STARCH GELATINIZATION:
A KEY STEP IN EFFICIENT ETHANOL PRODUCTION

5th Annual James B. Beam Institute Industry Conference
March 13, 2024

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A Reimagined Innovation Partner…

Unmatched scale, R&D capabilities and portfolio strength to lead industry evolution

With A Leading Portfolio To Address Evolving Consumer Trends…

- 1 or #2 position across nearly all categories
- The industry's broadest product offering

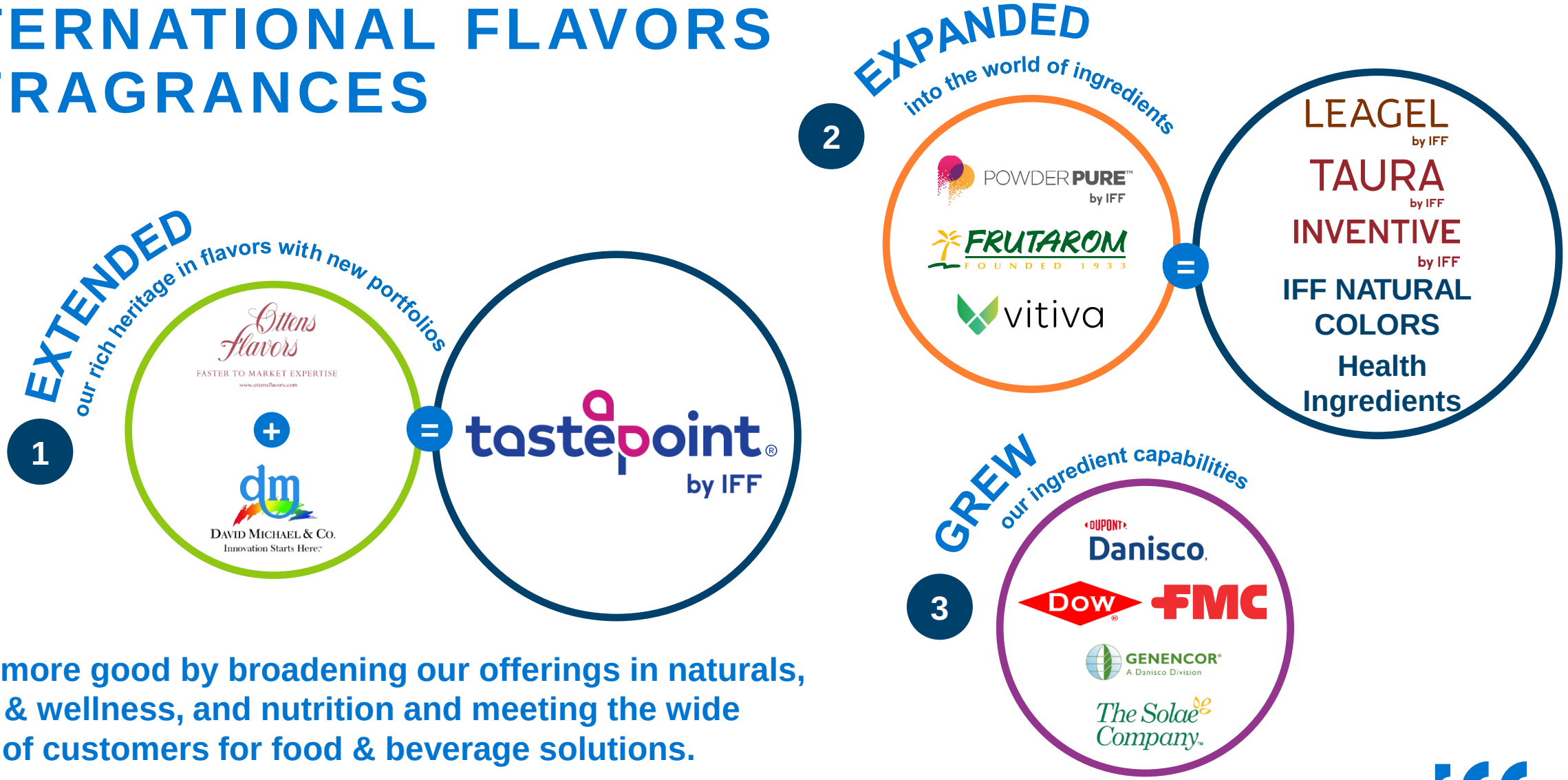
And an industry-defining commitment to sustainability…

Guided by core belief that clean, sustainable and responsible operations will drive value for all stakeholders

Driven by a highly talented global team focused on execution

Combination of deep expertise and insightful new voices to create value for all stakeholders

IFF IS NO LONGER JUST INTERNATIONAL FLAVORS & FRAGRANCES



Doing more good by broadening our offerings in naturals, health & wellness, and nutrition and meeting the wide needs of customers for food & beverage solutions.

AGENDA

What is Starch Gelatinization?

- What happens in gelatinization?
- How is starch converted to fermentable sugar?

Gelatinization Temperature Variability

- Natural variation
- Impact of drought

Addressing Grain Variability in Your Distillery

- RVA Analysis
- Iodine Check

Case Study

- Rye Analysis (RVA Analysis, Iodine Check, Enzyme Addition)

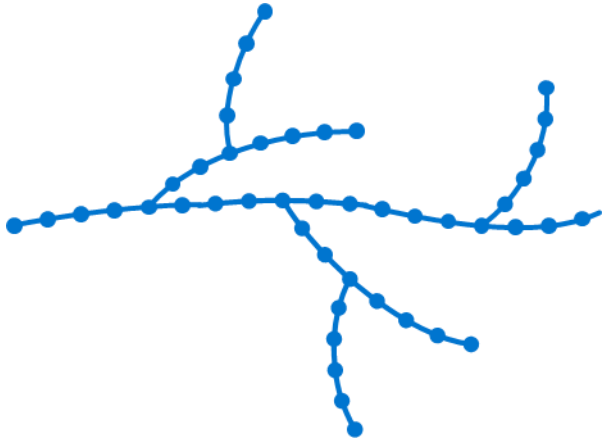
WHAT IS STARCH GELATINIZATION?

THREE STEPS TO FERMENTABLE SUGARS

Gelatinization must come first

Step	Input	Output	Enzyme
1. GELATINIZATION	Water, Heat	Soluble Starch	No Enzyme
2. LIQUEFACTION	Enzymes	Dextrin	**Malt:** Alpha Amylase **Commercial:** Alpha amylase
3. CONVERSION 6	Enzymes	Fermentable Sugars	**Malt:** Beta amylase*, limit dextrinase**, alpha-glucosidase** **Commercial:** Glucoamylase, pullulanase

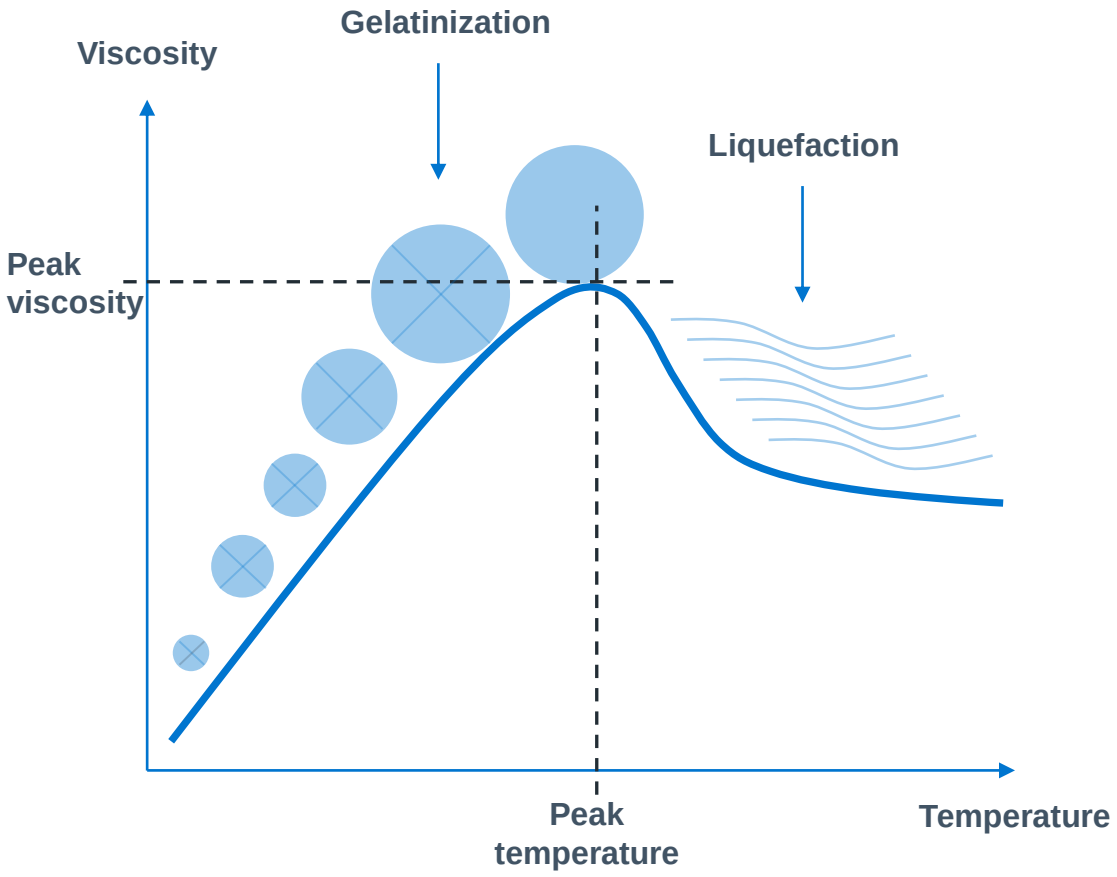
Amylose

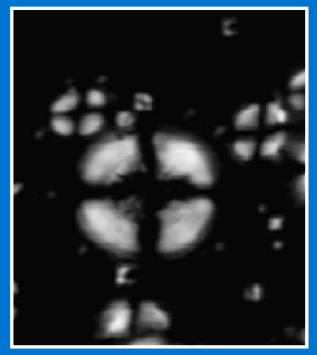


Amylopectin

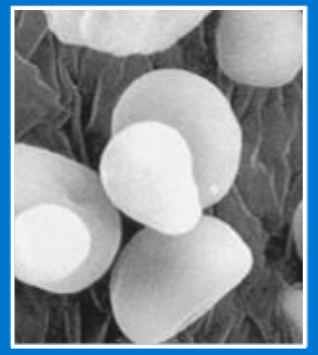
*=heat sensitive
**= limited activity, if any, in malt

WHAT HAPPENS DURING GELATINIZATION?



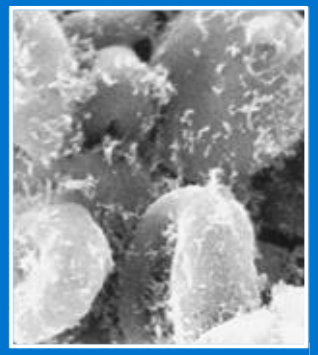


Birefringence

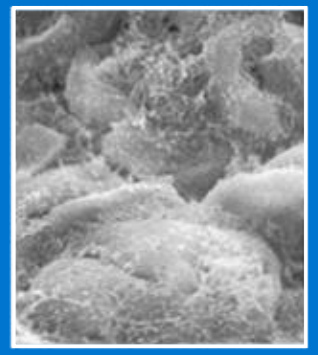


Uncooked cornstarch

Heated to 75° C



Heated to 85° C



Heated to 90° C

Heated to 95° C

Birefringence | Mariotti et al | Starch/Stärke (2005)
Starch Gelatinization | Baking Processes | BAKERpedia

GELATINIZATION TEMPERATURE VARIABILITY

WHAT IS THE CORRECT GELATINIZATION TEMP?

Gelatinization temperature of starches from select plants

The following table summarizes the gelatinization temperature of various

Source	Gelatinization temperature
Wheat	124–140°F (51–60°C)
Barley	124–140°F (51–60°C)
Corn	144–162°F (62–72°C)
Triticale	131–144°F (55–62°C)
Rice	154–172°F (68–78°C)
Rye	124–140°F (51–60°C)
Sorghum	154–172°F (68–78°C)
Potato	140–149°F (60–65°C)
Tapioca	153–158°F (67–70°C)

Gelatinization temperature		
	°C	°F
Maize	62-74	144-165
Rice	65-81	149-178
Sorghum	66-75	156-167
Millet*	54-80	129-176
Cassava	68-90	154-194
Wheat	52-64	126-147
Oat	56-62	133-144
Rye	63-72	145-162
Barley	60-67	140-153
Malted barley	60-67	140-153

urce	Gelatinisation Temperature (°C)	Shape
Barley	61-62	Round/ Lenticular
Wheat	52-54	Round/ Lenticular
Maize	70-80	Round/ Polygonal
Rice	70-80	Polygonal/ Compound
orghum	70-80	Round/ Polygonal
Oats	55-60	Polygonal/ Compound
Rye	60-65	Spherical/ Lenticular

mall starch granules of barley gelatinise at 75-80°C

- Each starch has its own gelatinization temperature.
- These temperatures will not be consistent across these references due to shifting climates during the growth of the grains.

Is your mash temperature high enough?

Egi (2014)
Starch Gelatinization | Baking Processes | BAKERpedia

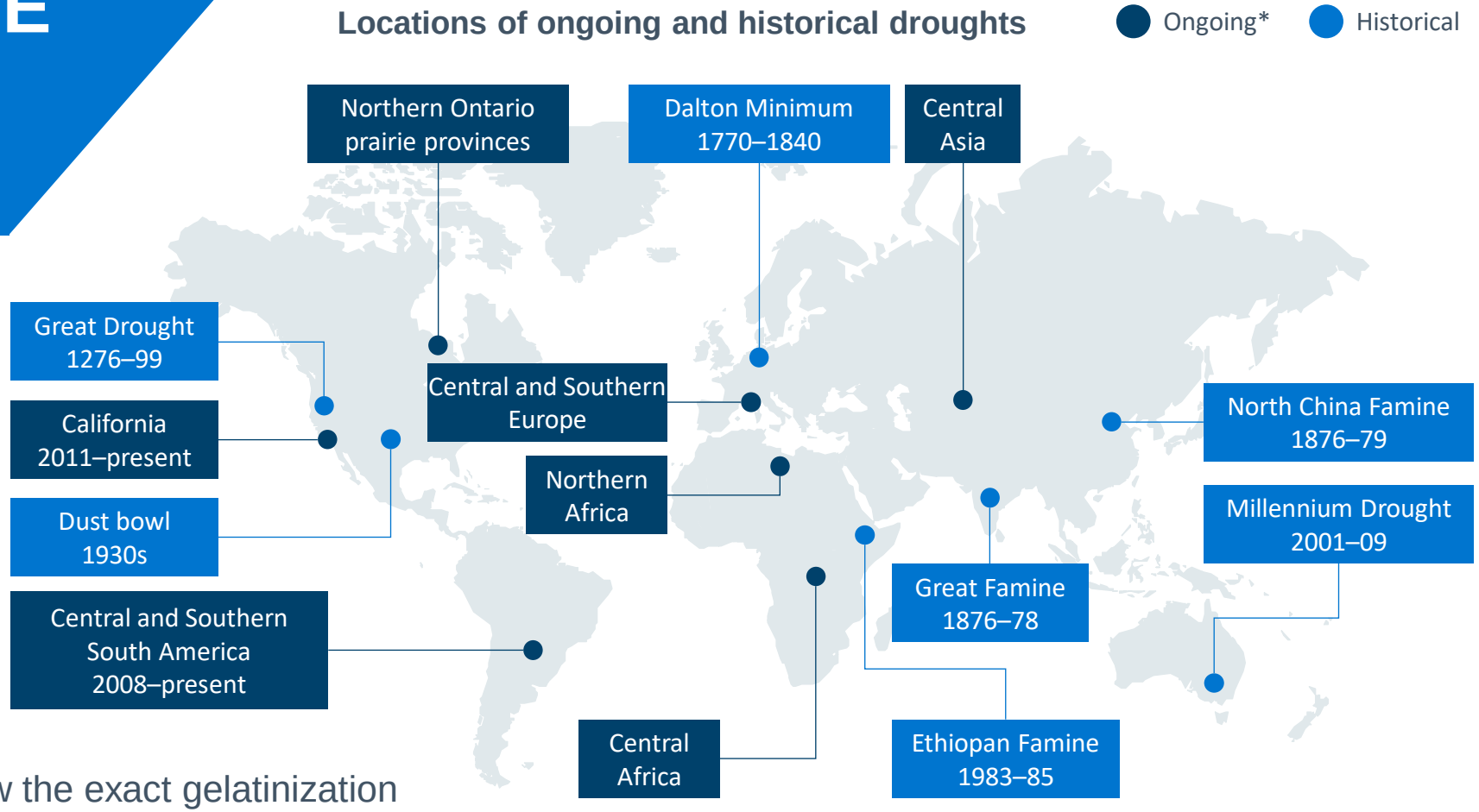
VARIABILITY IN GELATINIZATION TEMPERATURE

Driven by many factors

DROUGHT

An extended period of rainless weather that causes a considerable water imbalance

Locations of ongoing and historical droughts



GELATINIZATION TEMPERATURE IS VARIABLE DUE TO:

- Variety
- Year
- Growing region
- Growing conditions
- Drought, incl.
  - Heat stress
  - Moisture stress

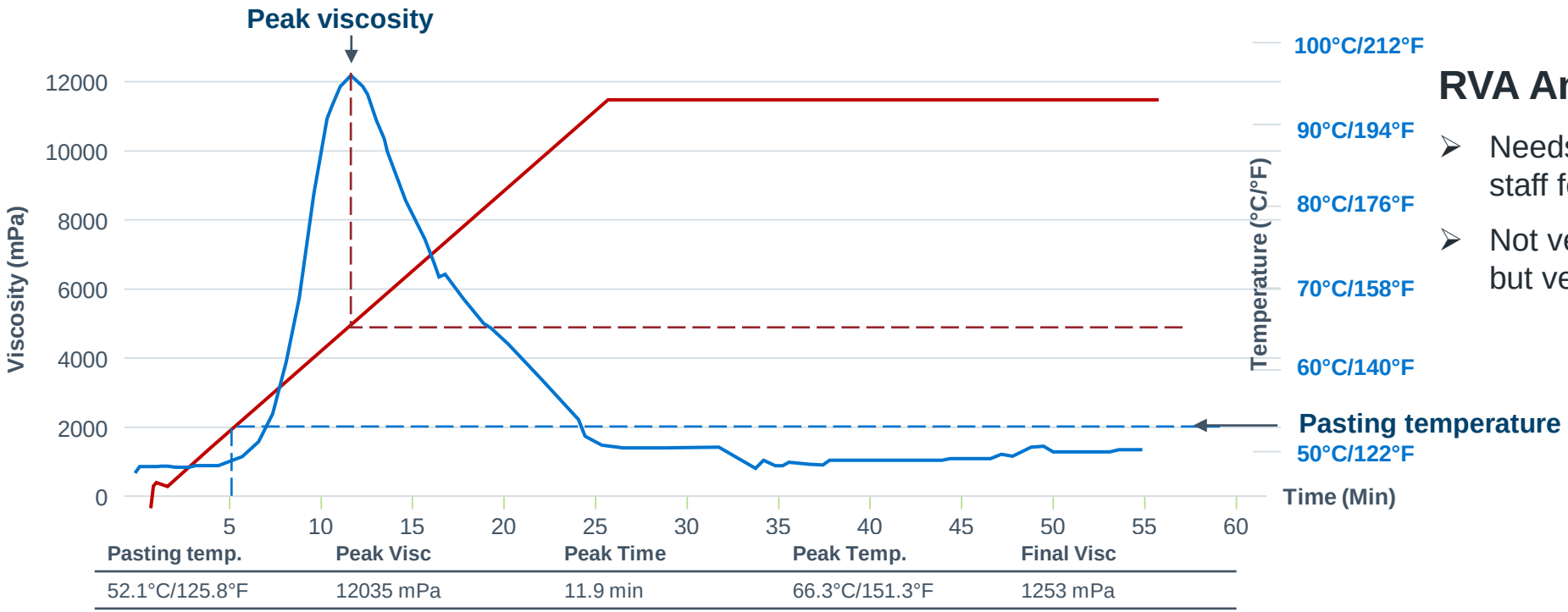
As a buyer, it is challenging to know the exact gelatinization temperature. It is not normally provided in a COA.

*As of August 2022 according to the National Integrated Drought Information System (NIDIS).

Source: https://cdn.britannica.com/52/190352-050-F1D2DF24/Infographic-droughts-locations-drought-episodes-history.jpg

ADDRESSING GRAIN VARIABILITY IN YOUR DISTILLERY

WAYS TO EVALUATE GELATINIZATION



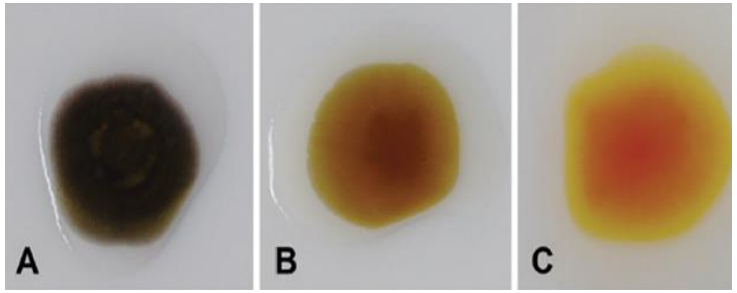
Pasting temp.	Peak Visc	Peak Time	Peak Temp.	Final Visc
52.1°C/125.8°F	12035 mPa	11.9 min	66.3°C/151.3°F	1253 mPa

RVA Analysis

- Needs an instrument and trained staff for laboratory analysis
- Not very fast to produce results, but very accurate/predictable.

Temp (°C)

Visc (mPa)



Iodine Check

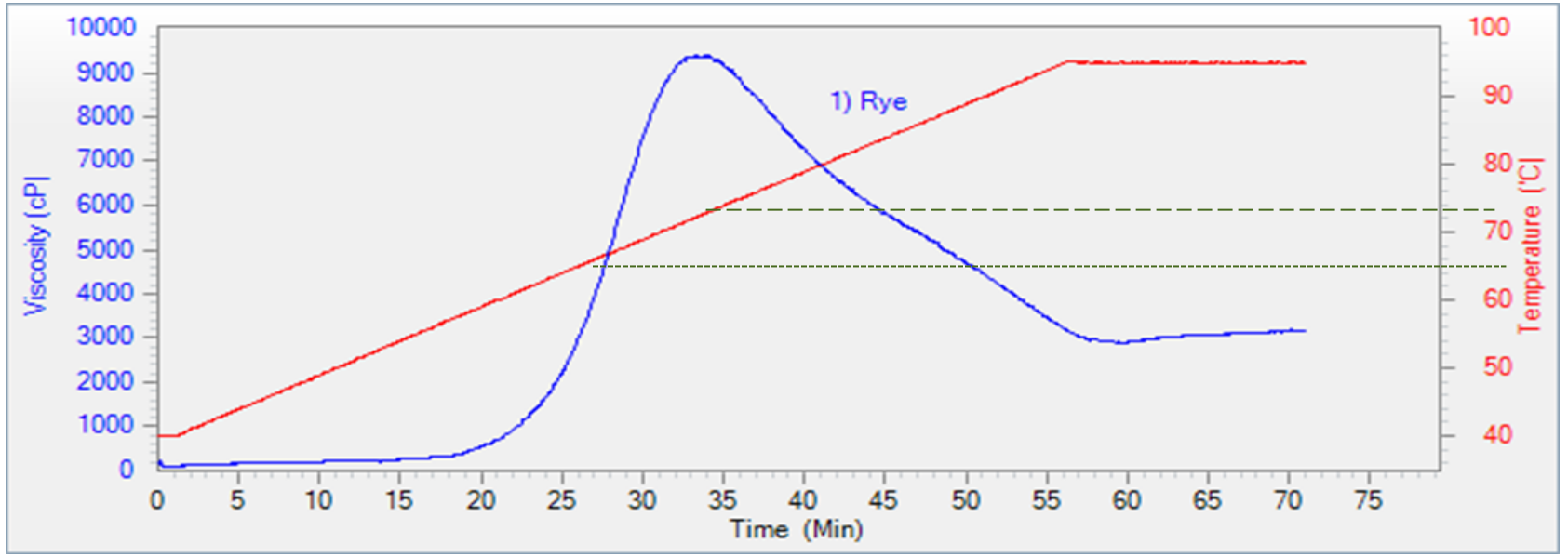
- Can be used in production.
- Not as accurate as RVA, but can be a simple go/no go test.
- Easy test to perform, but needs fresh iodine solution, stored away from light

A= black, positive for starch, B= brown, still signs of starch, C= OK, negative for starch

Shirmer et al | Starch/Stärke (2005)

CASE STUDY

EXAMPLE OF HIGH GELATINIZATION TEMP



Peak temp
162°F/72°C

Mash temp
149°F/65°C

Temp (°C)

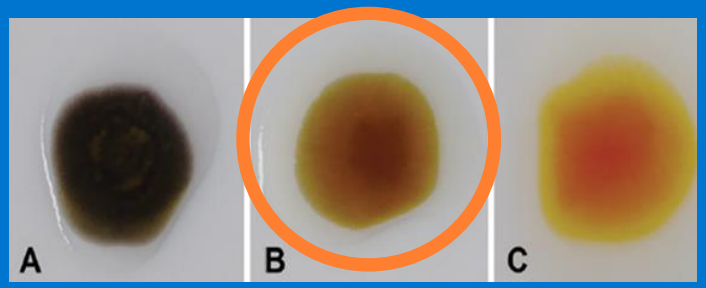
Visc (mPa)

Test	Pasting Temp.	Pasting Time	Peak Viscosity (cP)	Peak Time Min)	Peak Temp	Final Visc. (cP)
Rye	58 °C /136 °F	19 min	9407	33	72°C / 162°F	3183

Recipe calls 149°F/65°C conversion temperature.
High gelatinization temperature. Need to adjust mashing.

TEST 1: COOK TEMP AS IS

- 95% rye, 5% malt
- 4.9 pH
- Mash In
- 129° F/ 54 °C
- Cook (Gelatinize) 148°F/ 65°C
- LAMINEX® C2K for viscosity reduction
- DIAZYME® SSF for conversion



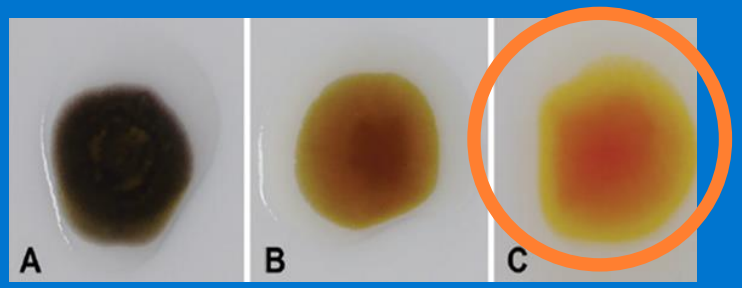
RESULTS

- Mash with malt only never fully gelatinized.
- Commercial enzymes still need 20-30 minutes to fully gelatinize.

1. Main Mashing 129°F/54°C, 30 min		2. Ramp to Conversion 148°F/65°C, 30 min Glucoamylase addition	3. Iodine check Iodine negative at 148°F/65°C				
AMYLEX®5T (kg/t)	AMYLEX®6T (kg/t)		0-5 min	5-10 min	10-20 min	20-30 min	30 min
Control malt only			black	dark brown	dark brown	dark brown	brown
			black	dark brown	dark brown	dark brown	brown
			black	dark brown	dark brown	dark brown	brown
			black	dark brown	dark brown	dark brown	brown
			black	dark brown	dark brown	dark brown	brown
Control malt only			black	dark brown	dark brown	brown	brown
0.25			black	OK?	OK	OK	OK
0.25			black	OK?	OK	OK	OK
0.25			black	OK?	OK	OK	OK
0.25			black	brown	OK	OK	OK
0.25			black	brown	OK	OK	OK
0.25			black	brown	OK	OK	OK
	0.25		black	dark brown	OK?	OK	OK
	0.25		black	dark brown	OK?	OK	OK
	0.25		black	dark brown	OK?	OK	OK

TEST 2: COOK TEMP BASED ON RVA RESULTS

- 95% rye, 5% malt
- 4.9 pH
- Mash In
- 129° F/ 54 °C
- Cook (Gelatinize) 158°F/ 70°C
- LAMINEX® C2K for Viscosity
- DIAZYME ® SSF for conversion



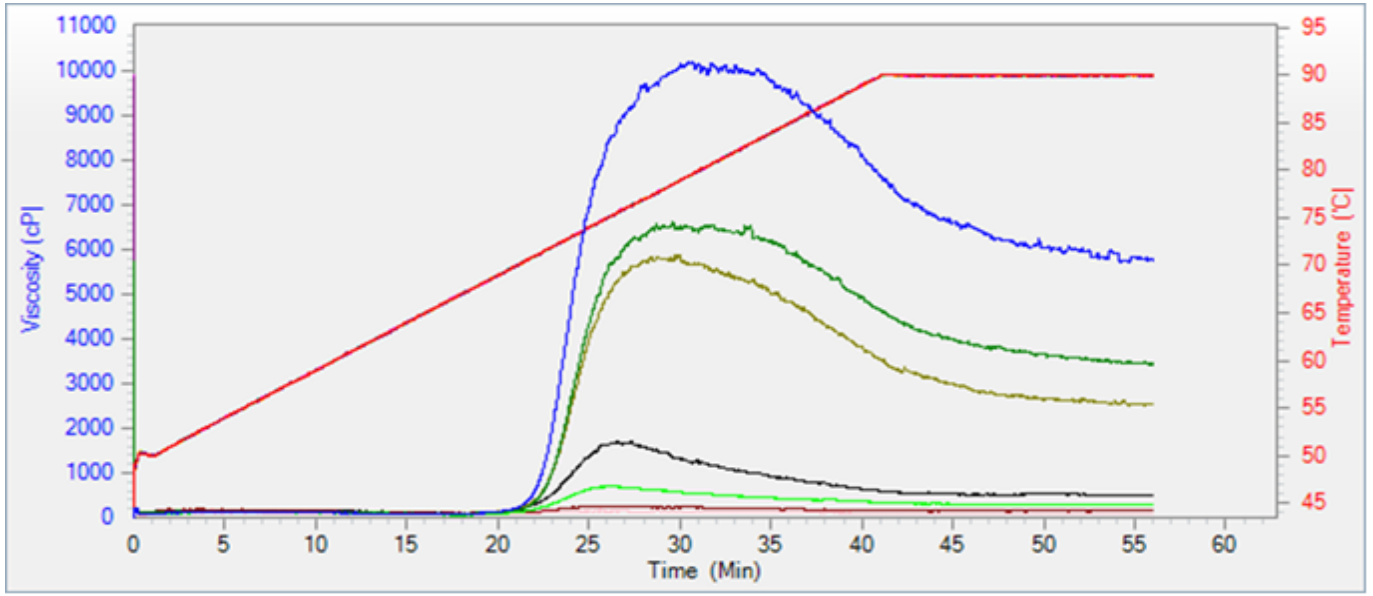
RESULTS

- Malt enzymes function, but it takes longer time to gelatinize due to low pH.
- Commercial enzymes fully gelatinized in 5-10 minutes.

1. Main Mashing 129°F/54°C, 30 min		2. Ramp to Conversion 158°F/70°C, 30 min Glucoamylase addition	3. Iodine check Iodine negative at 158°F/70°C				
AMYLEX®5T (kg/t)	AMYLEX®6T (kg/t)		0-5 min	5-10 min	10-20 min	20-30 min	30 min
Control malt only			black	brown/yellow	OK		
			black	brown/yellow	OK		
			black	brown/yellow	OK		
			black	brown/yellow	OK		
			black	brown/yellow	OK		
Control malt only			black	brown/yellow	OK??	OK	
0.25			black	OK			
0.25			brown OK?	OK			
0.25			OK				
0.25			OK				
0.25			OK				
0.25			OK				
	0.25		OK				
	0.25		OK				
	0.25		OK				

EFFECT OF pH ON ENZYME ACTIVITY AND VISCOSITY

- Increased yield
- Faster processing
- Less energy
- Lower viscosity



Test	Addition	pH	Pasting Temperature (C°/F°)	Peak Viscosity (cP)	Peak Time Min)	Peak Temp (C°/F°)	Final Visc. (cP)
1	Control, no enzyme	6.18	69.1 / 156.4	10192	30.7	79.6 / 175.3	5754
2	Alpha amylase	5.0	69.0 / 156.2	6624	29.6	78.5 / 173.3	3433
6*	Alpha amylase	5.1	69.0 / 156.2	5881	29.7	78.6 / 173.5	2541
7*	Alpha amylase	5.2	69.0 / 156.2	1696	27.3	76.3 / 169.3	511
3	Alpha amylase	5.3	69.0 / 156.2	700	25.9	74.9 / 166.8	283
4	Alpha amylase	5.6	err	269	25.7	74.6 / 166.3	171
5	Alpha amylase	5.9	err	197	25.7	74.6 / 166.3	89

Change of viscosity with pH change and constant dose of alpha amylase in ground corn.

CONCLUSION

Gelatinization takes place over a range of temperature. It is not a single point.

This range is highly variable due to factors discussed today, including crop variety, year, region, growing conditions, and drought.

Heat and drought are more frequent, and they increase gelatinization temperatures.

For efficient gelatinization, the cook temperature needs to be adjusted to the correct temperature.

If the cook temperature is too high, malt enzymes may be inactivated or denatured.

THANK YOU!

Please reach out to your local IFF or Gusmer Enterprises representative for more information.

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