Effect of Altitude on Falling Number Values of Flours

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ABSTRACT

Cereal Chem. 58(2):80–82

The effect of altitude on falling number (FN) values was studied with 18 hard wheat flours varying in sea level FN values. The experiments were carried out at sea level and at 2,500, 5,000, 7,500, and 10,000 ft of elevation. As elevation increased, FN values increased because of the lower boiling point of water at reduced atmospheric pressures. The increase in FN values became statistically significant at elevations above 2,500 ft. An equation was developed that permits calculation of sea level FN value from any FN value obtained at a different altitude. Results of a collaborative study with 13 laboratories, located at various elevations in four different countries, indicated that the equation produces reliable sea level FN values.

The falling number (FN) method, which provides information about the α-amylase activity of grains and flours, is a simple and quick method.

In several European countries it is used for the determination of sprout damage and as a general index of grain quality (Perten 1967). The International Association of Cereal Chemistry adopted the method as a check for sprout damage of grain. The U.S. Department of Agriculture has set a range of falling number values for flours in its procurement specifications (Greenaway and Neustadt 1967). The falling number method is an approved AACC method applicable to both meals and flours of wheat, rye, barley, other grains, and malted cereals (AACC 1969).

Because the method is widely used in the baking and milling industries to determine the quality of wheats and flours, all possible sources of experimental error affecting falling number values must be examined.

Sampling can be an error in all grain evaluation procedures (Tipples 1971). A sample size of at least 200 g of grain is necessary to assure a representative sample for sprout damage determinations by the FN method (Perten 1967, Tipples 1971). Samples must have a suitable average particle size and distribution (Greenaway and Neustadt 1967, Perten 1967). The moisture content of the meal or flour must be known because it determines the weight of the sample used in the test (Greenaway and Neustadt 1967, Perten 1967). Stirring time of the flour suspension in the water bath has been found to affect the results.

The effects of water bath level, mineral content of water, volume of water used in the test, weight of sample, the method of suspending the flour, the position of the tube during mixing, the severity of mixing, and flour enrichment and bleaching on FN values have been studied (Greenaway and Neustadt 1967).

The boiling point of water has been recognized as a major source of error in the test (Perten 1967). Ethylene glycol can be added to the water in the water bath to raise the boiling point to 100° C, when necessary. However, if the boiling point is raised more than 2° C by ethylene glycol addition, the contents of the tube may boil out.

The effect of altitude, or reduced atmospheric pressure, on FN values has not previously been studied. However, because the boiling point of water decreases as atmospheric pressure decreases, a change in FN values is expected. This is of significance when FN values of meals and flours are determined in the high altitude regions of the world (areas above 3,000 ft). One third of the area of the United States is located above 3,000 ft (Lorenz 1975), where satisfactory adjustments in boiling point with ethylene glycol cannot be made.

This study was undertaken to investigate the effects of altitude or reduced atmospheric pressure on FN values.

MATERIALS AND METHODS

A total of 18 hard wheat flours, varying in sea level FN values, were provided by two commercial mills. The 10 samples from mill A were of a hard red winter wheat flour and the eight samples from mill B of a hard red spring wheat flour to which various levels of barley malt had been added.

FN values were determined with a type 1400 Falling Number apparatus, using AACC method 56-81A (AACC 1969). The temperature of the water bath was not adjusted, however, for FN measurements at the various altitudes. Amylograph peak viscosities were determined with a Brabender amylograph, using AACC method 22-10 (AACC 1969).

The experiments were carried out in a special high altitude laboratory that permits adjustments of atmospheric pressure to simulate any altitude between sea level and 15,000 ft of elevation. This laboratory is equipped with temperature and humidity controls. The temperature inside the laboratory was maintained at 22° C and the relative humidity at 48–50%.

Determinations were made at atmospheric pressures equivalent to sea level and to 2,500, 5,000, 7,500, and 10,000 ft (762, 1,524, 2,286, and 3,048 m, respectively) of elevation.

All data were the averages of at least duplicate determinations. Reproducibility was ± 5%. The data were evaluated statistically using analysis of variance and the Fisher least significant difference procedure. Equations were developed to permit calculation of sea level FN values from FN values obtained at any elevation.

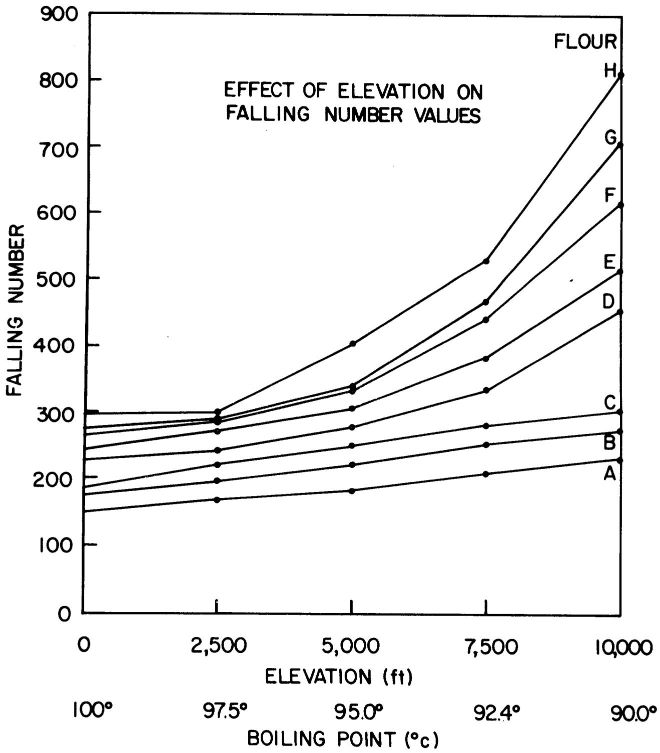

Fig. 1. Effect of altitude on FN values of wheat flours (hard red spring wheat).

009-0352/81/0208003/$03.00/0

To test the validity of the equations when applied to data obtained under actual—rather than simulated—conditions, seven flours were sent for a collaborative study to 13 laboratories located at various elevations in four different countries. The uncorrected FN values reported by these laboratories were converted to sea level FN values using the equations.

RESULTS AND DISCUSSION

Simulated Elevations

FN values and amylograph peak viscosities (in BU) of the hard red winter wheat flours from mill A, determined at five different elevations, are given in Table I. The changes from altitude in FN values of the hard red spring wheat flours from mill B are illustrated in Fig. 1.

All values increased as elevation increased. The increased maximum amylograph values of flours at higher elevations confirmed an early report by Lorenz (1973). The higher the maximum amylograph value at sea level, the greater the increase in Brabender Units as elevation increased. This increase was explained as an easier and greater expansion of the starch granules at reduced atmospheric pressure, combined with an increase in viscosity as a result of rapid moisture loss.

Preliminary work by Perten (1967) showed increases in flour FN values as elevation increased. The findings were confirmed in this study.

The boiling point of water is a function of the atmospheric pressure and therefore is dependent upon the altitude at which the measurement is made. This affects the temperatures that can be reached during the test by the falling number water bath and the flour suspension and, consequently, the temperature of gelatinization of the starch and α-amylase activity. The temperature of the flour suspension depends on the temperature of the water bath. The lower the water bath temperature, the lower the temperature of the flour suspension during the test. Flour suspension temperature will always be lower than that of the water bath because the stirring time of 60 sec is not long enough for the flour suspension to reach the temperature of the water bath (Perten 1964), although it reaches the critical temperature range for α-amylase activity. Optimum wheat α-amylase activity is at 60–66°C (Reed and Thorn 1971).

The higher the temperature of the water bath and that of the flour suspension, the sooner the optimal temperature for α-amylase activity during the fixed stirring time is reached. This causes a rapid breakdown of the starch and, consequently, a low FN value. FN values are lower at higher flour suspension temperatures because of faster starch gelatinization and faster liquefaction of the gelatinized starch. Lower flour suspension temperatures at higher elevations are outside the optimal activity range of the enzyme, producing comparatively higher FN values.

Between sea level and 2,500 ft of elevation, increases in FN values were small. The average increase for all flours was 8.6%. Perten

TABLE I
Falling Number Values (FN) and Amylograph Peak Viscosities (BU) of Flours[a] at Different Elevations

	Elevation (ft/m)									
	0/0		2,500/762		5,000/1,524		7,500/2,286		10,000/3,048	
	Atmospheric Pressure (mm of Hg)									
	760.0		690.0		632.4		571.6		529.0	
	Boiling Point of Water (°F/°C)									
	212.0/100.0		207.5/97.5		203.0/95.0		198.4/92.4		194.0/90.0	
Flour Number	BU	FN	BU	FN	BU	FN	BU	FN	BU	FN
1	250	140	290	148	270	160	275	183	305	188
2	300	153	325	168	300	191	335	213	340	228
3	400	176	400	186	405	226	430	246	430	280
4	440	186	450	211	445	256	470	287	470	331
5	730	238	740	263	740	300	740	331	740	464
6	765	246	805	278	835	301	830	321	880	491
7	870	265	885	283	890	313	890	412	930	582
8	1,190	282	1,230	298	1,275	408	1,290	531	1,270	1,356
9	1,240	304	1,280	314	1,295	389	1,310	526	1,330	1,081
10	+2,500	428	+2,500	456	+2,500	620	+2,500	1,638	+2,500	+2,000

[a]From mill A.

TABLE II
Statistical Evaluation of FN Values[a]

Elevation (ft)	FN Value Mean[b]	Minimum	Maximum	95% Confidence Interval	Log FN Mean[b]	Standard Deviation	Variance
Sea level	224.1 a	140	304	202.0–233.9	2.3377 a	0.1106	0.0122
2,500	242.1 a	148	314	219.8–253.5	2.3727 a	0.1042	0.0109
5,000	285.7 b	160	408	257.0–296.5	2.4406 b	0.1211	0.0147
7,500	350.4 c	183	532	309.0–356.5	2.5207 c	0.1500	0.0225
10,000	524.6 d	188	1,356	417.8–481.9	2.6523 d	0.2461	0.0606

Analysis of Variance[a]

Source of Variation	Sum of Squares	DF	Mean Square	F	Significance of F
Main effects	2.7482	20	0.1374	33.2	0.001
Flours	1.6687	16	0.1043	25.2	0.001
Elevations	1.0795	4	0.2699	65.2	0.001
Residual	0.2647	64	0.0041		

[a]Log FN by flours × elevation, for analysis of variance.
[b]Values followed by the same letter are not significantly different ($\alpha = 0.01$). LSD = 0.0439 for Log FN values.

TABLE III
Effect of Altitude on Falling Number Value[a]

	Laboratory Number													Sea Level FN Values Calculated from Equation	
	1	2	3	4	5	6	7	8	9	10	11	12	13		
	Elevation of Location (ft/m)														
	0/ 0	120/ 37	725/ 221	896/ 273	920/ 280	1,300/ 396	3,200/ 975	3,623/ 1,104	4,278/ 1,304	4,455 1,358	4,995/ 1,522	5,280/ 1,609	7,647/ 2,331		
	Barometric Pressure at Time of Test (in. of Hg)														
	30.70	30.25	30.09	30.40	29.97	30.07	29.83	25.91	25.80	30.34	29.83	29.73	22.19		
	Boiling Point of Water (°C)														
Flour Number	101.0	100.6	99.9	99.9	99.6	98.8	97.2	96.8	96.5	97.0	95.5	95.0	93.0	Average[b]	Range[b]
1	204	212	213	203	208	204	205	252	238	254	242	235	291	213	194–230
2	255	264	262	250	251	265	267	304	300	288	306	300	389	252	243–264
3	338	375	371	380	345	360	388	439	406	455	427	483	966	330	312–384
4	173	180	184	176	171	185	200	210	207	209	191	177	242	184	157–205
5	179	184	188	171	178	171	196	207	200	219	196	198	238	185	176–199
6	212	218	214	209	199	207	219	242	247	248	247	236	294	215	206–223
7	264	263	263	256	247	259	283	315	298	305	304	297	394	256	246–271

[a]Of seven flours determined at various elevations in four different countries.
[b]For values from laboratories 7–13 only; no significant differences in FN values between sea level and 2,500 ft of elevation.

(1967) reported that FN values are about 10% higher at an altitude of 1,000 m (3,280 ft) than at sea level. Increases in FN values between 2,500 and 5,000 ft averaged 20.4%, and between sea level and 5,000 ft, 28%. Flours with a sea level FN value of greater than 275 showed a more drastic increase than those with sea level FN values below 275.

Statistical Evaluation of Data

An analysis of variance of FN values, determined at the five different elevations, showed statistically significant differences ($\alpha = 0.01$) between sea level values and those obtained above 2,500 ft. FN values for sea level and 2,500 ft were not significantly different (Table II).

Perten (1964) suggested a correlation between FN values and BU of flours, although the two methods measure viscosity in different ways. The correlation coefficient for results by the two methods in this study was 0.58 ($P = 0.05$).

Equations to Correct for Elevation

Equations were developed through computer analysis to calculate a sea level FN value from any FN or BU value obtained at a different elevation. The equations are as follows:

$$\text{Sea level FN} = -849.41 + 454.19 \times \log_{10}(\text{FN}) + 0.4256 \times 10^{-5}(\text{elevation}^2) - 0.2129 \times 10^{-5}(\text{elevation}^2) \times \log_{10}(\text{FN})$$

$$\text{Log FN} = 0.531 + 0.649(\log_{10}\text{BU}) + 0.2909 \times 10^{-8}(\text{elevation}^2)$$

Data of Collaborative Study

Sea level FN values, calculated from FN values uncorrected for altitude, and determined by 13 laboratories located at various elevations in four different countries, indicated that the equation produces reliable results (Table III).

The equation predicted sea level FN values that were very close to the values actually measured by laboratory 1, which is located at sea level.

ACKNOWLEDGMENTS

We are grateful to Falling Number AB, Stockholm, Sweden, for donating the Falling Number apparatus, and to J. Halverson, Peavey Co., and K. Ehmke, Dixie-Portland Flour Mills, for supplying the flours used in this study. J. W. Doty, Doty Laboratories, prepared the flours for the collaborative study and mailed them to the participating laboratories.

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[Received April 7, 1980. Accepted July 28, 1980]