U.S. Wheat Associates

Research Report
September 2022

Title: **Development of a mechanized folding method for sponge cake production and its comparison to the traditional hand folding method**

Introduction

USW promotes SW wheat across a wide variety of markets with various end products, but Japanese-style sponge cake remains the standard measurement of soft wheat performance and quality. For over 50 years USW has relied on the hand-folded sponge cake method developed in Japan by Nagao et al. (1976). This methodology is the industry standard and produces excellent end-products but relies heavily on the skill of individual technicians. Product quality can vary between technicians and laboratories given their level of training and skill.

To compensate for the potential variability among operators, a mechanical mixing method was developed. The mechanical sponge cake method, described by Choi et al. in 2012, suggests that the range of sponge cake volume may decrease, but overall consistency improves. The USDA Western Wheat Quality Laboratory (USDA WWQL) has adopted this method as its default Japanese sponge cake method. However, the method has not been systematically reviewed and further developed for potential standardization.

Hand and mechanized folding method descriptions

A simplified flow chart of the traditional hand folding method developed by Dr. Nagao is provided in Figure 1. This is the standard method that Wheat Marketing Center (WMC) uses for the production of all Japanese sponge cakes. A key point of the method is bulk egg + sugar batter production sufficient for seven cakes. In practice, only five cakes are folded and baked from this bulk egg + sugar batter given the kinetics of foam drainage and collapse. These foam kinetics render the final two portions of egg + sugar batter too inconsistent for use. Discarding these final two portions of egg + sugar batter ensures greater quality consistency across all cakes. The specific gravity target at WMC (elevation: sea level) for the bulk egg + sugar batter at sea level is 15.4 – 16.4 g in a 60 mL cup, or 0.256 g/mL – 0.273 g/mL.

The bulk batter is weighed out to individual portions with 100 g of flour folded in by hand. Folding proceeds in an elliptical pattern for a total of 80 folds. The first 40 folds are conducted at a slower speed with the bowl containing the egg + sugar batter and flour. The bowl is rotated ¼ of a turn every 10 folds. At the conclusion of the first 40 folds, a second set of 40 folds is initiated at a faster speed. Again, the bowl is rotated ¼ of a turn every 10 folds until the second set of folds is complete.

The final batter is deposited into a lined cake pan and baked for 30 min at 180°C (sea level baking time and temperature). The top and bottom of each deck is set at 190°C to the internal bake temperature in the chamber is 180°C. The cake is removed from the oven and dropped from a maximum height of 20 cm onto a solid surface to limit collapsing.

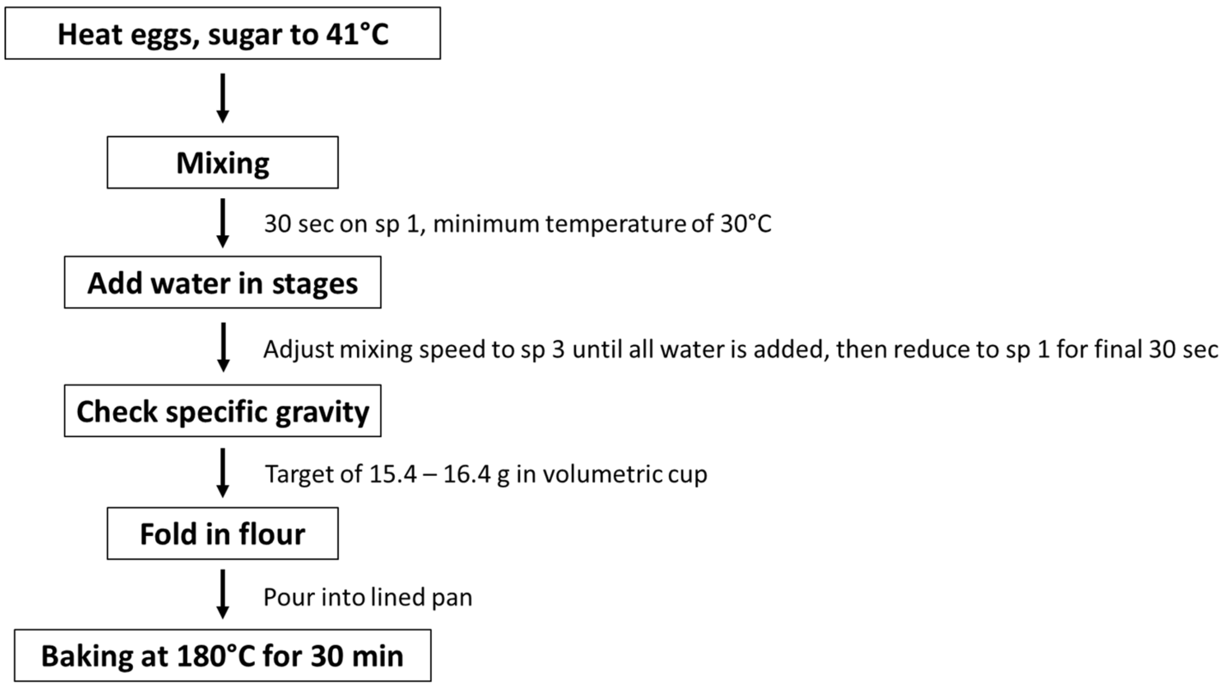


Figure 1. Flow chart summarizing the major steps in the traditional hand folding method for Japanese sponge cake production.

The mechanized folding method developed by Choi, Harris and Baik (2012) is summarized in a flow chart depicted in Figure 2. A key difference in this method is the production of individual egg + sugar batters instead of a larger bulk batter. Each individual batter is mixed separately, and, in practice, the specific gravity is measured twice daily: once in the morning, and once in the afternoon. The specific gravity target at the USDA WWQL (elevation: 2,350 ft or 715 m) is 14.6 – 15.4 g in a 60 mL cup, or 0.243 g/mL – 0.257 g/mL. Given the preparation of individual egg + sugar batters in this method, the kinetics of foam drainage and collapse become negligible as every batter proceeds to folding shortly after production. It should be noted, however, that specific gravity has the potential to drift over the course of production as temperature and barometric pressure fluctuate.

The mixing accessory is changed out after egg + sugar batter production from a wire whip to a rubber-edged beater blade. The rubber edges of the beater extend out to the edges of the bowl and serve to scrape the batter + flour from the sides, thereby ensuring complete incorporation of flour. Flour is added to the egg + sugar batter after the beater blade is installed and beating progresses for 10 sec at a slower speed and 10 sec at a faster speed.

The final batter is deposited into a lined cake pan and baked at 190°C for 35 min (USDA WWQL elevation time and temperature). The cake is removed from the oven and dropped from a maximum height of 25 cm onto a solid surface to limit collapsing.

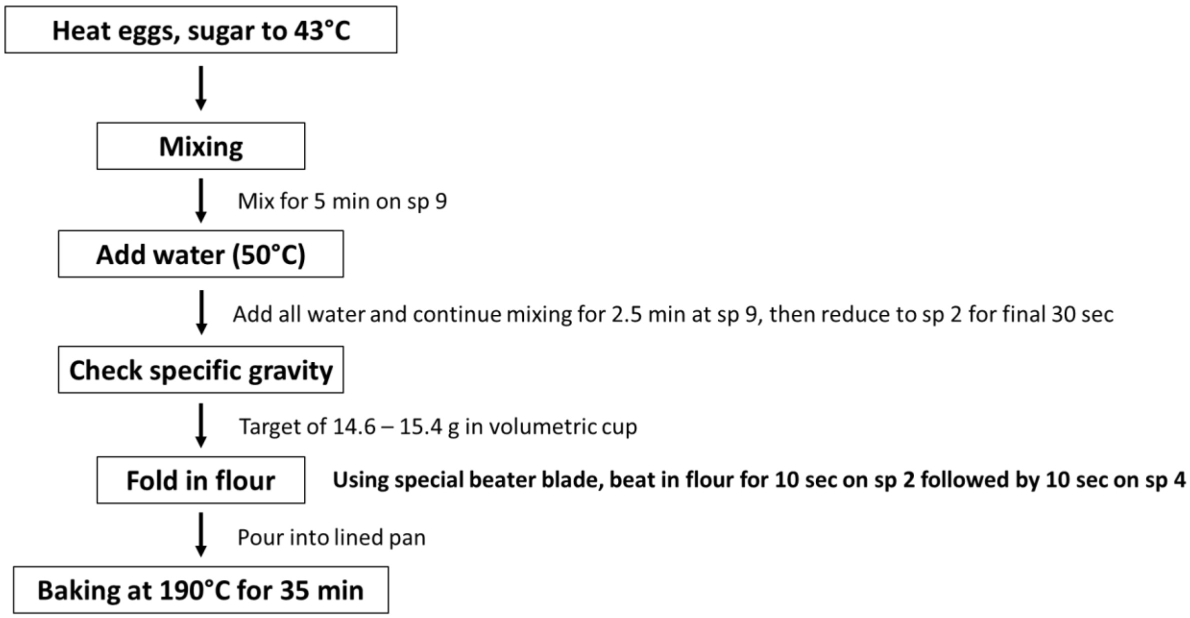


Figure 2. Flow chart summarizing the major steps in the mechanized hand folding method for Japanese sponge cake production.

Mechanized method development process (see Appendix A for final mechanized method)

Several points of differentiation were noted between the traditional hand and mechanized folding methods. These points were considered and addressed during the development process, including:

1) Batch egg + sugar batter production → Single portion egg + sugar batter production
2) Equipment availability and geometries
3) Mixing speed/time combinations
4) Batter specific gravity targets
5) Cake batter weights
6) Bake time/temperature combinations

1) Maintaining the same output as the batch production method requires at least 3 operators working simultaneously on separate mixers using the mechanized folding production method. Foam kinetics also change when changing over from batch production to single cake production and requires the development of new statistical control measures.

2) The equipment used to develop the mechanized folding method is no longer available on the market. New equipment has to be identified and validated and readily available to other labs. An additional consideration is that new equipment changes mixing geometry and mixing action/forces. This has implications for mixing speed/time requirements and foam characteristics.

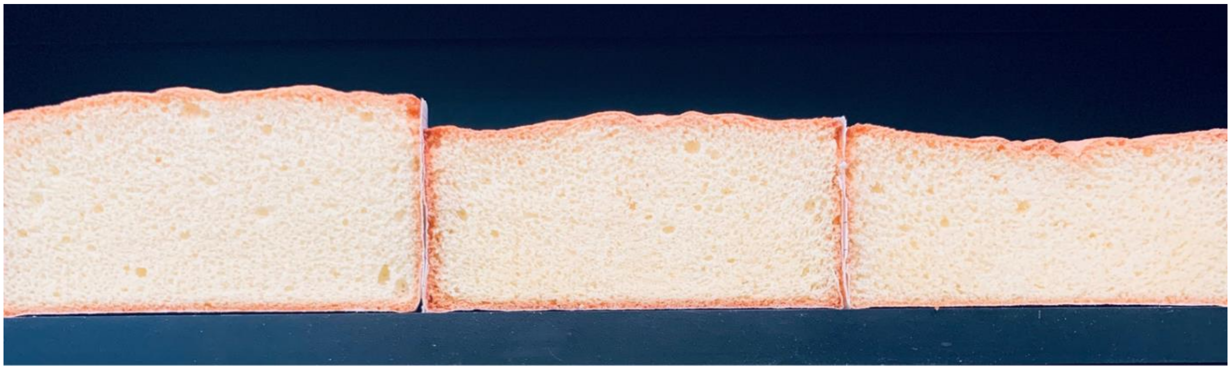
3) The mixing speed/time guidelines established by Choi, Harris and Baik (2012) and the USDA WWQL were developed for a different set of mixing equipment. Mixing speed/time requirements are specific to each unique equipment combination for achieving the egg + sugar batter specific gravity target.

4) The specific gravity target for the USDA WWQL is 0.25 – 0.26 g/mL at an elevation of 2350 ft (715 m). The WMC specific gravity target has been 0.26 – 0.28 g/mL at sea level.

5) The cake batter weight deposited into the pan affects heat transfer and baking kinetics. The mechanized method developed by Choi, Harris and Baik (2012) and the USDA WWQL method does not specify a consistent target cake batter weight. WMC has typically targeted a cake batter weight of ~340 g per pan.

6) Bake time/temperature combinations are primarily determined by elevation. Changes to foam kinetics and batter specific gravity targets can require changes in bake time/temperature.

The WMC technical team visited the USDA WWQL in March 2022 to learn and train on the mechanized folding method. The team spent two days learning the method and assessing a combination of adjustments to various method conditions. An example is presented in Figure 3.



10 sec sp 2, 10 sec sp 4 **20 sec sp 2** **30 sec sp 2**

Figure 3. Cakes baked from a flour folding time and speed experiment.

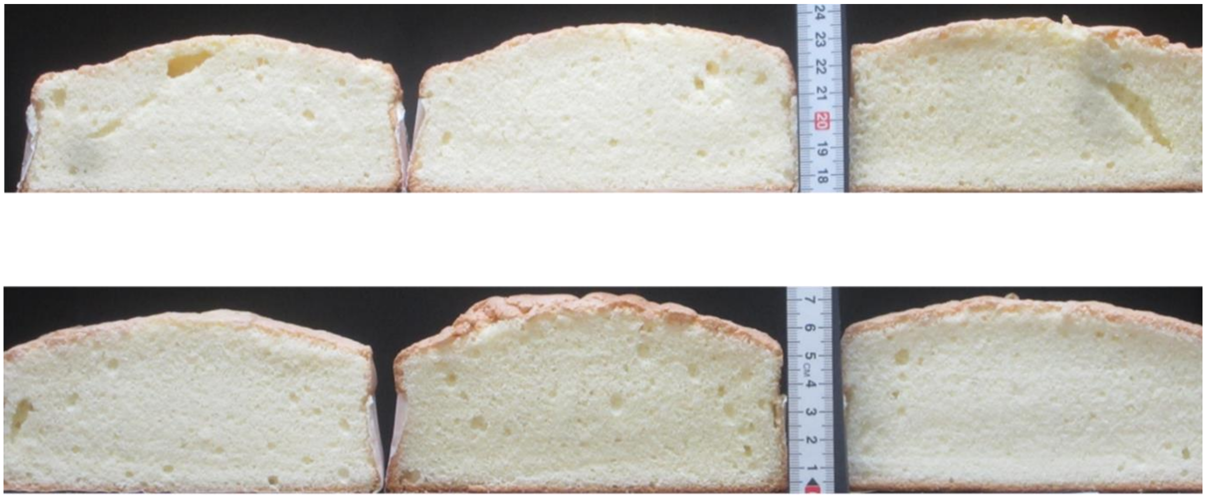
One major impediment to adoption of the method was the discontinuation of the specific equipment used to develop the method. The USDA WWQL has continued to use this equipment. WMC had to identify alternate equipment to pursue further method development. The equipment used and recommended by WMC meets three criteria that should allow for widespread adoption: 1) it is not cost prohibitive when possible; 2) it is the closest available option to the equipment originally used to develop the method; and 3) it is robust enough to survive at least 10 years of heavy use. The specific equipment is identified below:

- Batter Mixer: Hobart Commercial Countertop 12-Qt Mixer (Models: A-120 or HL120)
- Batter Bowl: Hobart Commercial 12-Qt Stainless Steel Bowl (Standard with mixer; A and HL model bowls not interchangeable)
- Batter Whisk: Hobart Commercial Stainless Steel Whisk (Model: D; A and HL whisks not interchangeable)
- Folding Mixer: KitchenAid Commercial Grade 8-Qt Lift Mixer (Model: KSM8990)
- Folding Bowl: KitchenAid Commercial Grade NSF Stainless Steel 5-Qt Bowl J-Handle (Model: KSMC 5QTBOWL)
- Folding Beater Blade: New Metro Design BeaterBlade Metal 6-, 7-, and 8-Qt Lift Mixers (Model: 6L-M)

A second major impediment to adoption of the method was the inconsistency in the specific gravity obtained for the individual egg + sugar batters. Even adjusting the specific gravity target for elevation did not result in consistent specific gravity results. Given the inconsistency in specific gravity, WMC opted to maintain a bulk egg + sugar batter production method to improve batter consistency.

Consistency of the egg + sugar batter is critical to ensuring consistency across cake replicates. Examples are shown in Figure 4.

A)



B)

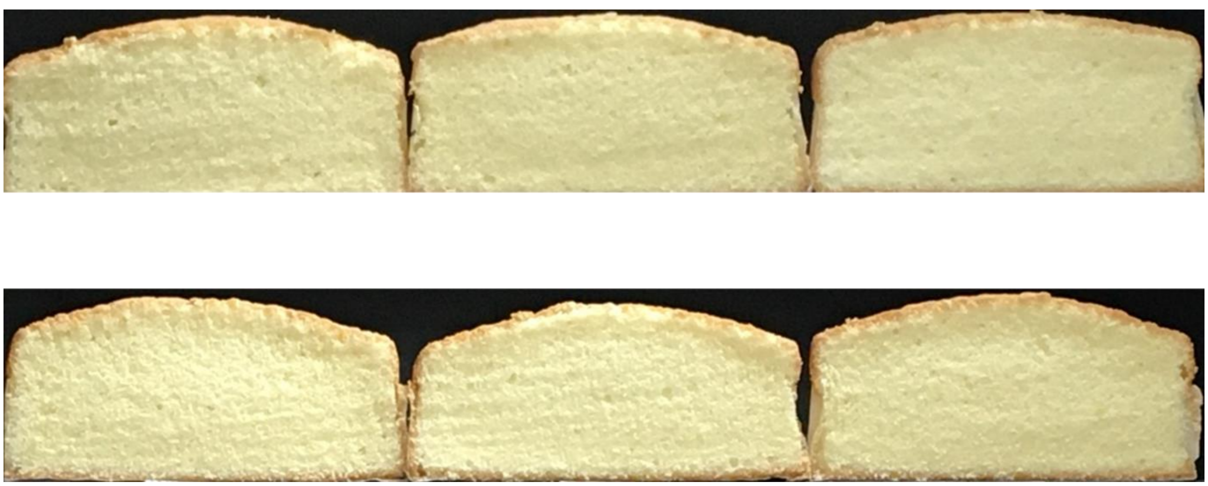


Figure 4. Cake replicates from two flours baked from A) individual egg + sugar batches or B) bulk egg + sugar batches.

The final impediment was the need to adopt a consistent final batter depositing protocol to ensure the removal of large air pockets. All cake batters need to be poured into the lined pan from a height of ~12 – 18 in. (~30 – 45 cm) to reduce the incorporation of air pockets. Once deposited to the correct weight, the pan is then shocked by dropping the pan from a short height (~2.5 in. or 6 cm) to disrupt any remaining air pockets.

The final method is detailed in Appendix A with the modifications for the six identified concerns summarized below:

1) Egg + sugar batters are produced using the bulk method with each portion folded individually
2) Equipment and mixing accessories have been identified based on current market offerings
3) Mixing speeds and times have been adjusted to suit the equipment

4) A batter specific gravity target of 0.26 – 0.28 g/mL is appropriate at sea level but may require adjustment at higher elevations
5) Cake batter weight is measured and controlled every time for consistent baking
6) Bake time and temperature are 190°C for 30 min at sea level and will require adjustment at higher elevations

Results (see Appendix B for additional figures)

Two flours were tested in tandem using both methods: a soft white (SWH) long patent flour milled at WMC using a Miag Multomat experimental mill and a commercial Japanese western white (80% SWH:20% Club) short patent flour. Table 1 summarizes the compositional and quality data for both flours. Overall, the flours are similar with minor differences in SRC and Amylograph characteristics. Alveograph extensibility (L value) was greater for the Japanese short patent flour which resulted in a smaller P/L ratio. However, the difference is not practically relevant in the context of a sponge cake.

Table 1. Flour composition and quality data for a long patent (LP) SWH and Japanese short patent sponge cake control flour.

	Test	LP SWH Flour	Japanese Short Patent Control Flour
	Moisture (%)	13.1	13.8
	Protein (%) (14%, mb)	8.2	8.0
	Ash (%) (14%, mb)	0.383	0.368
	Starch Damage (%) (14%, mb)	5.58	3.55
	Falling Number (s) (14%, mb)	349	370
SRC	Water (%, 14% mb)	53.3	55.3
SRC	Sucrose (%, 14% mb)	102.5	101.7
SRC	Sodium Bicarbonate (%, 14% mb)	78.4	73.3
SRC	Lactic Acid (%, 14% mb)	99.6	88.5
SRC	Gluten Performance Index	0.55	0.51
	Wet Gluten (%)	23.4	21.1
Amylograph	Peak Viscosity (BU)	635	622
Amylograph	Breakdown Viscosity (BU)	537	486
Amylograph	Final Viscosity (BU)	1145	1076
Amylograph	Setback (BU)	510	454
Amylograph	Breakdown (BU)	98	136
Amylograph	Total Setback (BU)	608	590
Alveograph	P (mm)	47	40
Alveograph	L (mm)	75	91
Alveograph	W (10^{-4} J)	104	99
Alveograph	P/L	0.63	0.44

The only parameter not characterized was flour particle size distribution. However, it is well known that experimental mills produce larger particle sizes due to their shorter mill flows and limited separation gradients.

A total of 24 cakes were baked for each flour per method. Averages are presented for each flour and method combination in Table 2. Cake volume and specific volume trended greater when hand folded regardless of flour type, but the difference was significant only for the experimentally milled flour. Compared to more aggressive mechanized folding, hand folding is less likely to damage the initial egg + sugar foam especially when considering the larger particle size distribution of experimentally milled flour. Indeed, a small set of cake batter (egg + sugar + flour) specific gravities were collected in the initial round of testing, and mechanically folded batters showed approximately +7 g/mL (Japanese short patent flour) to +10 g/mL (experimental long patent flour) greater specific gravities compared to their respective hand folded batters (limited data set shown in Table 4, Appendix B). With formulations and initial egg + sugar batter densities being held constant, greater specific gravity indicates less air is retained in the final cake batter after folding in the flour. Less air translates to lower volumes, and this has implications for texture.

Greater volumes typically lend products to softer textures, and this is what we observed with cake texture in this study. Hand folded cakes produced softer textures than mechanically folded cakes. This relationship is based on greater volumes containing more air pockets relative to solid product matrix. Whereas a texture analyzer probe is designed to detect resistance from a solid product matrix on compression, it detects no resistance from air. While the texture difference was significant for both flours, the magnitude of difference was greater for the experimentally milled flour. Again, this is likely a function of larger particle sizes for the experimentally milled flour exacerbating foam damage induced by mechanical folding.

Cake scoring was performed by comparing cake characteristics against the Japanese short patent cakes produced with either the hand or mechanical folding method, as appropriate. For scoring purposes, cakes from the Japanese short patent flour were set to 70% of total points. In this way experimentally milled flours can produce cakes that are better than, similar to, or worse than a commercial control. This protocol serves to provide a stable baseline for normalizing scores, thereby reducing variability due to day-to-day differences in atmospheric and laboratory conditions.

Scores for external cake characteristics showed consistent trends between the methods. The experimentally milled flour showed significantly worse external scores for the mechanically folded cakes. The main scoring discrepancy was cake shape/symmetry. The mechanically folded cakes from the experimentally milled flour had a domed shape which is not desirable in Japanese sponge cakes. While the Japanese short patent cakes produced by mechanical folding also showed a slight dome, it was less pronounced than that for cakes from the experimentally milled long patent flour. Internal cake scores, in contrast, showed a significantly greater score for the experimentally milled mechanically folded cakes. Finer and more even crumb structures were observed for both flours when mechanically folded. The more aggressive folding action for mechanically folded cakes likely collapses larger gas cells, leaving smaller, more homogenous gas cells that contribute to the finer crumb grain.

The texture scores are determined by calculating the average cake firmness (g) and standard deviation of the Japanese short patent cakes for each folding method on each given bake day. Again, this is a mechanism for normalizing scores and reducing variability from constantly changing atmospheric and laboratory conditions. Each standard deviation above and below the Japanese short patent mean represents an increase or decrease of three points. Within each standard deviation, the range of texture values are divided by three so that points can be deducted or added as individual cake textures are increasingly removed from the Japanese short patent mean. Softer cakes gain points while firmer cakes lose points. Cakes from experimentally milled flour gave lower texture scores than their Japanese short patent flour equivalent, as expected based on texture measurements. Hand folded cakes from experimentally milled flour lost 7 texture points overall relative to their Japanese short patent equivalents, whereas their mechanically folded counterparts lost 10 texture points. Again, this relates to the more aggressive mechanical folding leading to foam damage, which reduces volume and increases firmness.

Overall cake scores reflect the negative impact of larger particle size distributions from experimental milling on cake quality relative to a Japanese short patent flour. It is typical to see a small number of lost points from external and internal cake parameters regardless of folding method, but the biggest loss of points is almost always attributable to texture differences. Mechanical folding appears to exacerbate this texture difference between commercial and experimentally milled flours. Even when scoring against a mechanically folded Japanese short patent equivalent, an experimentally milled long patent flour gives a significantly lower overall score compared to hand folded counterparts. External cake shape and texture are the two main parameters where points are lost, and it is expected that this loss of points will be slightly greater for an experimentally milled straight grade flour.

Table 3 shows the coefficient of variation (CV) for each flour and method combination. In general, the CVs are small and within accepted statistical ranges for most parameters. CVs are considered good for a test if they are less than 10% and excellent if they are less than 5%. The parameter that shows the greatest variability is firmness. Texture is well known to exhibit larger CVs than other analytical tests due to its dependence on the unique structural characteristics of each replicate. While WMC requires CVs for each individual replicate to be less than 10%, the CV across all replicates can be larger. Interestingly, the CVs for volume, specific volume, firmness, and external score are all smaller for hand folded cakes. This is possibly related to the inconsistent nature of foam damage during mechanical flour folding.

Table 2. Dimensions, volume, and texture for sponge cakes made with hand and mechanical flour folding methods using two different flours.

Folding Method	Flour	Weight (g)	Volume (cc)	Specific Volume (cc/g)	Firmness (g)	External Score	Crumb Grain Score	Texture Score	Overall Score
Hand Folded	Japanese Control Flour	284.9±3.7[b]	1137±25[a]	3.99±0.09[a]	268±22[b]	14±0[a]	21±0[a]	21±0[a]	56±0[a]
Mechanical Folded	Japanese Control Flour	287.5±2.8[a]	1121±40[a]	3.90±0.16[a]	356±42[a]	14±0[a]	21±0[a]	21±0[a]	56±0[a]
Hand Folded	Long Patent SWH	288.4±1.5[a]	1069±17[a]	3.71±0.07[a]	343±22[b]	13±1[a]	18±1[b]	14±2[a]	45±2[a]
Mechanical Folded	Long Patent SWH	288.7±2.3[a]	1020±34[b]	3.53±0.12[b]	502±56[a]	11±1[b]	19±0[a]	11±4[b]	42±4[b]

Results are reported as means ± standard deviations (n=24).
Means for the same flour in the same column followed by the same letters are not significantly different (P > 0.05).

Table 3. Coefficient of variation for sponge cakes made with hand and mechanical flour folding methods using two different flours.

Folding Method	Flour	Weight	Volume	Specific Volume	Firmness	External Score	Crumb Grain Score	Texture Score	Overall Score
Hand Folded	Japanese Control Flour	1.3	2.2	2.2	8.0	0.0	0.0	0.0	0.0
Mechanical Folded	Japanese Control Flour	1.0	3.5	4.1	11.8	0.0	0.0	0.0	0.0
Hand Folded	Long Patent SWH	0.5	1.6	1.8	6.4	3.8	2.9	16.4	4.7
Mechanical Folded	Long Patent SWH	0.8	3.3	3.4	11.1	4.4	0.0	31.4	8.7

Conclusions:

Converting from a hand to a mechanized folding method presents some challenges. The primary challenge of identifying suitable equipment has been addressed in this study with specifications set for mixers, bowls, and mixing accessories. A secondary issue of egg + sugar batter consistency has also been addressed, and WMC has determined that the individual batter preparation method does not allow for specific gravity targets to be achieved efficiently or consistently. As a result, WMC recommends that a bulk method be followed for egg + sugar batter preparation. This bulk preparation method also allows for improved production efficiency relative to the original mechanized folding method developed by Choi, Harris and Baik (2012) and currently utilized by the USDA WWQL.

While appropriate mixing speeds and times were developed to match the equipment identified in this study, adjustments to mixing time will likely be necessary as elevation and specific gravity targets change. Similarly, baking temperatures and times will need to be adjusted as elevation increases. If this method is disseminated to USW customers, then these points will need to part of the communication as many customers will be located at higher elevations.

Overall, cake volumes decrease when moving from hand to mechanical folding. The volume decrease is statistically significant for cakes from mechanically folded experimentally milled flours and is likely due to the larger particle size distribution. The decrease is ~50 cc when moving from hand to mechanical folding at sea level but may be more significant at higher elevations. Cake firmness also significantly increases as volume decreases. This increase in firmness results in greater points loss for mechanically folded cakes from experimental flours despite being compared against a mechanically folded Japanese short patent control. And while actual texture values are not reported in the USW CQ or the Pacific Northwest (PNW) SWH reports, it is important for USW technical staff to be aware of the texture outcomes for the mechanical versus hand folding methods when responding to customer inquiries.

As USW considers switching to a mechanized folding method for the CQ report, there will be differences in results. It is advisable to collect at least two years of data wherein both the hand and the mechanized folding methods are used so that a true correlational analysis can be conducted across a set of practically relevant samples. Additionally, if USW ultimately decides to pursue the mechanized method for CQ reporting, hand and mechanical folding results will need to be reported side-by-side for at least two years so that customers can see how the results differ between the methods. In this way customers can be prepared for the volume and potential scoring differences. If the two SWH crop years are significantly different from one another (e.g., 2020 vs. 2021), then it is advisable for USW to consider collecting and reporting both methods for a third year before making a permanent switch.

Reference

Choi HW, T Harris and BK Baik. 2012. Improvement of sponge cake baking test procedure for simple and reliable estimation of soft white wheat quality. *Cereal Chem* 89:73-78.

Nagao S, S Imai, T Sato, Y Kaneko and H Otsubo. 1976. Quality characteristics of soft wheats and their use in Japan. I. Methods of assessing wheat quality for Japanese products. *Cereal Chem* 53:988-997.

Appendix A

Egg Sugar Mixture Procedure for Mechanized Folding

1. Beat eggs for 3 min at speed 1 in Hobart 12 qt. mixing bowl. Beat enough eggs for the entire day. Keep at room temperature for duration of bake.
2. Weigh 750g beaten egg and 750g sugar into a Hobart 12 qt. mixing bowl
3. Place egg-sugar mixture in ~60°C water and add thermometer. Heat the mixture until 43°C while constantly stirring with a whisk. Remove from water bath.
4. Whip the heated mixture to achieve a specific gravity of 15.4-16.4g using 60 mL cup
    a. Set timer to 6 min 45 sec.
    b. Mix for 30 seconds at speed 1 and then switch to speed 3
    c. Add 150 mL (50°C water (bath set at 57.5°C)) deionized water when there are 3 min remaining
    d. Add 150 mL water when there are 2 min remaining
    e. Mix until egg/sugar mixture achieves optimal consistency. Mixing time at speed 3 may need to be increased to achieve target specific gravity.
    f. Turn mixer to speed 1 for the final 30 seconds
    g. Measure egg/sugar mixture specific gravity

Mechanized Folding Method

1. Pour 264g of egg-sugar mixture into a 5 qt. bowl fitted for an 8 qt. Kitchen Aid mixer. There is enough mixture to prepare 6 cakes.
2. Attach a curved beater with rubber scraper
3. Sprinkle 110g of sifted flour in the bowl and mix for 10 seconds at speed 2 and then 10 seconds at speed 4
4. Take the bowl out of the mixer and remove the beater
5. Unload the finished cake batter (319g) into a lined pan
6. Shock the cake batter from a height of 6 cm.
7. Bake for 30 min in deck oven at 190°C so chamber is 180°C (356°F)
8. Drop the pan from ~20cm height
9. Grab the cake liner with two hands and remove the cake from the pan
10. Place the cake on a wired cooling rack

Appendix B

Table 4. Specific gravity* of sponge cake batters made with hand and mechanical flour folding methods using two different flours.

Folding Method	Flour	Specific Gravity* (g)
Hand Folded	Japanese Control Flour	25.4±0.3
Mechanical Folded	Japanese Control Flour	32.8±1.0
Hand Folded	Long Patent SWH	27.1±0.1
Mechanical Folded	Long Patent SWH	37.4±0.4

*Specific gravity was measured using a 60 mL cup
n=2

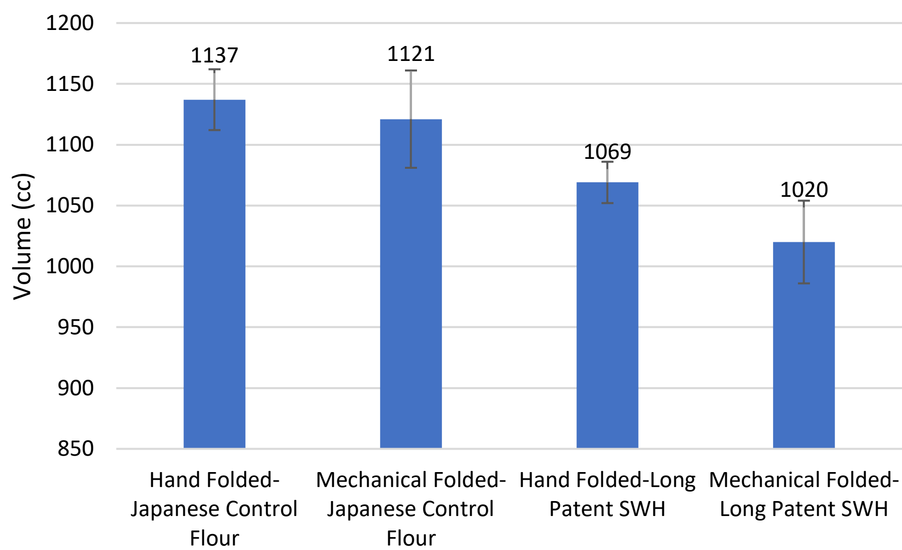


Figure 5. Effect of flour folding technique on sponge cake volume for a Japanese control flour and long patent soft white flour.

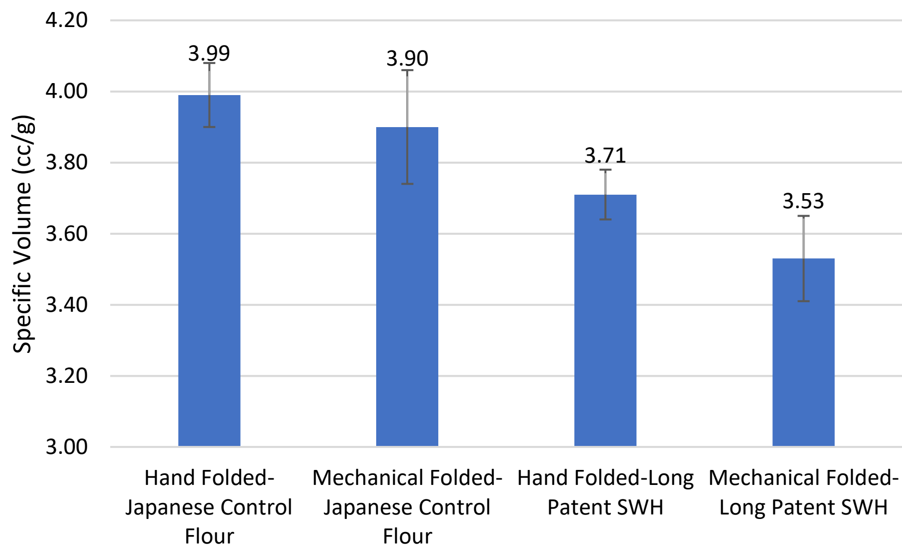


Figure 6. Effect of flour folding technique on sponge cake specific volume for a Japanese control flour and long patent soft white flour.

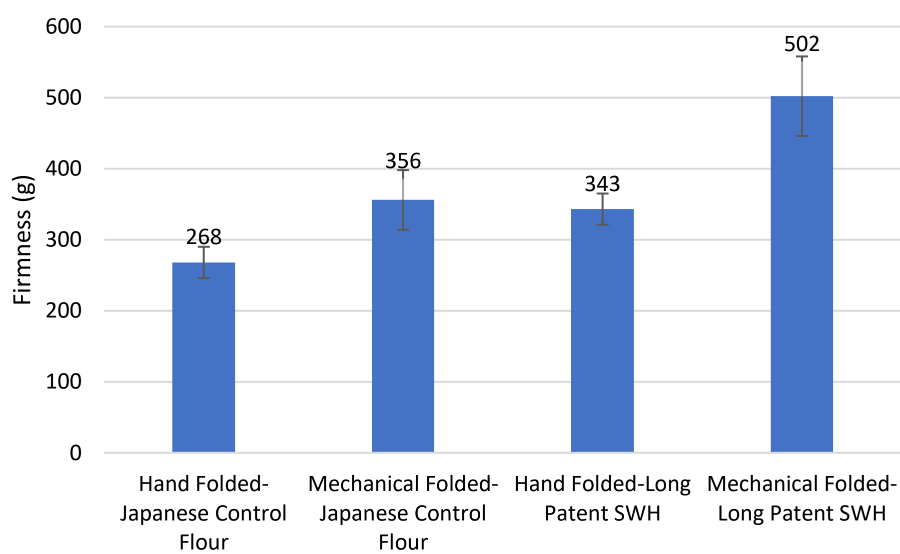


Figure 7. Effect of flour folding technique on sponge cake crumb firmness for a Japanese control flour and long patent soft white flour.

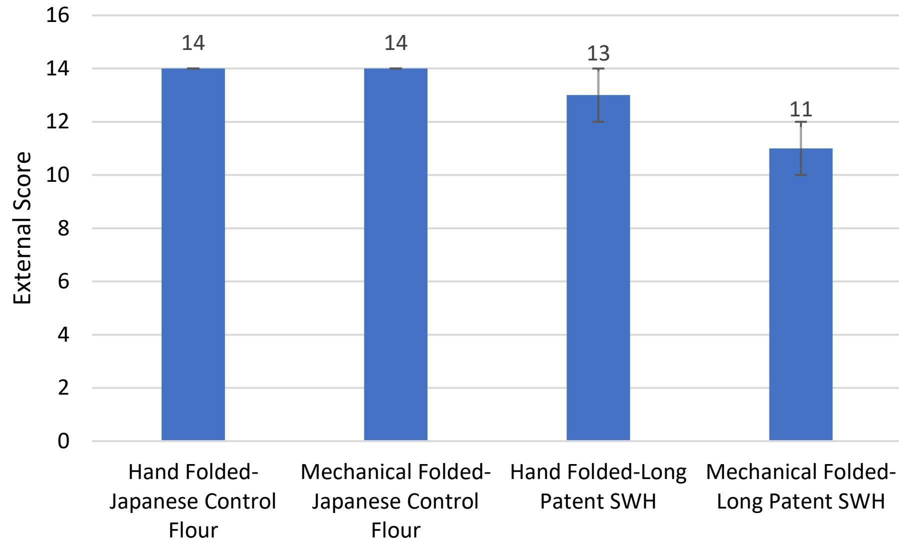


Figure 8. Effect of flour folding technique on sponge cake external score for a Japanese control flour and long patent soft white flour.

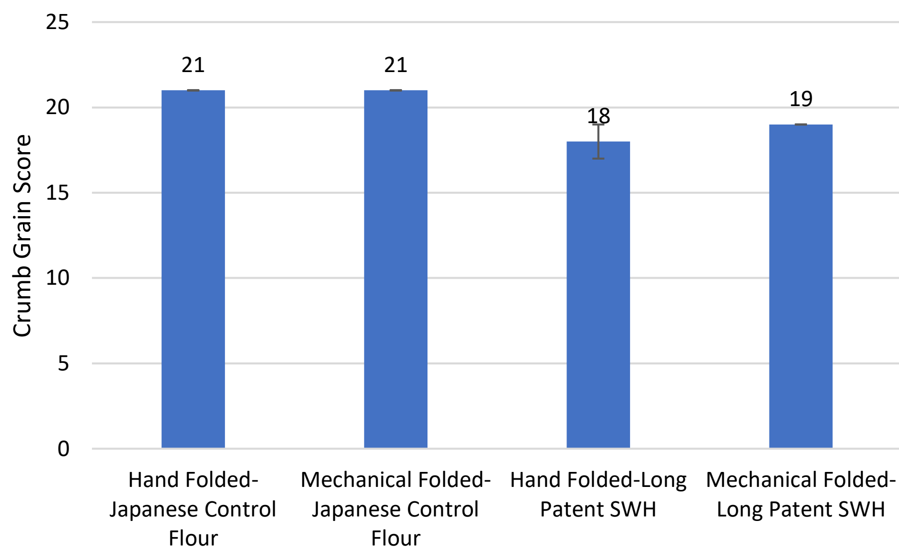


Figure 9. Effect of flour folding technique on sponge cake crumb grain score for a Japanese control flour and long patent soft white flour.

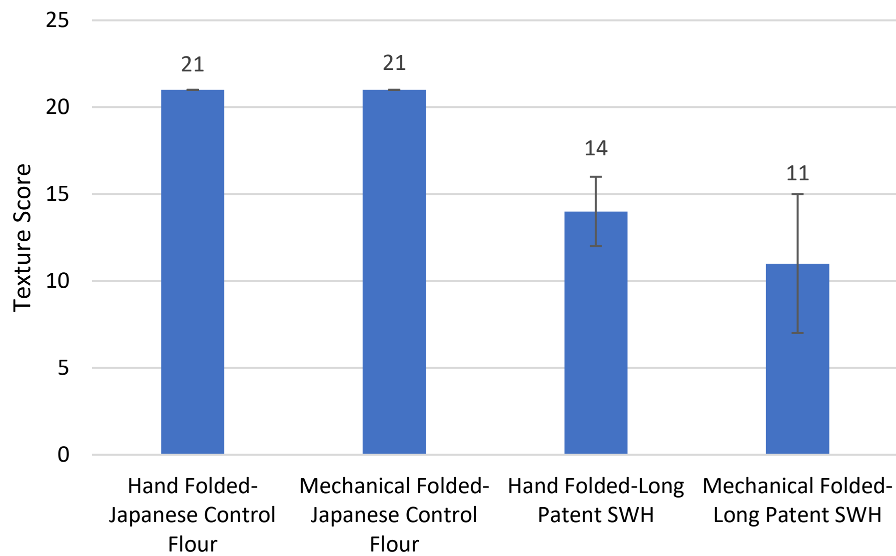


Figure 10. Effect of flour folding technique on sponge cake texture score for a Japanese control flour and long patent soft white flour.

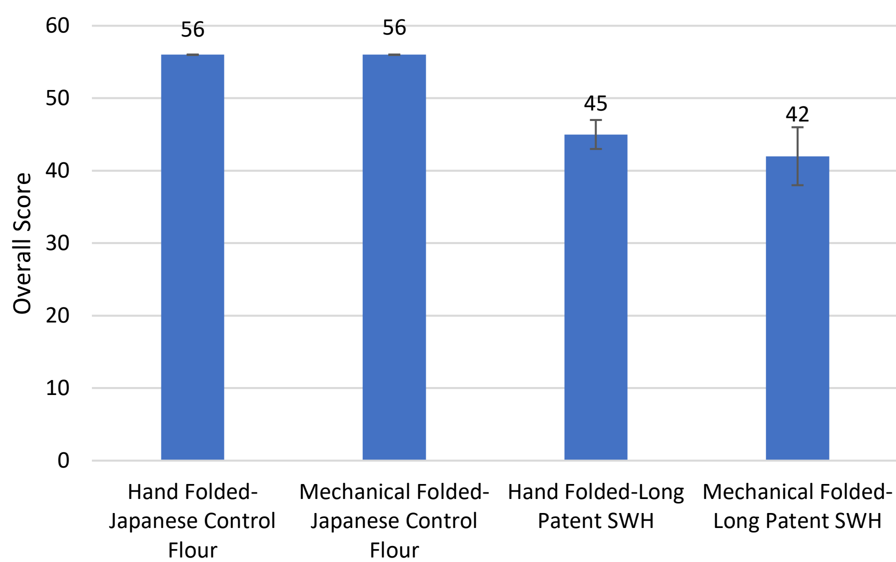


Figure 11. Effect of flour folding technique on sponge cake overall score for a Japanese control flour and long patent soft white flour.