NOTE

ANALYTICAL TECHNIQUES AND INSTRUMENTATION

Sample Frequency Effects on Mixograms[1]

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Since the development of the mixograph, researchers have tried to measure and predict the physical properties of dough by recording the bowl movements with a mechanical pen device (Swanson and Working 1933). Today, with advances in computerization and electronics, scientists are able to collect and save data in ways that were not possible in the 1930s. Some researchers (Navickis et al 1990, Stearns and Barta 1990) have stressed the necessity of sampling at high frequencies (at least 50 Hz), whereas others (Voisey et al 1966) found that a moderate frequency of 4 Hz was satisfactory. However, very low sampling frequencies (1–2 Hz) caused problems during data collection and analysis (Rubenthaler and King 1986).

A useful technique for studying the relative merits of sampling at different frequencies is to initially collect data at a high frequency and then systematically 'strip', or remove part of the data (Walker and Walker 1992). By controlling the stripping pattern, the effects of sampling frequency can be shown in a manner that is exactly the same as originally collecting data at different frequencies, but without the small random error and variability that occur between two replicate samples.

The objective of this study was to examine the effects of sampling frequency on mixogram data. This was accomplished by collecting data from both moving and fixed bowl mixographs at a high frequency and then electronically stripping the data to generate mixograms at lower frequencies.

MATERIALS AND METHODS

Mixograph Description

A 10-g mixograph was provided by the National Mfg. Div. of TMCO (Lincoln, NE). The mixograph was operated in two interchangeable configurations, moving bowl (mb) and fixed bowl (fb). The mb design was computerized for digitized data acquisition by placing a linear taper rotary contact potentiometer in the original bowl bearing housing (Wooding and Walker 1992). The potentiometer provided to the computer an analog voltage signal, which was proportional to the bowl's position and, hence, collected data identical to that of the mechanical pen trace (digitized mb).

For the fb configuration, a bracket and load cell were attached to the bearing housing to immobilize the moving bowl arm at the 50% pen position. The analog voltage output of the load cell is proportional to the torque imparted to the bowl pins by the action of the planetary mixing head on the dough. A transducer power supply and signal amplifier with integral 10-bit A/D converter conditioned the analog signal from either mixograph configuration and transmitted it to the parallel port of an MS-DOS computer. The signal was acquired and analyzed by Mixsmart software (AEW Consulting, Lincoln, NE, commercially available through National Mfg.).

For both the mb and fb designs, data were collected randomly (nonsynchronized) with respect to the starting position of the rotating mixing head, although it was at a regular 50-Hz clock interval. A special sampling technique for the fb design, referred to as fixed bowl-synchronized (fb-s), also was used (Hazelton 1994). This method was configured to sample bowl torque at every 12° of the mixing head rotation, starting at 0° offset or "home" position (~44 Hz).

Software Description

The mixogram data file stripping feature is a special utility modification of the Mixsmart software program. To preserve the original file, the utility is capable of generating new files that contain the new header file information (time, frequency, etc.). It works by selecting every *n*th data point for retention and eliminating those points in between. For example, setting the stripping factor at 2 (every second point is retained) strips a file collected at 50 Hz to an effective sampling rate of 25 Hz. The stripping factor need not be an integer. For instance, setting the stripping factor at 2.5 will alternately retain the second and then the third data points, eliminating first one, then two intermediate values. However, an occasional problem occurs when using a noninteger stripping value. The true time intervals between the samples are no longer uniform, resulting in files that may be different from those actually run at the desired frequency. Note that the stripping factor must be greater than one.

Flour Description and Methodology

A high-protein, spring wheat flour (14% mb, 64.3% absorption, 14.2% protein, and 0.51% ash), supplied by the Bay State Milling Co. (Quincy, MA), was used. Approximate mixograph absorption was predicted first according to Finney (1945) and subsequently adjusted, based on preliminary runs with the fb configuration. Flour-water mixograms were run at 25 ± 1°C following the standard method (AACC 1995), modified only to accommodate the computerized format. Mixer speed was 88.2 rpm, and mixograms were collected for 10 min.

Experimental Design

To evaluate the effects of sampling frequency and eliminate the variability that would have resulted from separate runs, three mixogram replicates were collected at 50 Hz (nonsynchronized mb and fb) and 44 Hz (fb-synchronized at 12° step-size, 0° offset). The data files then were stripped systematically to 25, 10, 5, 2, and 1 Hz for the nonsynchronized mb and fb protocols, and to 22, 11, 4.4, 2.2, and 1.1 Hz for the fb-s sampling method. One-way analysis of variance (ANOVA) was performed on selected mixing parameters to identify any significant differences among sampling frequencies.

RESULTS AND DISCUSSION

For both the mb and fb configurations, no significant differences occurred among the values derived from the original mixograms, regardless of the sampling frequencies considered ($P > 0.01$). Although below 5 Hz, the similarity across frequencies applied even as low as 1 Hz, but show small differences, especially in the bandwidths at different locations (Table I, and Fig. 1). Although only one flour was used, similar results would hold

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TABLE I
Averaged Mixogram Values for High Frequency Mixograms and Mixograms Created by Electronic Stripping Methods

	Midline Peak[a]							
	Time		Height		Width		Integral	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Moving bowl								
50 Hz	4.62	0.07	59.30	0.72	23.07	2.06	208.07	6.81
25 Hz	4.62	0.07	59.30	0.72	22.97	2.07	208.10	6.85
10 Hz	4.64	0.05	59.33	0.71	20.63	1.60	208.87	5.42
5 Hz	4.65	0.04	59.33	0.71	20.83	1.45	209.33	5.05
2 Hz	4.69	0.00	59.37	0.91	14.10	0.79	212.20	2.82
1 Hz	4.55	0.55	60.53	1.10	...	...	204.67	33.42
Avg	4.63	0.13	59.53	0.81	20.32	1.60	208.54	10.06
CV (%)[b]		2.81		1.36		7.85		4.82
Fixed bowl								
50 Hz	4.67	0.10	47.33	1.03	57.77	0.74	160.83	9.90
25 Hz	4.64	0.16	47.23	1.00	54.57	0.29	159.40	12.46
10 Hz	4.75	0.11	47.23	1.19	44.33	0.93	164.17	10.04
5 Hz	4.64	0.08	47.43	1.33	40.47	1.37	159.63	2.67
2 Hz	4.55	0.16	47.53	1.42	20.67	0.40	154.97	11.51
1 Hz	4.62	0.23	48.57	2.06	...	...	159.17	4.24
Avg	4.65	0.14	47.56	1.34	43.56	0.74	159.69	8.47
CV (%)		2.99		2.81		1.71		5.30
Fixed bowl (Synchronized)								
44 Hz	4.49	0.06	49.60	0.96	60.53	0.74	159.43	4.68
22 Hz	4.42	0.09	49.53	1.08	54.10	0.17	155.73	6.21
11 Hz	4.49	0.15	47.63	0.91	50.27	0.85	148.83	8.32
4.4 Hz	4.31	0.03	57.10	1.28	32.77	0.59	177.00	2.31
2.2 Hz	4.44	0.03	47.40	0.98	12.80	1.04	139.60	2.01
1.1 Hz	4.55	0.02	48.40	1.45	...	...	143.50	4.08
Avg	4.45	0.06	49.94	1.11	42.09	0.68	154.02	4.60
CV (%)		1.39		2.22		1.61		2.99

[a] Average (Avg) and standard deviation (SD).
[b] Coefficient of variance.

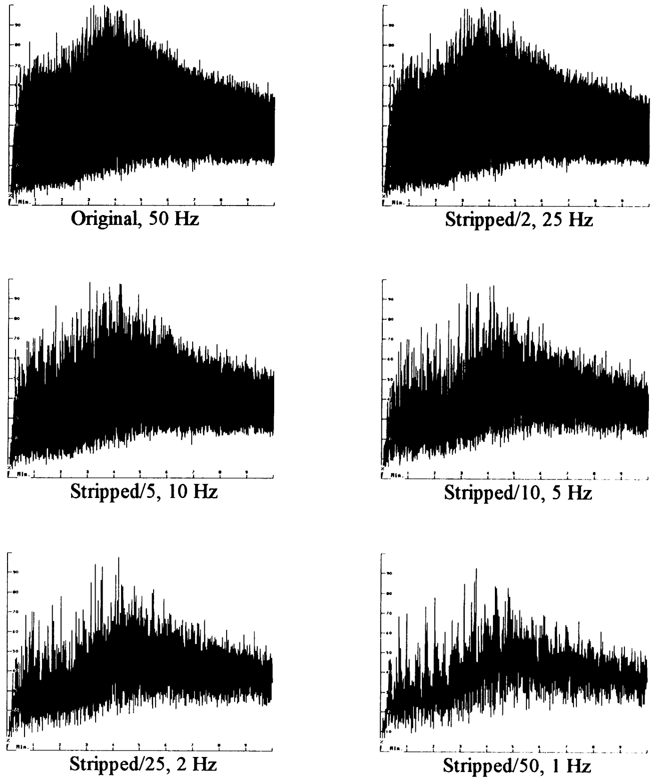
Original, 50 Hz
Stripped/2, 25 Hz
Stripped/5, 10 Hz
Stripped/10, 5 Hz
Stripped/25, 2 Hz
Stripped/50, 1 Hz

Fig. 1. Fixed bowl mixograms created from a file collected at 50 Hz with random starting position (nonsynchronized) and subsequently stripped to emulate lower sampling frequencies.

true for any other flour of differing protein and mixing characteristics. These results support earlier findings (Walker and Walker 1992). From those studies, in which sampling frequency was shown to be important, the differences may be attributed to the nature of the software employed to calculate the various parameters (Voisey et al 1966, Rubenthaler and King 1986, Navickis et al 1990, Stearns and Barta 1990).

Fb mixograms are characteristically wide because the load cell is more responsive to rapid fluctuations than in the heavily dampened mb. This was documented by the fact that bandwidths steadily decreased as sampling frequency was reduced (Table I). As the sampling frequency decreased, less probability existed of capturing the extremes, so bandwidth began to decrease. Although relatively little change occurred down to 10 Hz, the reduced bandwidth became apparent at 5 Hz, and pronounced at 2 and 1 Hz (Fig. 1). The change in bandwidth as a function of sampling frequency was more dramatic for the fb than mb configuration (Table I).

In the case of the fb-s mixograms, a similar bandwidth pattern was also observed (Table I). Sampling at known head positions can affect mixogram results (Hazelton 1994). At relatively small step sizes (12° of head rotation, or ~44 Hz), the mixing torque was sampled sufficiently often so that the extremes of the range were measured, and the bandwidth was essentially the same as in the case of the random sampling. However, at every 120° of head rotation (4.4 Hz), the curve suddenly becomes much narrower, especially after the mixing peak. This reduction in bandwidth was the result of sampling only intermediate points in the torque curve, rather than at the minima or maxima (Hazelton 1994). Larger step sizes (lower frequencies) resulted in even more narrow bandwidths, more so than the random samples at similar frequencies (Table I). The nonsynchronized, or random method still offers a finite probability of sampling at the torque extremes, so the average bandwidth was wider than that of the synchronized version at comparable frequencies under ~5 Hz. Sampling at shorter intervals (48° step size, ~11 Hz) collected points at locations other than the selected 'near mid span of the torque range' locations at 120° of rotation.

Starting at about 2 Hz, a cyclical or harmonic pattern can be seen (Fig. 1). An harmonic pattern is the result of the interaction of two or more frequencies beating against each other, producing a frequency equal to the difference between them. Such interactions usually occur when a time-based (nonsynchronized) sampling frequency is used, although some apparent cyclic tendency does appear in the synchronized mixograms. This phenomenon was probably caused by the very complex mixing action. Furthermore, restrictions of the computer monitor can result in a pattern that appears to repeat, almost like a sine wave, but the apparent variation in mixing resistance is purely an artifact of the collection and display process. Nevertheless, the software analysis uses only the actual data points to produce the mid and envelope lines, even at very low sampling frequencies.

CONCLUSIONS

Differences among mixogram parameters from the same file but analyzed at different apparent frequencies are similar to, or less than, the differences between replicate samples. Except for bandwidth, essentially the same results were found for the different sampling frequencies. This justifies the use of lower sampling frequencies (10 Hz and lower) rather than the much higher frequencies sometimes used by engineers to collect data.

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