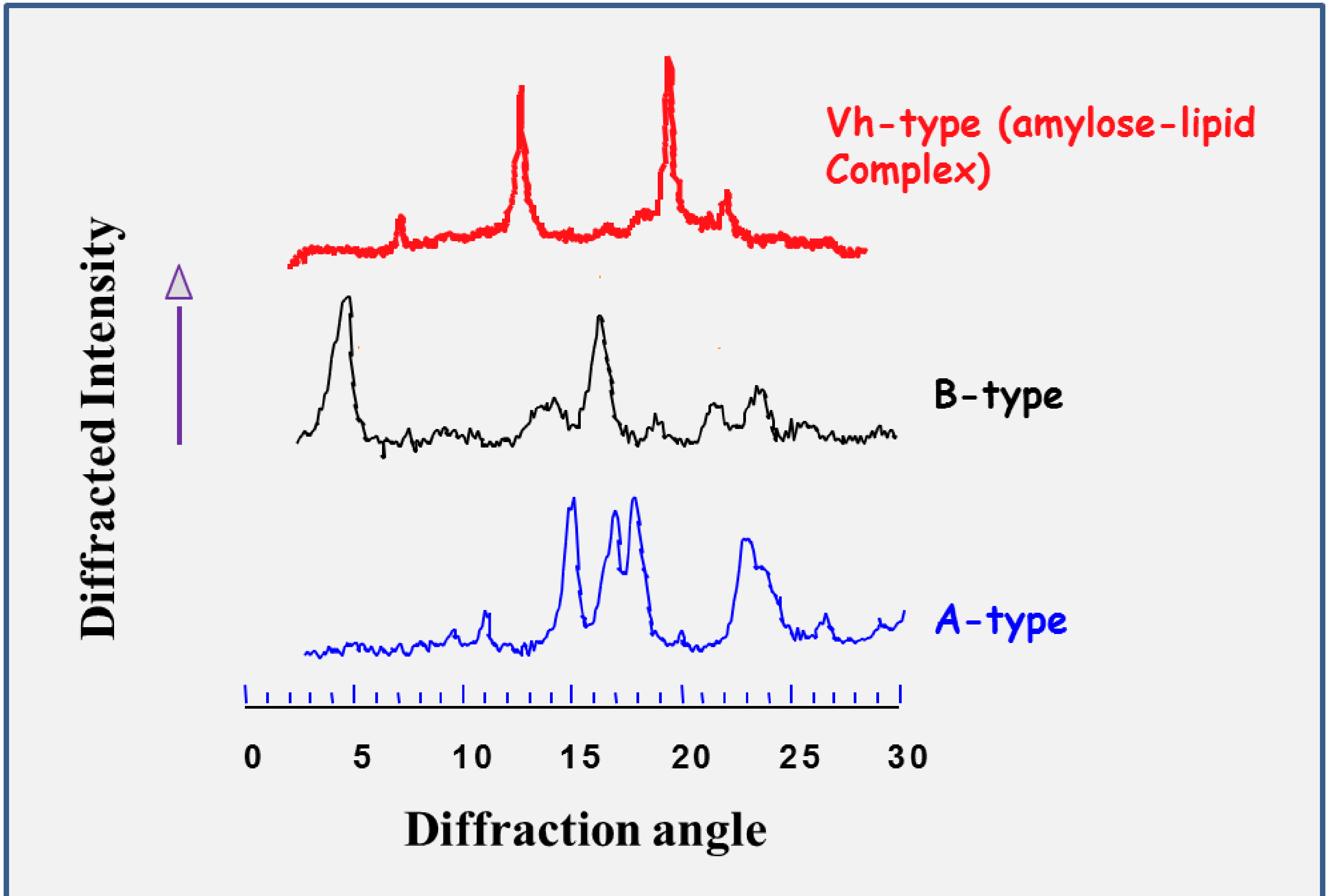
Treated flour



Treated grain



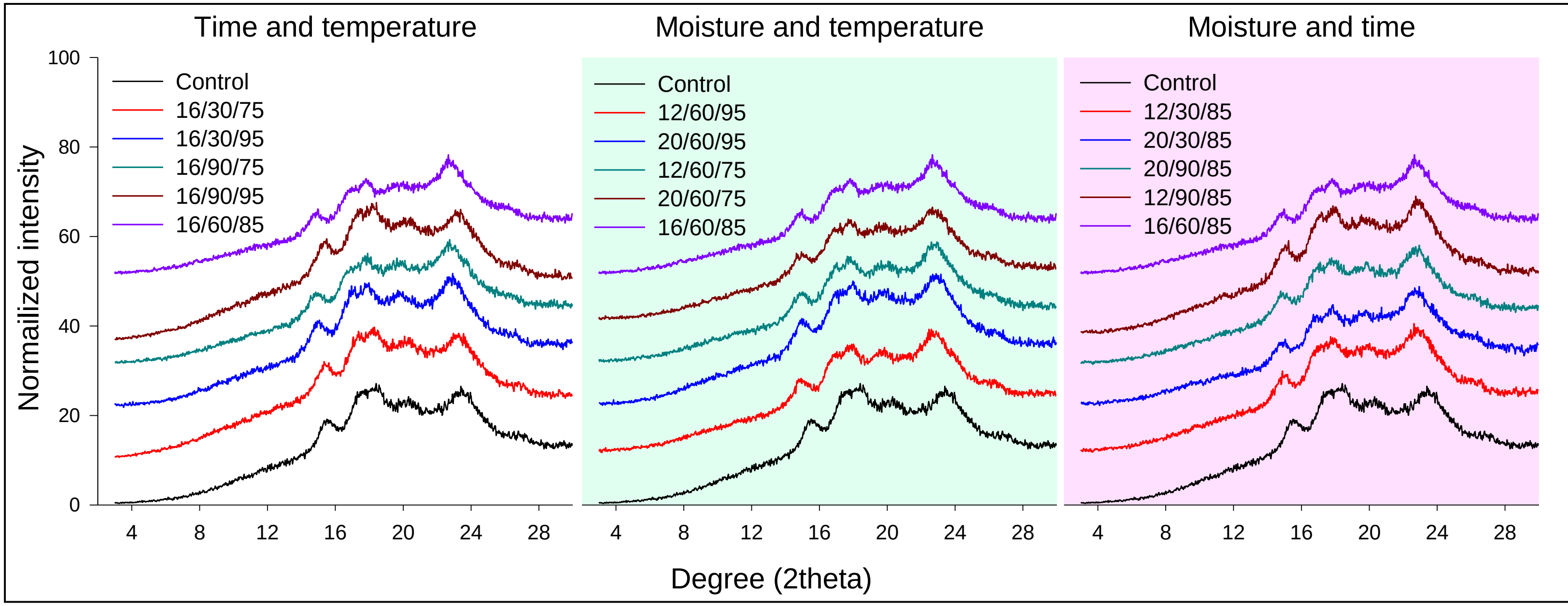
Typical crystallinity types



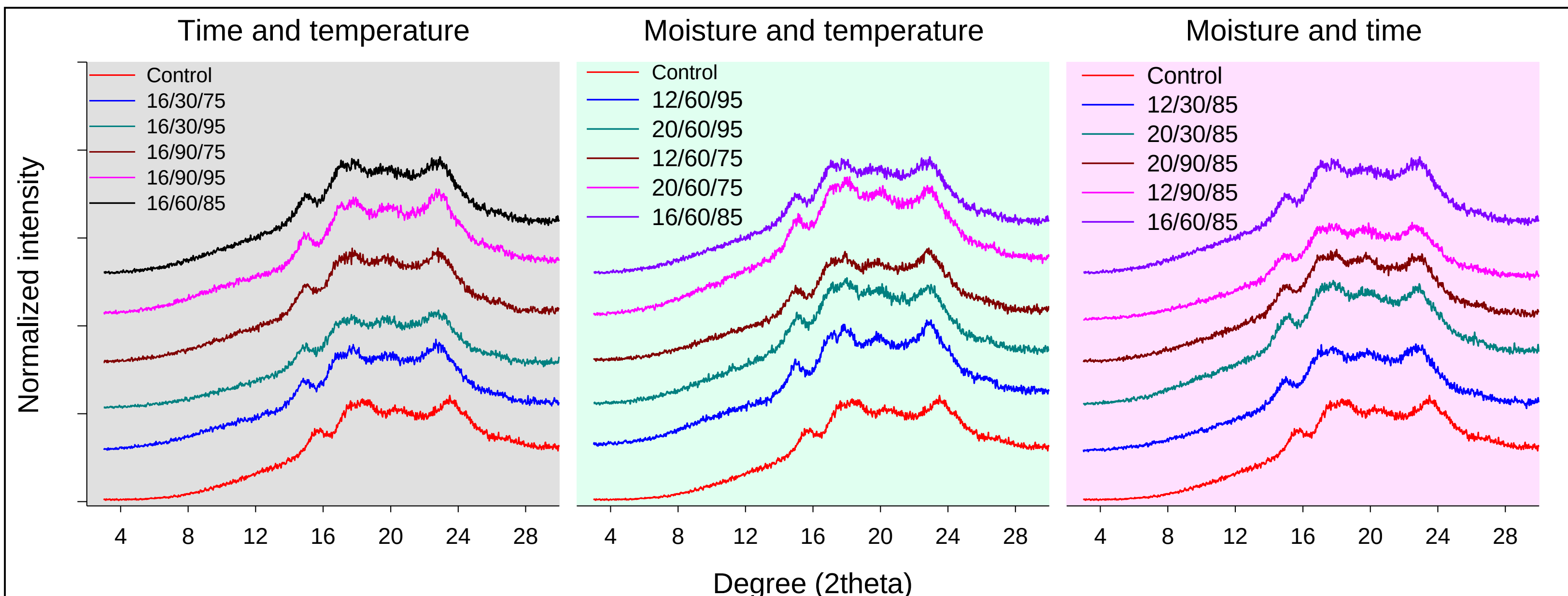
(Gerard et al. 1999)

Relative crystallinity

TWWF



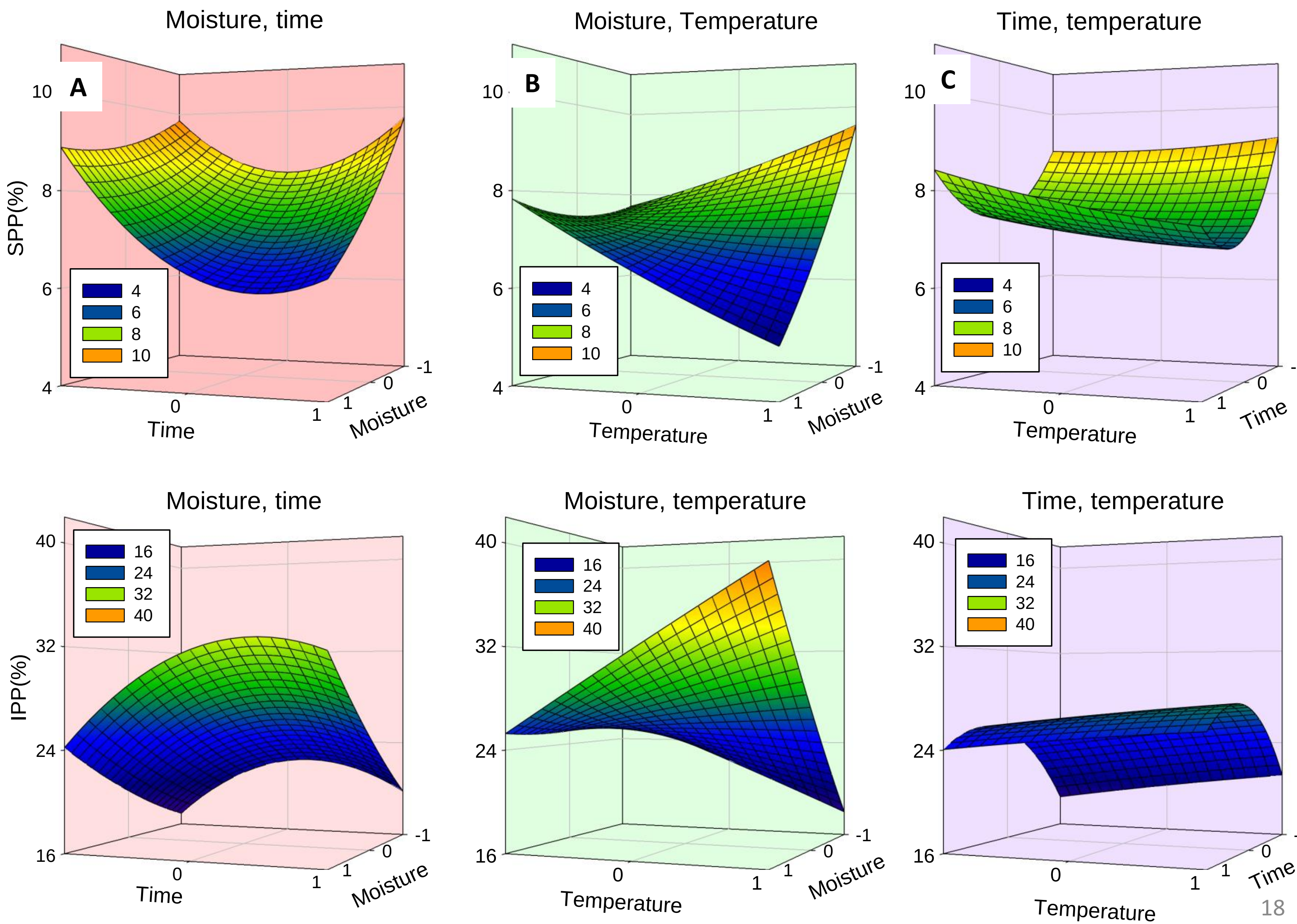
TGWWF



Protein extractability

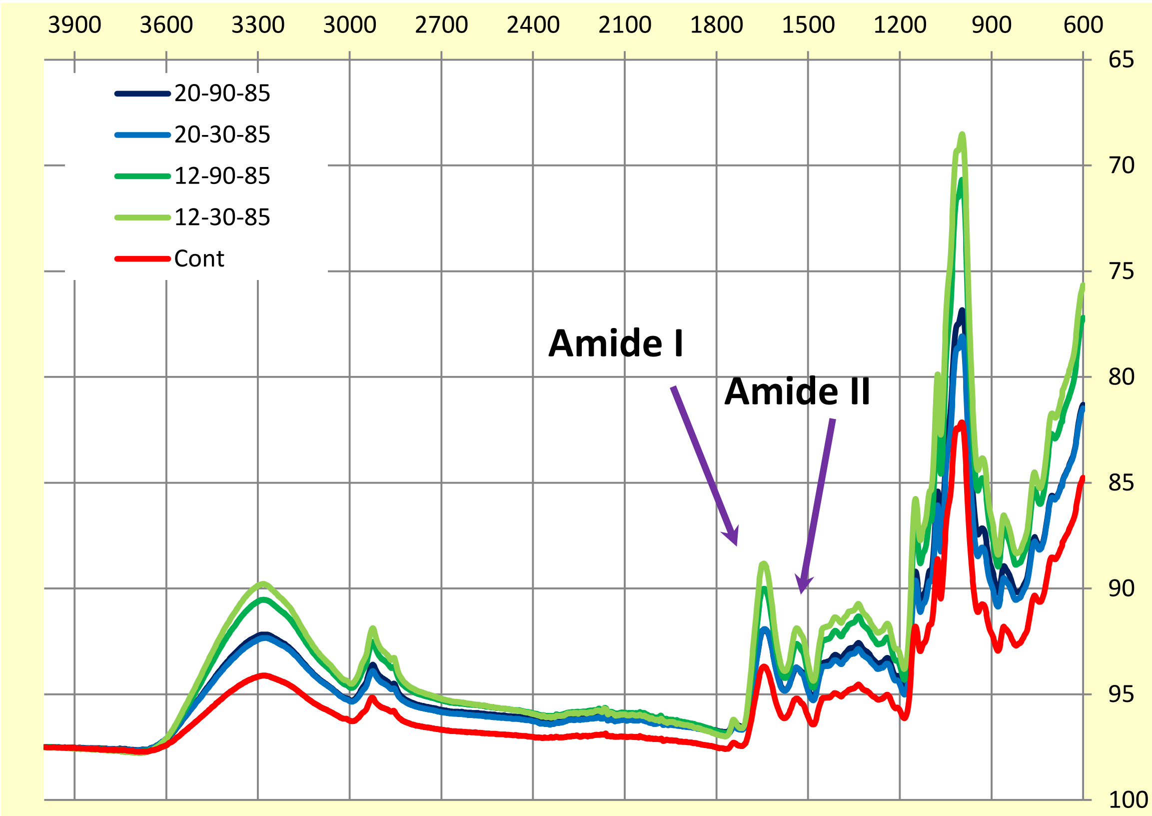
SPP

IPP

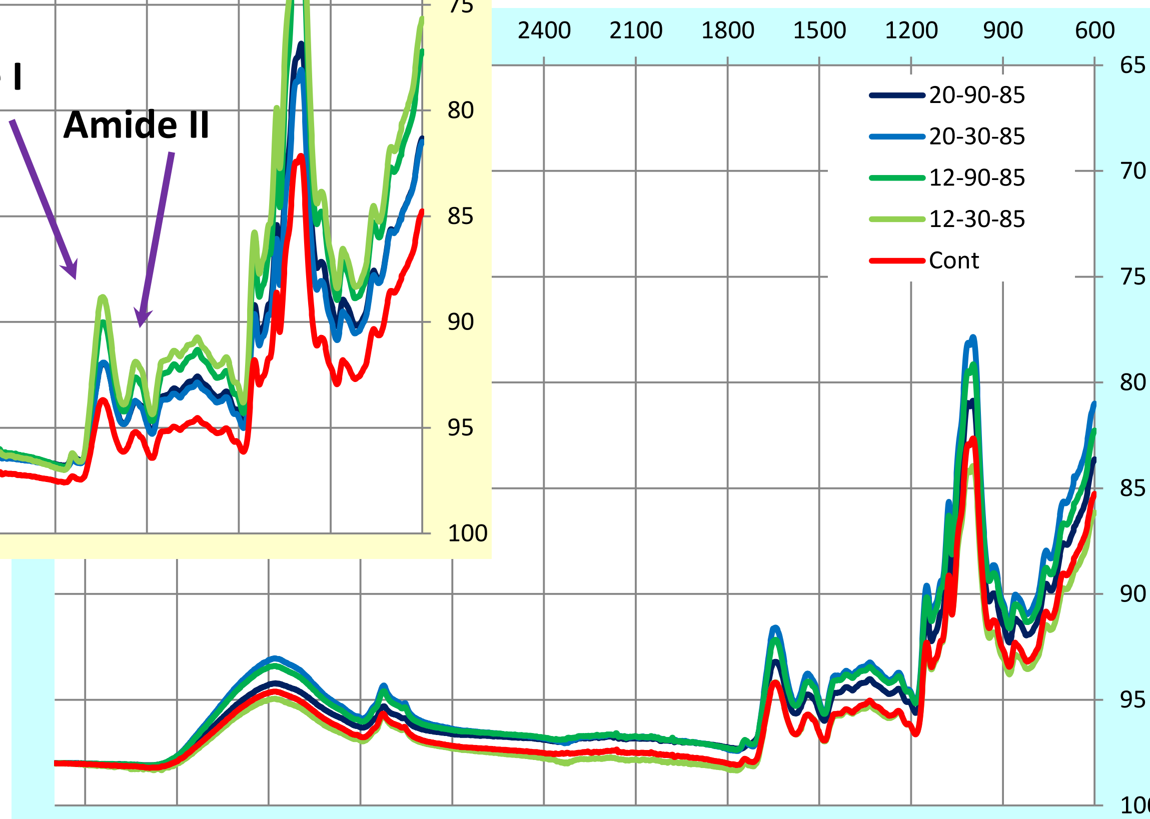


FTIR spectra of select samples

Treated flour



Treated grain



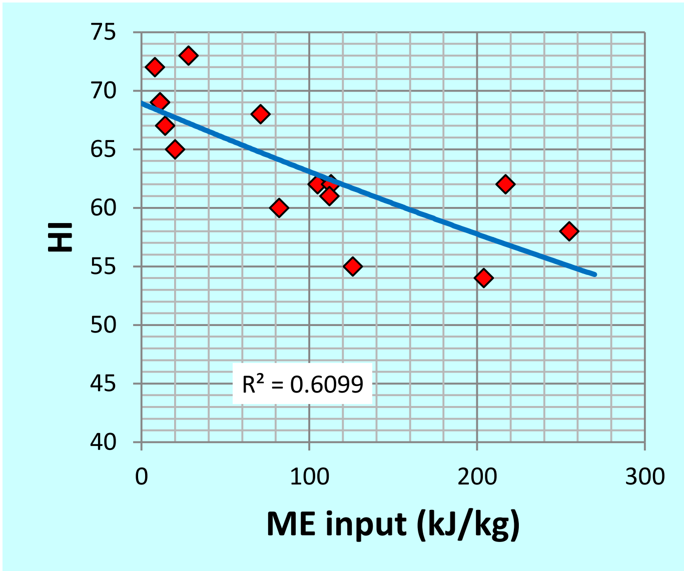
position (cm^{-1})	assignment
1699–1698	turns or β hairpins
1684–1681	β sheets
1670–1665	β turns
1650–1649	random coils and α helices
1632–1629	antiparallel β sheets, more weakly hydrogen-bonded β sheets
1614–1613	strongly hydrogen-bonded β sheets, β edges, extended hydrated chains,[a] some possible contribution from glutamine side chains, intermolecular β sheets
1598–1594	glutamine side chain (NH_2)

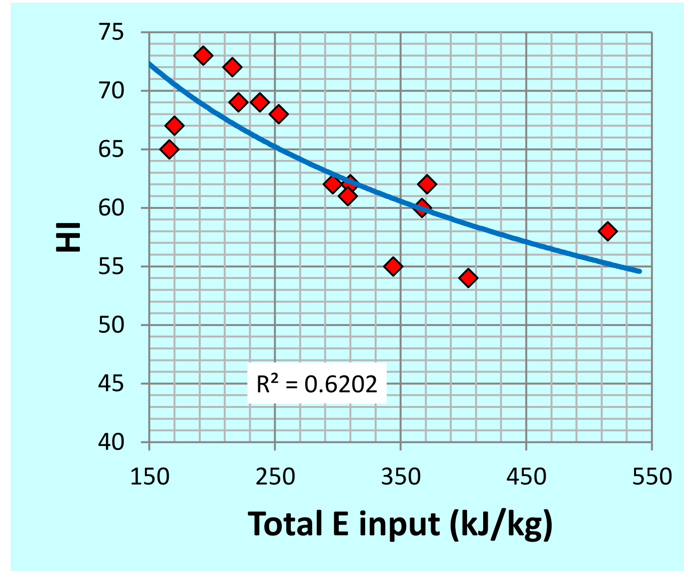
Interrelationship between the <u>system</u> and <u>product</u> parameters

Energy input vs kernel hardness

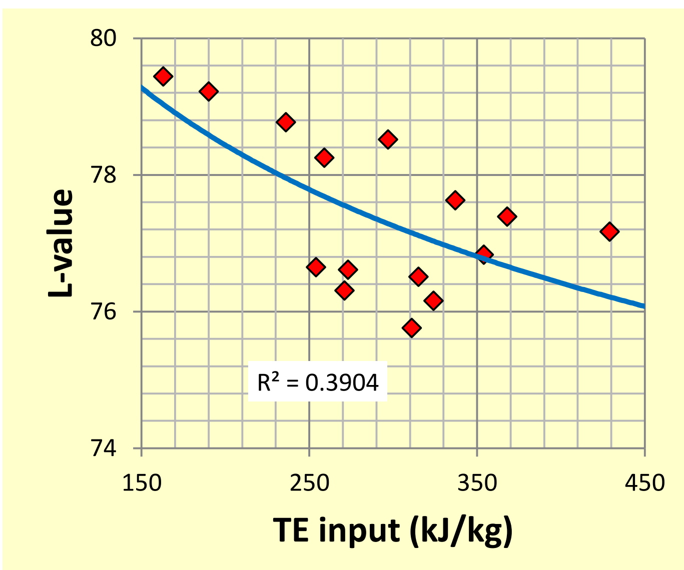
TGWWF

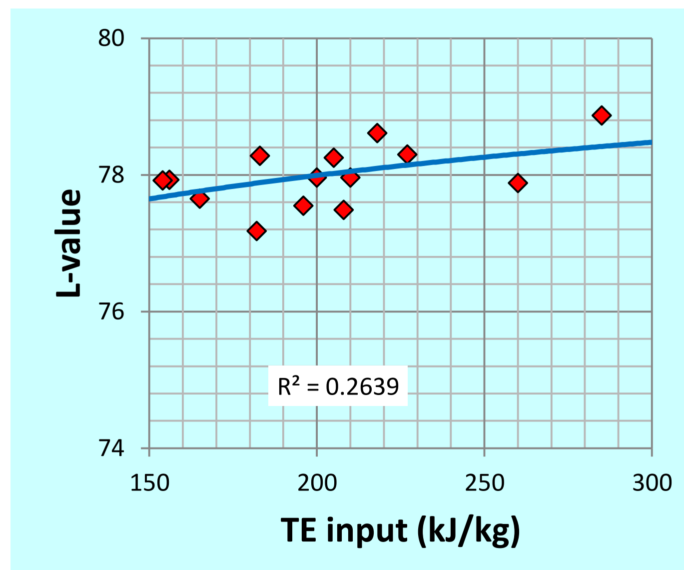
TWWF





Thermal energy input vs color

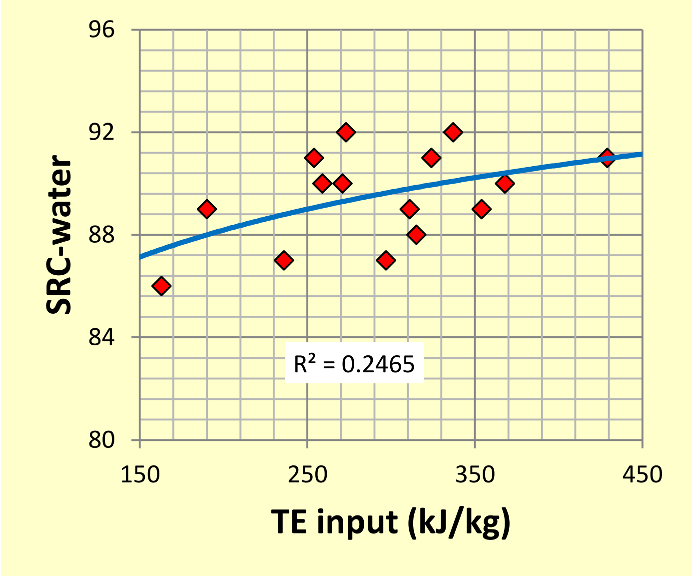


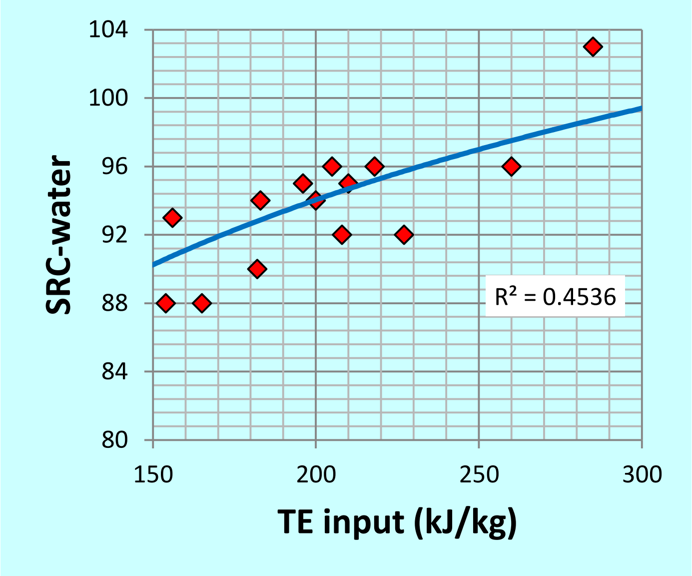


Thermal energy input vs water holding capacity

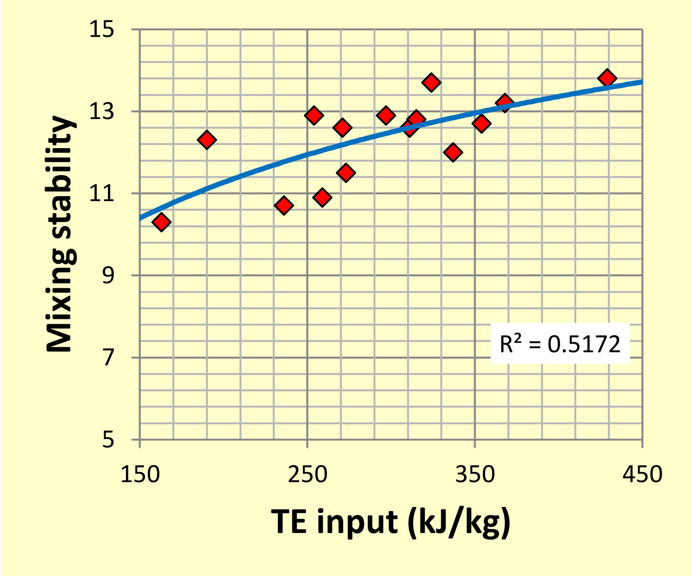
TGWWF

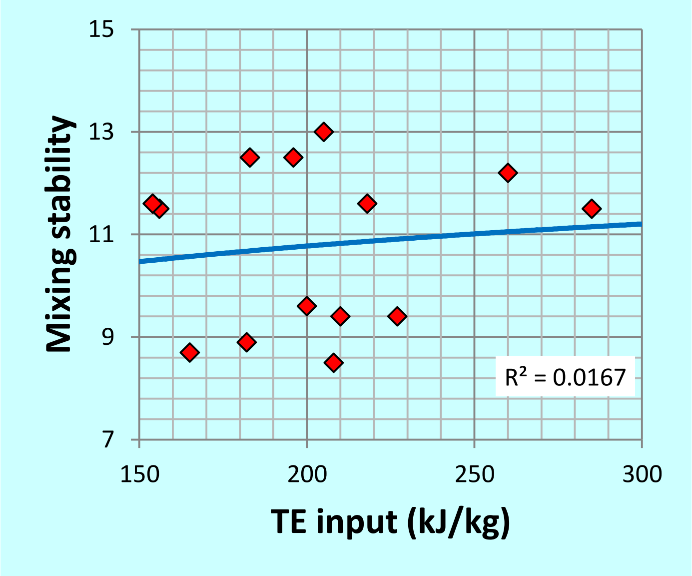
TWWF





Thermal energy input vs mixing stability

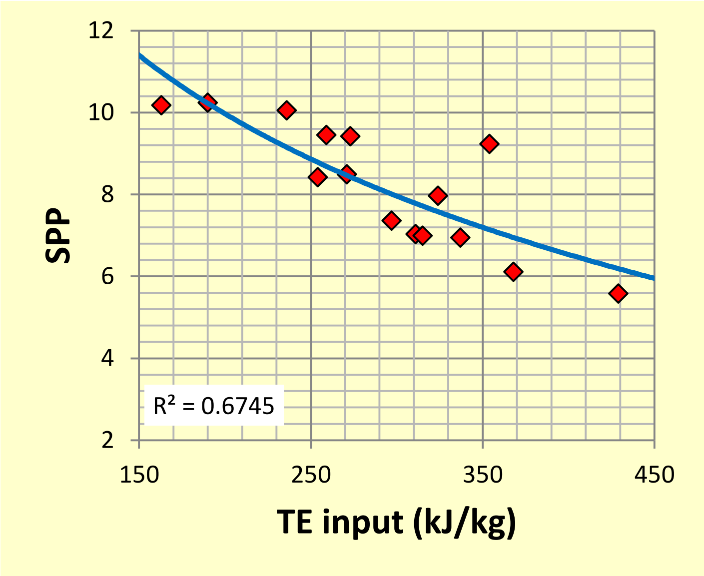


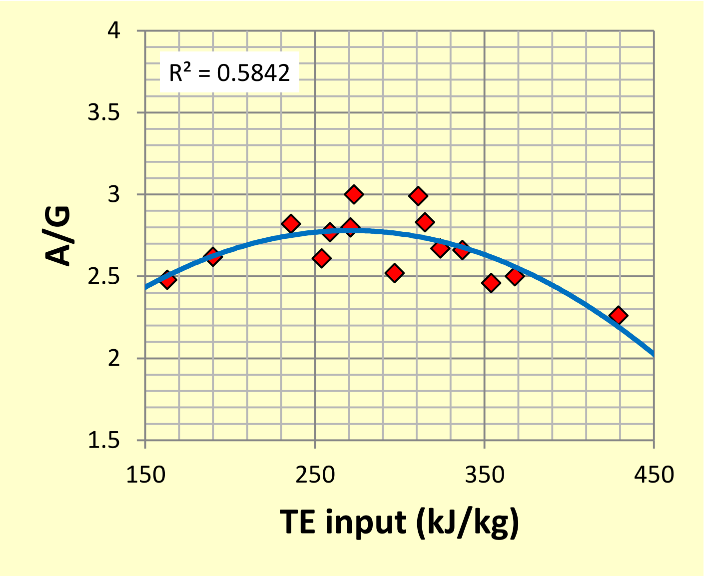


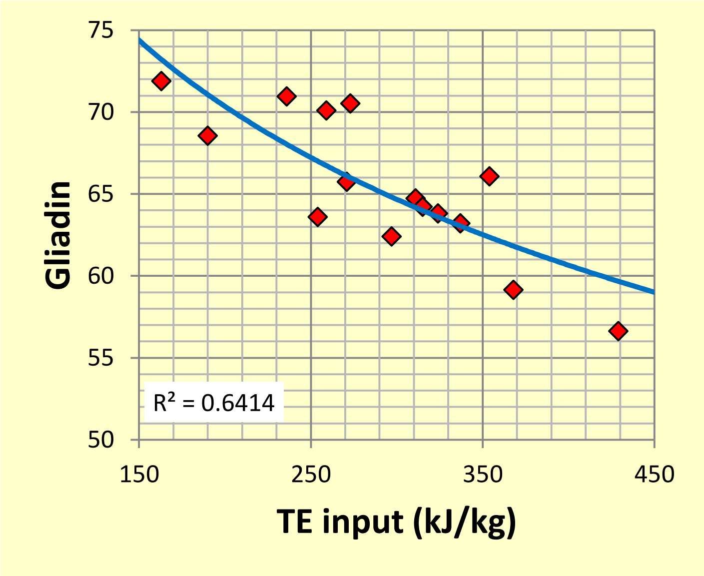
Thermal energy input vs protein quality

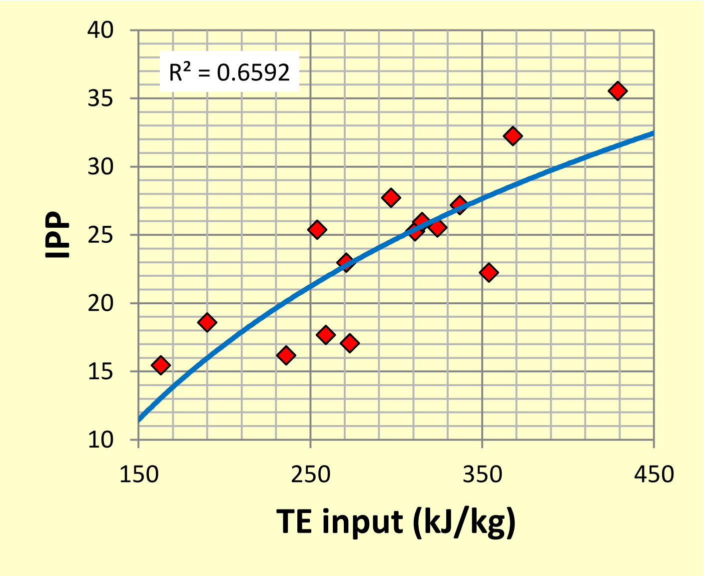
TGWWF

TWWF





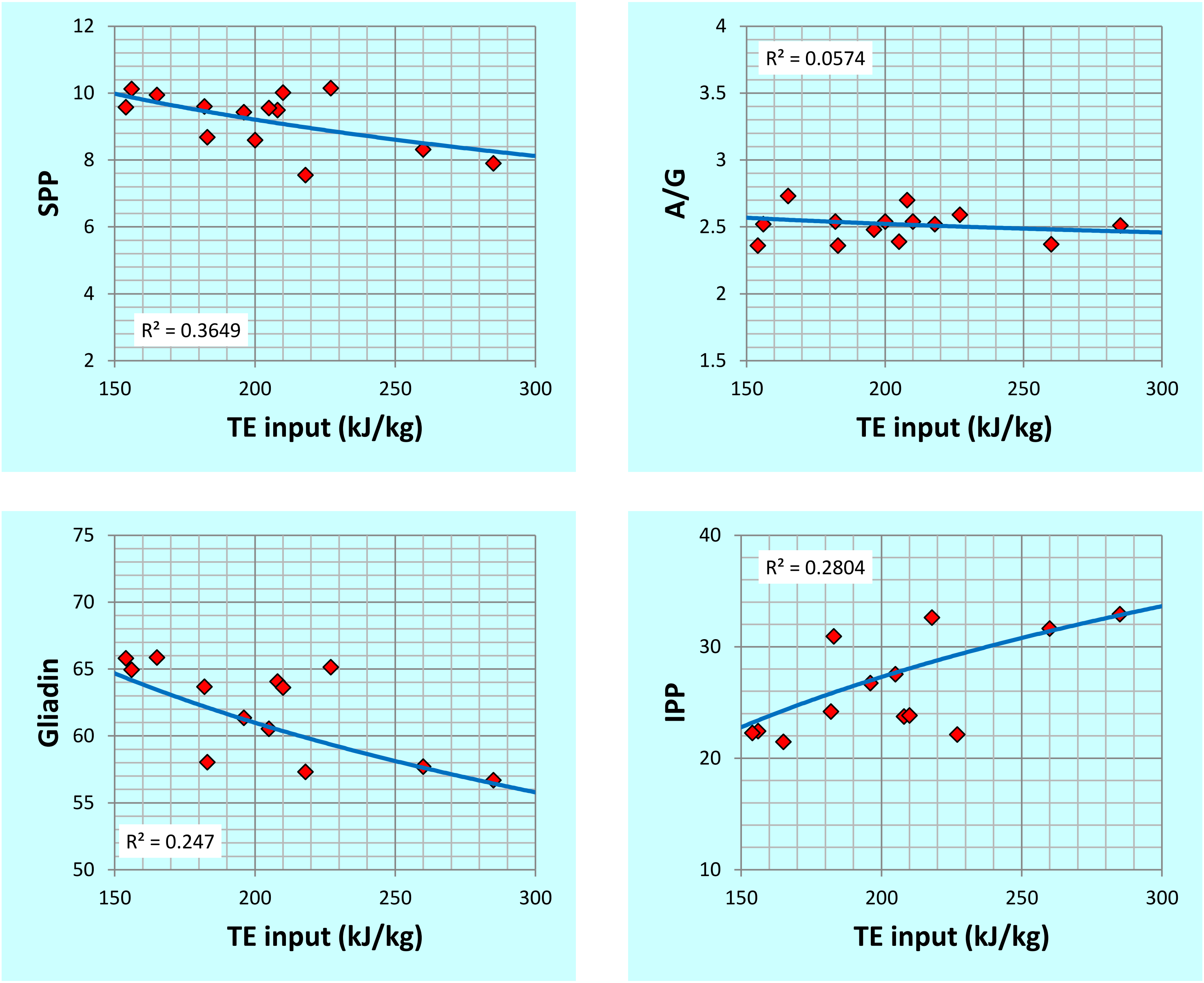




Thermal energy input vs protein quality

TGWWF

TWWF



Summary

- Water holding capacity and the mixing stability of heat treated flours were significantly higher than that of control samples.
- Mechanical energy in put did not correlate well any of the product parameters except for the kernel hardness.
- Thermal energy input is a good predictor change in the percentage distribution of protein fractions.
  - Soluble proteins (SPP, A/G and gliadins) decreased while insoluble proteins (IPP) increased with the intensity of thermal energy input.
- The mathematical models relating input parameters to the response functions will be useful in predicting the end product quality at a given process condition.
- *Solidaire* heating unit is very effective in processing whole wheat flour and wheat grain. Process parameters can easily be manipulated in a controllable manner to achieve targeted end-quality and functionality.

Acknowledgements

Dr. Scot Bean, Dr. Jeff Wilson, Reth Koufman, Bryan Ioerger (USDA-ARS)
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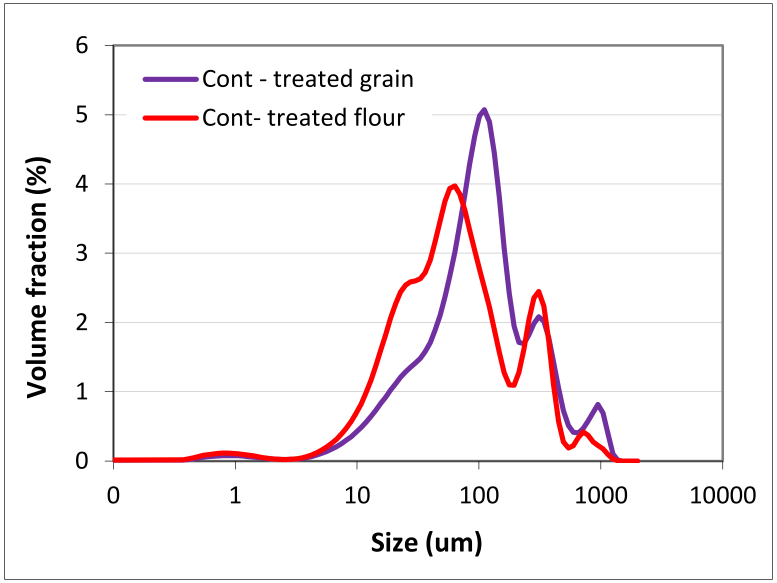
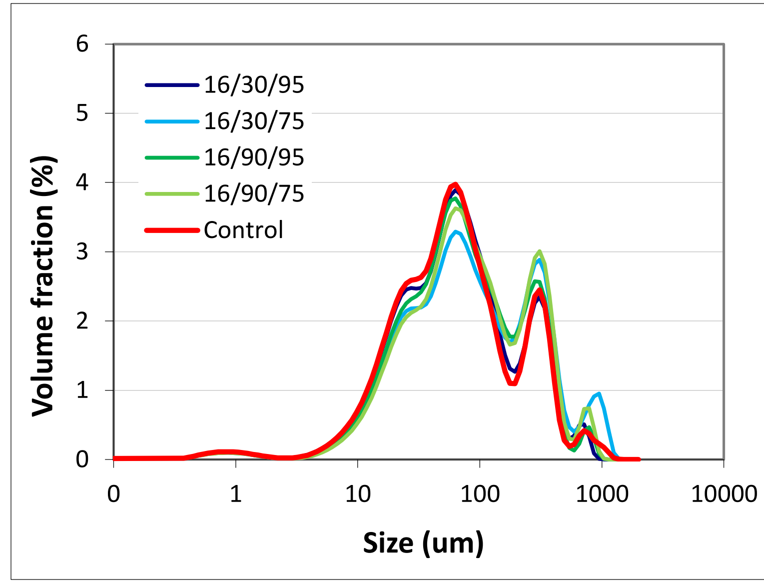
Bepex Technologies LLC, Minneapolis, MN

Questions?

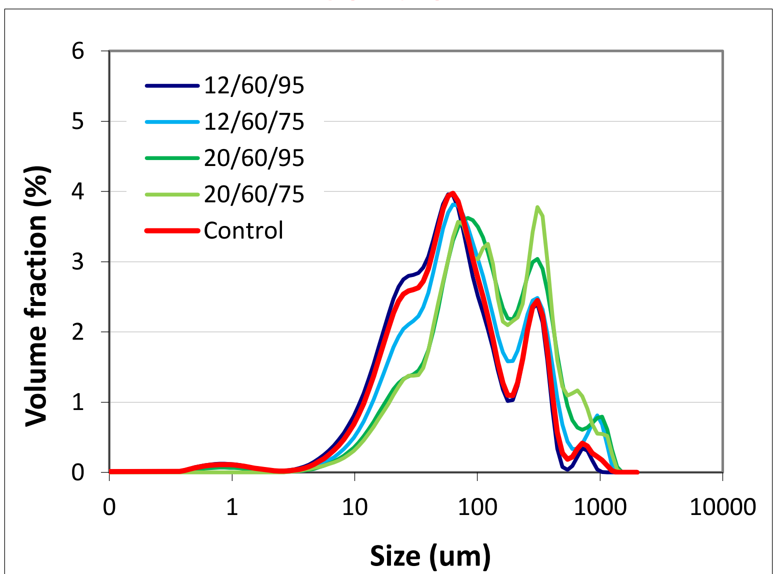
PSD - Treated whole wheat flour



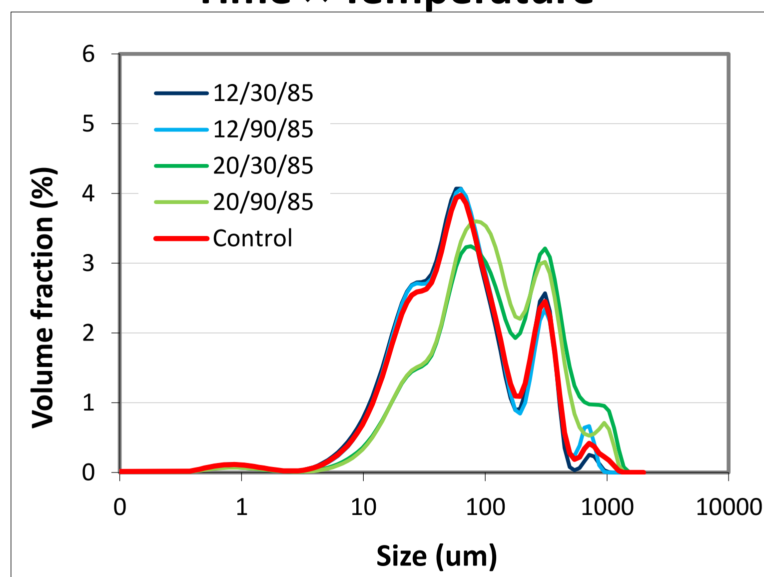
Control



Time × Temperature

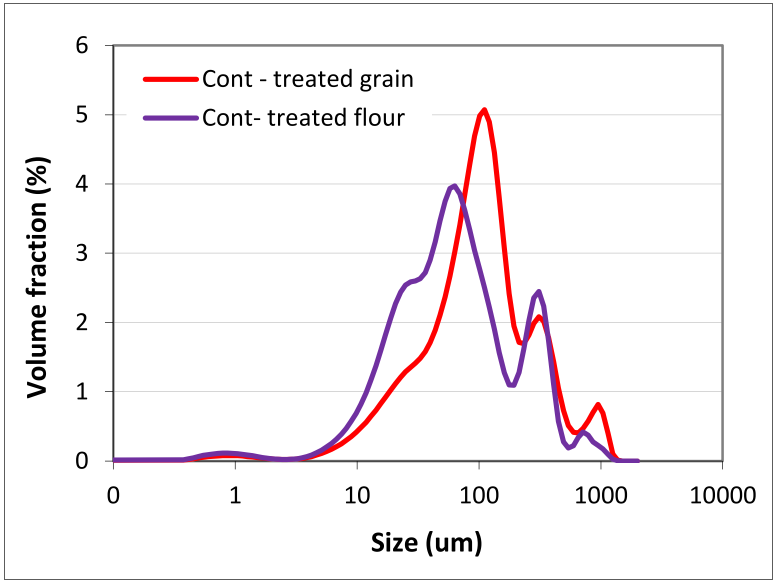


Moisture × Temperature

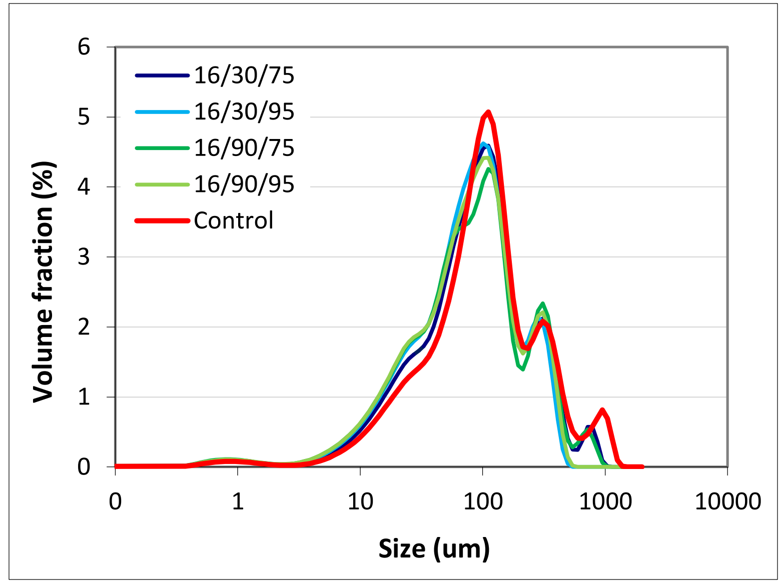


Moisture × Time

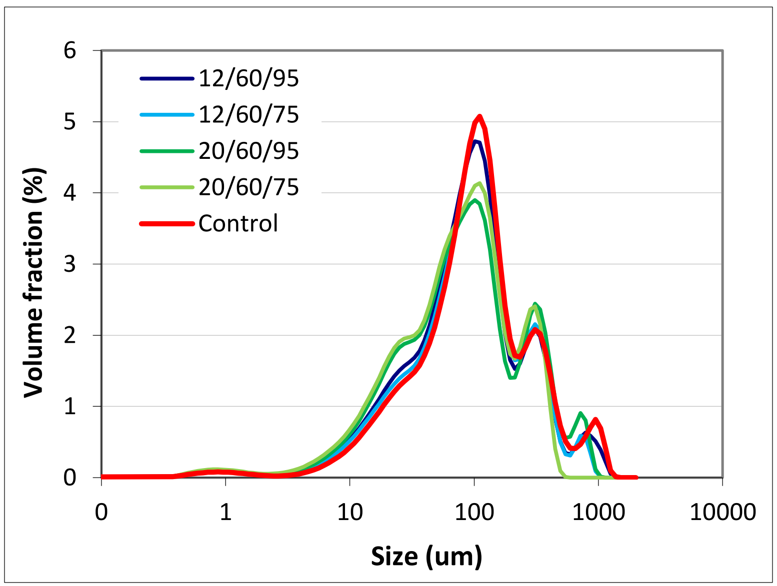
PSD - Treated grain whole wheat flour



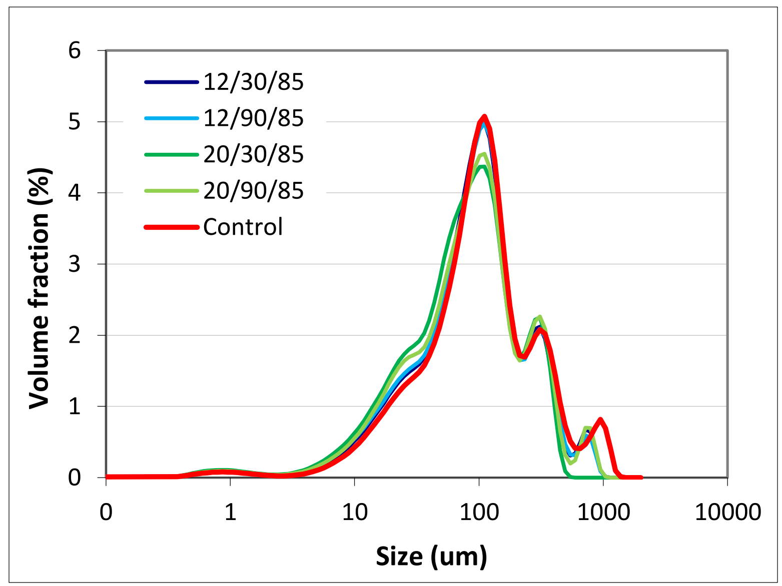
Control



Time × Temperature



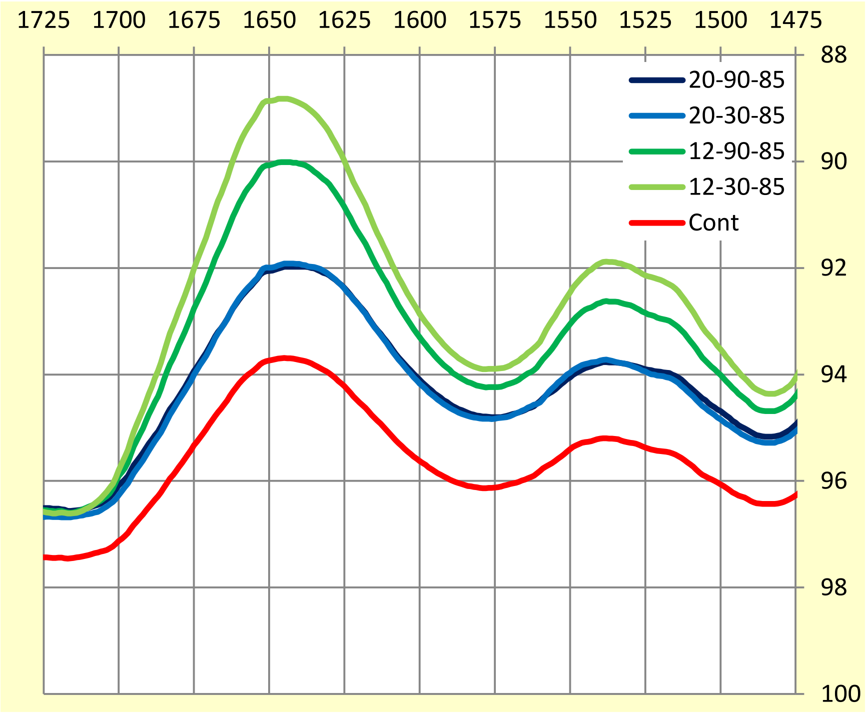
Moisture × Temperature



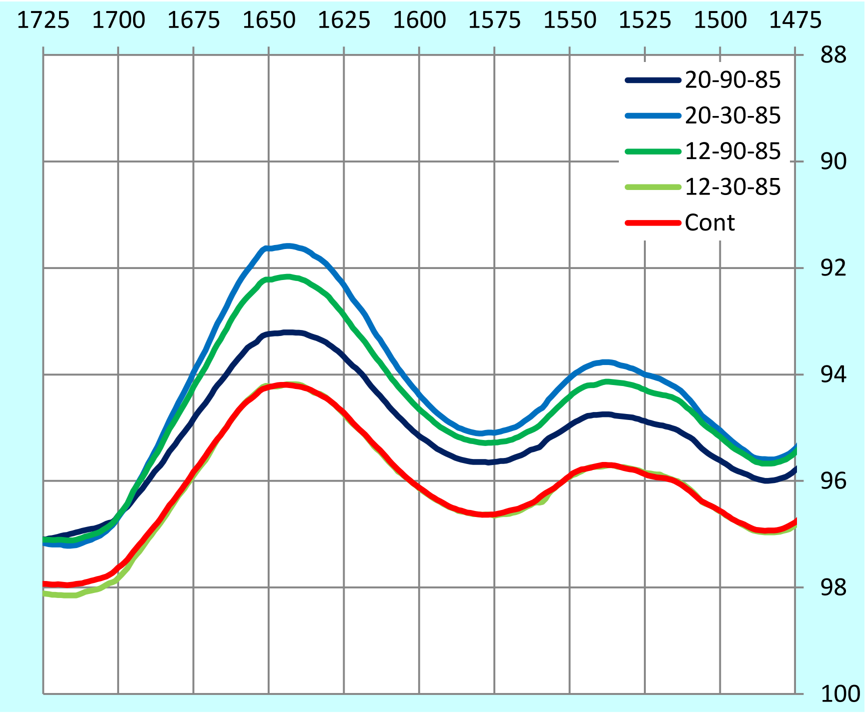
Moisture × Time

Amide I and Amide II

Treated flour



Treated grain



FTIR deconvolution Assignment for secondary structure analysis of the amide I and amide II bands

position (cm^{-1})	assignment
1699−1698	turns or β hairpins
1684−1681	β sheets
1670−1665	β turns
1650−1649	random coils and α helices
1632−1629	antiparallel β sheets, more weakly hydrogen-bonded β sheets
1614−1613	strongly hydrogen-bonded β sheets, β edges, extended hydrated chains,[a] some possible contribution from glutamine side chains, intermolecular β sheets
1598−1594	glutamine side chain (NH_2)

Gluten components with different degree of polymerization *(Schober et al. 2006)*

Individual classes, sums and ratios	Description
IPP	Insoluble glutenin polymers of the highest Mw having a greater HMW/LMW subunit ratio than SPP
EP	All proteins soluble in 50% 1-propanol (SPP, Gli, AG)
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Gli	Monomers of lower Mw than SPP
AG	Metabolic proteins (non-gluten proteins) of lower Mw than Gli
IPP/EP	Ratio of insoluble (highest Mw polymers) to 50% 1-propanol soluble proteins (SPP, Gli, AG)
IPP/SPP	Ratio of insoluble (large) to soluble (smaller) glutenin polymers
IPP/Gli and SPP/Gli	Ratio of large and smaller glutenin polymers, respectively, to monomers
(IPP+SPP)/Gli	Ratio of glutenin (polymers of all sizes) to gliadin
IPP/(SPP+Gli)	Ratio of insoluble to soluble gluten proteins (AG excluded)
IPP [%]+SPP [%]	Percentage of glutenin in flour protein
SPP [%]+Gli [%]	Percentage of soluble (lower Mw) gluten proteins in flour protein

RSM – Box Behnken design

	Coded			Un-coded		
Treatment ID	X_1	X_2	X_3	*Moisture (%)*	*Time (s)*	*Temperature (°C)*
1	-1	0	-1	12	60	75
2	1	0	-1	20	60	75
3	-1	0	1	12	60	95
4	1	0	1	20	60	95
5	-1	-1	0	12	30	85
6	1	-1	0	20	30	85
7	-1	1	0	12	90	85
8	1	1	0	20	90	85
9	0	-1	-1	16	30	75
10	0	-1	1	16	30	95
11	0	1	-1	16	90	75
12	0	1	1	16	90	95
13	0	0	0	16	60	85
14	0	0	0	16	60	85
15	0	0	0	16	60	85

Objectives

- Develop an indirect, rapid and continuous thermal processing technique for treating whole wheat flour and whole grain (to reduce microbial load) while preserving or improving the flour functionality in targeted applications.
- Characterize the resulting functional wheat flours for their mixing, pasting, and breadmaking performance.
- Explore the potential use of these new products in dough- and batter-based formulations.

Data Analysis

Means comparisons

- Analyzed using analysis of variance (ANOVA) with the GLM procedure
- Bonferroni multiple-range tests indicated by ANOVA, significance at $p < 0.05$

Correlations

- Pearson's coefficient of correlation (r)

Mathematical modeling

- *Step-1* Stepwise regression to identify the relevant variables
- *Step-2* Multiple regression (standard least square fitting) to fit a second order mathematical model, according to the following polynomial equation:

$$y = B_0 + \Sigma B_i X_i + \Sigma B_{ii} X_i^2 + \Sigma B_{ij} X_{ij}$$

where y is the dependent variable (i.e. response), B_0 is a constant value, i and j are the independent variables in coded values, and B_i ,B_{ii} and B_{ij} are the regression coefficients of the model