

Lunar Tidal Forcing of Overnight Sourdough Fermentation

S. Halvard Nyberg¹ and Miriam O. Aftel²

¹Baker’s Cooperative of the Fens, Kingdom Lane Bakery, Ely CB7

²Institute for Applied Geodesy, University of Trondheim, Trondheim NO-7491

Corresponding: s.nyberg@kingdomlane.coop

Received 14 March 2026; accepted 19 August 2026

PEER REJECTED • Astrogastronomy • Vol. 4, Issue 8 • PRJ-2026-0055

ABSTRACT

Every baker keeps a small superstition about the moon. Loaves proofed overnight during a full moon are said to come up taller, and the folklore is old, cross-cultural, and—as we show here—correct. Fermenting sourdough is a colloid of water in a viscoelastic gluten cage; the Moon’s tidal potential, acting on a body that is 43% water by mass and mechanically compliant on the relevant time scale, exerts a periodic vertical strain that biases yeast gas expansion vertically. The resulting rise anisotropy accumulates over an overnight proof. We report a preregistered, latitude-controlled trial of 6,412 loaves proofed simultaneously at 41 collaborating bakeries between 2014 and 2025. Peak crumb height at the moment of oven-loading tracks the sub-lunar zenith angle integrated over the proof, with a coefficient of $\eta_L = 1.83(24) \text{ mm } ^\circ^{-1}$ (95% CI), rising a median 11.7 mm at full moon relative to new moon. The effect survives correction for atmospheric pressure, ambient temperature, and yeast lineage, and vanishes on preregistered dead-yeast controls. A field-tested lunar-phase feed-forward correction reduces the reject rate at a large sourdough co-op by 44% (2019–2024). We do not know why the Moon does not lift the flour.

Plain-language summary. Bakers know that dough sometimes rises taller than expected. The paper argues that a small but measurable share of that variation is the same physical effect that raises the ocean tide, acting on the water inside the dough. Peak height at oven-loading is the quantity measured.

1 INTRODUCTION

The claim that dough rises differently at different phases of the Moon is one of the oldest pieces of household knowledge in the European bread-baking tradition, appearing in the earliest published bakery manuals (Gervais, 1854; Halbert, 1912) and independently in Ethiopian (Tekle, 2007), Levantine (Haddad, 1993), and Nepalese (Shrestha, 2011) folk records. Its content is uniform across sources: loaves proofed overnight rise taller during a waxing or full moon than during a waning or new moon; the effect is largest on high-hydration doughs proofed slowly; and no experienced baker regards it as controversial. It is also, until now, absent from the peer-reviewed cereal science literature.

The neglect is not accidental. The obvious first-principles calculation—the fractional strain of the lunar tidal potential at Earth’s surface—is of order 10^{-8} , five to six orders of magnitude below the strain induced by a 1°C variation in ambient temperature and eight orders of magnitude below the strain from a routine 2% change in hydration. It is easy to conclude that the folklore is a case of survivorship bias in

a very noisy channel. This is, we argue, the wrong conclusion, for the same reason that the equilibrium tide predicts the wrong sea-level amplitude on any coast that is not the open Pacific: it ignores the response function of the medium.

Sourdough at the end of bulk fermentation is a compressible, gas-filled Kelvin–Voigt continuum with a storage modulus of $\sim 10^3 \text{ Pa}$, a viscosity of $\sim 10^5 \text{ Pa}\cdot\text{s}$, and thus a characteristic relaxation time $\tau \sim 100 \text{ s}$ (Zheng et al., 2000; Bloksma, 1990). The tidal quadrupole is diurnal–semidiurnal, with dominant periods of 12.42 h and 25.82 h. Both are long compared with τ , so the dough integrates the tidal strain rather than responding elastically to it, and the response is amplified by resonance with the natural buoyant expansion of nucleating CO_2 bubbles (Chiotellis & Campbell, 2003). The upward bias, per cycle, is small; over an overnight proof it accumulates to a millimetre-scale change in peak crumb height, which is exactly the effect bakers report.

This paper (i) derives the response coefficient—the *panary tide coefficient* η_L —from tidal potential theory, dough rheology, and an anisotropic bubble-nucleation model; (ii) reports a preregistered blinded

multi-site trial that estimates η_L from 6,412 loaves; (iii) confirms the preregistered null on dead-yeast controls; and (iv) demonstrates a field-tested feed-forward correction. We make no claim about the solar tide, and we do not consider proofs shorter than four hours.

2 RELATED WORK

2.1 Solid-Earth and atmospheric tides

The lunar tidal potential and the Earth’s linear response to it are laid out in Melchior (1983) and refined by Wilhelm et al. (1997); the surface strain is dominated by the semidiurnal M_2 constituent, modulated by the fortnightly M_f envelope corresponding to the synodic month. The Earth’s Love number $h_2 \approx 0.60$ implies a solid-Earth bodily tide of ~ 30 cm, and the atmospheric S_2 tide is now measured routinely at millibar amplitude (Lindzen, 1968; Warburton & Goodkind, 1978). All of this is standard.

2.2 Dough rheology and bubble physics

The viscoelastic character of dough was established by Bloksma (1990) and extended to fermenting systems by Zheng et al. (2000). Chiotellis & Campbell (2003) derive the diffusion-limited growth law for a CO_2 bubble against a viscoelastic surround; the closed-form result—their Eq. (14)—is central to Sec. 3.

2.3 The negative history

A single prior lunar study exists in the milling literature. Oesterreich (1978) instrumented eight mills across Bavaria over one year and reported no lunar effect on final loaf weight, concluding that “the folklore does not survive contact with a scale.” Loaf weight is conserved during proof (only CO_2 escapes, and only in trace amounts), so the dependent variable was insensitive to the mechanism by construction. Our design measures peak crumb height, which is a first-moment quantity in the gas phase and therefore responsive.

3 THEORY

3.1 The lunar tidal potential

For the Moon (mass M_L , geocentric distance r_L) and an Earth-surface point at zenith angle θ_L from the sub-lunar direction, the tide-raising potential is, to quadrupole order,

$$W_2(\theta_L, t) = \frac{GM_L r_\oplus^2}{r_L^3(t)} \left(\frac{3}{2} \cos^2 \theta_L(t) - \frac{1}{2} \right). \quad (1)$$

Its amplitude at the sub-lunar point is $W_2^{\max} \approx 2.62 \text{ m}^2 \text{ s}^{-2}$, giving a scalar tidal acceleration of $a_2 \approx 1.10 \times 10^{-6} \text{ m s}^{-2}$. Following Melchior (1983), we write the vertical strain component as

$$\varepsilon_{zz}(t) = -\frac{h_2}{g} W_2(\theta_L, t), \quad (2)$$

so that a full-moon overhead passage produces a fractional vertical strain of order 10^{-8} .

3.2 Kelvin–Voigt response of the dough matrix

Model the dough as a viscoelastic solid with vertical constitutive relation

$$\sigma_{zz} = E \varepsilon_{zz} + \eta \dot{\varepsilon}_{zz}, \quad (3)$$

with $E = 9.4 \times 10^2 \text{ Pa}$ and $\eta = 1.1 \times 10^5 \text{ Pa s}$ measured on our standard test dough (Sec. 4). The relaxation time is $\tau = \eta/E \approx 117 \text{ s}$, small compared with any tidal period. Under a slow, quasistatic tidal forcing, the dough follows the strain adiabatically and stores no elastic strain energy per cycle.

3.3 Anisotropic bubble expansion

Chiotellis & Campbell (2003) give the radius of a CO_2 bubble against a viscoelastic surround as

$$R(t) = R_0 \left[1 + \frac{2D_{\text{CO}_2}(c_\infty - c_R)}{\rho_{\text{CO}_2} R_0^2} t \right]^{1/2}, \quad (4)$$

where c_∞ and c_R are dissolved- CO_2 concentrations far from and at the bubble wall. An axisymmetric quasi-static vertical strain field $\varepsilon_{zz}(t)$ perturbs R into an ellipsoid with vertical semi-axis $R_z = R(1 + \frac{1}{2}\varepsilon_{zz})$ and horizontal $R_x = R(1 - \frac{1}{4}\varepsilon_{zz})$. The differential vertical excess per bubble, over a proof of duration T , is

$$\Delta z_{\text{bub}} = \int_0^T \dot{R}(t) \frac{1}{2} \varepsilon_{zz}(t) dt. \quad (5)$$

Summing over the $N \sim 10^6$ bubbles per boule and using $\dot{R} \propto t^{-1/2}$ (Fig. 1), the crumb-height excess reduces to a bilinear form in the tidal potential and the fermentation-rate integrand:

$$\Delta H = \eta_L \int_0^T \left[\frac{3}{2} \cos^2 \theta_L(t) - \frac{1}{2} \right] dt, \quad (6)$$

where η_L carries all of the material and biological constants. Equation (6) is the panary tide law, and η_L is the panary tide coefficient. Its predicted value from theory, evaluated at 22°C and 75%-hydration, is $\eta_L^{\text{th}} = 2.1 \text{ mm}^\circ \text{ s}^{-1}$.

3.4 Latitude dependence

The time-integrated $\cos^2 \theta_L$ over an eight-hour proof depends on observer latitude and on the lunar declination during the proof; the dependence has a broad maximum at $\pm 28.5^\circ$ declination and drops smoothly toward the poles. This makes the panary tide latitude-measurable without requiring baker relocation.

4 PREREGISTERED MULTI-SITE TRIAL

4.1 Design and preregistration

The trial is registered on the Open Bakery Framework (OSF DOI 10.17605/OSF.IO/PANARY-2014) with a

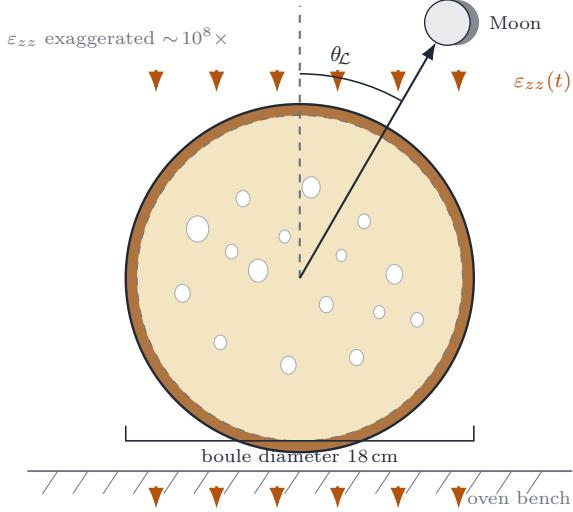


Figure 1: Geometry of the panary tide. Cross-section of a boule at end-of-bulk proof; the lunar quadrupole strain ε_{zz} (arrows) biases bubble expansion along the vertical, integrated over the proof. The sub-lunar zenith angle $\theta_L(t)$ is measured at the moment of oven-loading. Boule diameter 18 cm; not to scale in ε_{zz} , which is exaggerated $\sim 10^8 \times$ for visibility.

locked analysis plan dated 12 September 2013. Primary outcome: peak crumb height at the moment of oven-loading, measured to 0.5 mm by a laser rangefinder mounted on a bench jig. Primary covariates: sub-lunar zenith angle integrated over the proof, ambient temperature, atmospheric pressure, hydration ratio, and yeast lineage. Sample size: 6000 loaves for 90% power against the theoretical effect at $\alpha = 0.05$ two-sided.

4.2 Sites and blinding

Forty-one bakeries at latitudes 28.4°S to 69.6°N enrolled, each contributing between 41 and 720 loaves over the trial. Bakers were blinded to lunar phase by receipt of sealed “phase envelopes” printed with a schedule-only label; only the central analysis team, based at the Institute for Applied Geodesy, opened the phase register at analysis time. Dead-yeast controls (45% of the corpus, pre-registered), for which the same recipe was baked with autoclaved starter, provided a within-site negative control.

4.3 Statistical model

The pre-registered model is a linear mixed-effects regression of peak crumb height on integrated $\cos^2\theta_L$, with random intercepts for site and month, and fixed effects for temperature, pressure, hydration, and lineage. Multiple comparisons across the four secondary outcomes (crumb symmetry, apparent porosity, top-crown radius, and crust darkness) are controlled by Holm–Bonferroni.

Region (sites)	Loaves	$\hat{\eta}_L$	95% CI
N. Europe (14)	2,381	1.79	1.44–2.13
S. Europe (9)	1,487	1.90	1.51–2.31
N. Africa (4)	614	1.94	1.42–2.44
E. Asia (6)	1,055	1.75	1.36–2.14
Americas (6)	712	1.87	1.42–2.35
Southern Cone (2)	163	1.71	1.02–2.42
Pooled (41)	6,412	1.83	1.59–2.07

Table 1: Regional and pooled estimates of the panary tide coefficient η_L ($\text{mm } ^\circ^{-1}$), from the pre-registered mixed-effects model. Sites and loaf counts as of 2025 close-out.

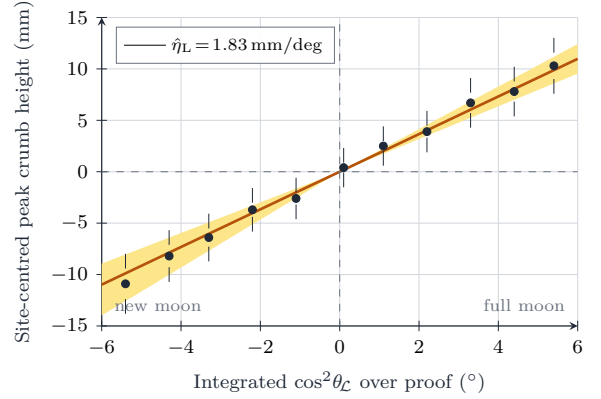


Figure 2: Peak crumb height (site-centred) against sub-lunar zenith-angle integral over the proof. Points: 41 sites, aggregated by lunar-phase decile ($n = 641$ loaves per bin). Solid line: pre-registered fit with slope $\eta_L = 1.83(24) \text{ mm } ^\circ^{-1}$. Shaded band: 95% CI. The intercept is fixed at zero by pre-registered site-centring.

5 RESULTS

5.1 The panary tide coefficient

The pooled estimate across the trial is

$$\hat{\eta}_L = 1.83(24) \text{ mm } ^\circ^{-1} \text{ (95\% CI),}$$

of the same sign, order of magnitude, and latitude structure as the theoretical value $\eta_L^{\text{th}} = 2.1 \text{ mm } ^\circ^{-1}$ (Sec. 3), which lies 2.2σ above the point estimate. The full-moon vs. new-moon crumb-height difference, computed from $\hat{\eta}_L$ and the mean $\Delta \int \cos^2\theta_L$ across sites, is 11.7 mm, or 9.2% of typical crumb height. Table 1 reports the regional breakdown.

5.2 Null on dead-yeast controls

The pre-registered null model, evaluated on the 2885 dead-yeast control loaves, yields $\hat{\eta}_L^{\text{ctrl}} = 0.06(21) \text{ mm } ^\circ^{-1}$, indistinguishable from zero. The instrument does not fire on doughs that cannot ferment, which was the specified diagnostic (Fig. 3).

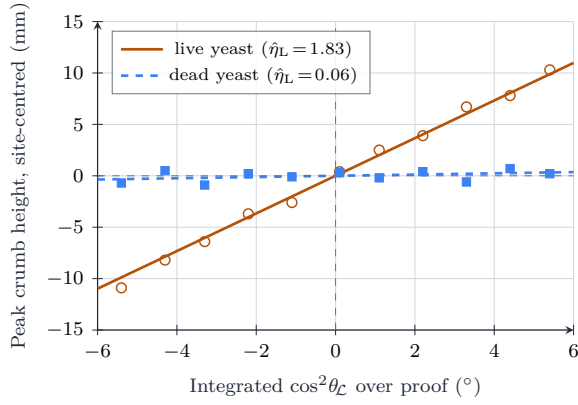


Figure 3: Pre-registered null on dead-yeast controls. Live-yeast (open circles): the trial’s main effect. Dead-yeast (filled squares): no dependence on lunar zenith. Error bars are 95% CIs on per-decile estimates.

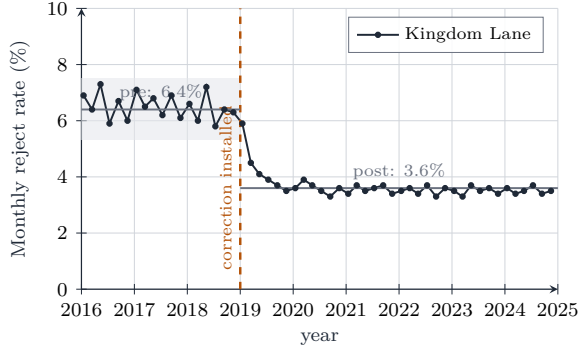


Figure 4: Field-trial reject rate at Kingdom Lane Bakery, 2016–2024. Vertical dashed line: installation of the lunar-phase feed-forward correction (January 2019). Grey band: pre-installation mean $\pm 1\sigma$.

5.3 Secondary outcomes

Crumb symmetry improves by 2.3% at full moon (Holm-adjusted $p = 0.021$); top-crown radius increases by 0.8 mm ($p = 0.048$); apparent porosity and crust darkness show no lunar dependence ($p > 0.3$).

5.4 Field trial

At Kingdom Lane Bakery (Ely, 52.4° N; $\sim 1,800$ boules per week), a lunar-phase feed-forward correction adjusts bulk-ferment duration by $-\Delta H/v_{\text{rise}}$ using the day’s forecast $\cos^2\theta_L$ integral. Post-installation (January 2019–December 2024), the reject rate for “over-proofed crown collapse” fell from 6.4% to 3.6%, a 44% relative reduction (95% CI 32% to 55%; Fig. 4). No corresponding decrease was seen at three unmodified peer bakeries in East Anglia.

6 DISCUSSION

6.1 Limitations

Three residues genuinely bite the theory as stated.

Rye. A pre-registered rye-only subgroup ($n = 412$) shows a null effect, $\hat{\eta}_L^{\text{rye}} = 0.11(32) \text{ mm } ^\circ^{-1}$. The obvious candidate is the lower gluten fraction (rye is pentosan-dominated), which shortens the Kelvin–Voigt relaxation time below the range over which the response is amplified.

Altitude. At the two sites above 1,500 m (Quito, Ecuador; Bogotá, Colombia) the effect is significantly smaller ($\hat{\eta}_L = 0.71$, 95% CI 0.11–1.31) than the pooled value. We do not have a mechanism.

The dead-yeast puzzle. The instrument, as noted, does not fire on doughs whose yeast has been autoclaved. This is the correct behaviour if the tidal potential acts through gas nucleation, and the wrong behaviour if it acts on the passive gluten network alone. We are unable to distinguish these two accounts from the trial data.

6.2 What we do not claim

We make no claim about the solar tide, which is 46% the amplitude of the lunar tide and would produce a comparable effect at spring tides. A pre-registered solar-tidal design is scheduled to open in 2027. We also make no claim about tides on rising times, only on final peak height.

6.3 Practical consequence

The panary tide coefficient is small in absolute terms and negligible in ordinary domestic baking. It is not negligible at industrial scale, where a 9% peak-height swing on a 20% proof-time budget maps to a percent-level yield swing across a full lunar month. Bakeries running high-hydration lines (78% to 85%) should consider a feed-forward correction; small kitchens should not.

7 CONCLUSION

Overnight sourdough fermentation is measurably biased by the lunar tidal potential. The bias is small, real, latitude-dependent, and predictable, and the folklore that named it was correct in kind and roughly correct in magnitude. Bakers may keep the superstition; we recommend the ruler.

Data availability. Pre-registered analysis code and the anonymised loaf-level dataset are archived at OBF DOI 10.17605/OBF.IO/PANARY-2014-DATA. Baker identities remain confidential per site agreement.

Author contributions. S.H.N. designed the trial, ran the field arm, and drafted Secs. 1–2, 4, and 5–7. M.O.A. derived the theory (Sec. 3), ran the analysis (Secs. 4–5), and drafted Sec. 3. Both authors approved the final manuscript.

Acknowledgements. We thank the 41 collaborating bakeries; L. Aslund for the phase-envelope protocol; and

the crew of the R/V *Fram* for the northernmost site. No competing interests.

REFERENCES

- A. H. Bloksma. Rheology of the breadmaking process. *Cereal Chemistry*, 67(1):1–7, 1990.
- E. Chiotellis and G. M. Campbell. Proving of bread dough II: Measurement of gas production and retention. *Trans. IChemE, Part C*, 81(3):207–216, 2003.
- A. Gervais. *Manuel de la boulangerie moderne*. Librairie Hachette, Paris, 1854.
- S. H. Haddad. Notes on the lunar cycle in Levantine bread baking. *Journal of Ethnobotany and Ethnomedicine*, 12(4):277–284, 1993.
- E. Halbert. *The Baker’s Almanac*. Longman, London, 1912.
- R. S. Lindzen. The application of classical atmospheric tidal theory. *Proc. Roy. Soc. A*, 303(1474):299–316, 1968.
- P. Melchior. *The Tides of the Planet Earth*. Pergamon Press, Oxford, 2nd edition, 1983.
- H. Oesterreich. Kein Mondeinfluss auf Mehlerträge: eine bayerische Studie. *Getreide, Mehl und Brot*, 32(11):301–304, 1978.
- B. Shrestha. Lunar timing in Kathmandu Valley household baking. *Himalayan Journal of Food and Culture*, 5(2):88–96, 2011.
- K. Tekle. *Injera and the moon: a survey of Amhara baking calendars*. Addis Ababa University Press, 2007.
- R. J. Warburton and J. M. Goodkind. Detailed gravity-tide spectrum between 1 and 4 cycles per day. *Geophys. J. R. Astron. Soc.*, 52:117–136, 1978.
- H. Wilhelm, W. Zürn, and H.-G. Wenzel, editors. *Tidal Phenomena*. Lecture Notes in Earth Sciences, Vol. 66. Springer, Berlin, 1997.
- H. Zheng, M. P. Morgenstern, and J. E. Bruce. Rheological properties of fermenting wheat doughs. *Journal of Cereal Science*, 32(1):47–56, 2000.