













## Abstract

# Heat Treatment of Bovine Milk Impacts Gastric Emptying and Nutrient Appearance <sup>†</sup>

Amber M. Milan <sup>1,2,3,\*</sup> , Matthew P. G. Barnett <sup>2,4</sup> , Warren C. McNabb <sup>3,4</sup> , Nicole C. Roy <sup>3,4,5</sup> , Schynell Coutinho <sup>1</sup>, Caroline L. Hoad <sup>6</sup> , Luca Marciari <sup>6</sup> , Samson Nivins <sup>1,7</sup> , Hayfa Sharif <sup>6</sup> , Timothy R. Angeli-Gordon <sup>3,4,8,9</sup> , Peng Du <sup>8</sup>, Armen A. Gharibans <sup>8,9</sup>, Greg O'Grady <sup>8,9</sup>, Pankaja Sharma <sup>1</sup> , Aahana Shrestha <sup>1</sup>  and Richard F. Mithen <sup>1,3,4</sup> 

- <sup>1</sup> The Liggins Institute, The University of Auckland, Auckland 1023, New Zealand; s.coutinho@auckland.ac.nz (S.C.); samson.nivins@ki.se (S.N.); p.sharma@auckland.ac.nz (P.S.); a.shrestha@auckland.ac.nz (A.S.); r.mithen@auckland.ac.nz (R.F.M.)
  - <sup>2</sup> Physiology and Health Team, AgResearch Limited, Palmerston North 4442, New Zealand; matthew.barnett@agresearch.co.nz
  - <sup>3</sup> The High-Value Nutrition National Science Challenge, Auckland 1023, New Zealand; w.mcnabb@massey.ac.nz (W.C.M.); nicole.roy@otago.ac.nz (N.C.R.); t.angeli@auckland.ac.nz (T.R.A.-G.)
  - <sup>4</sup> The Riddet Institute, Palmerston North 4474, New Zealand
  - <sup>5</sup> Department of Human Nutrition, The University of Otago, Otago 9016, New Zealand
  - <sup>6</sup> Translational Medical Sciences, NIHR Nottingham Biomedical Research Centre at Nottingham University Hospitals NHS Trust, The University of Nottingham, Nottingham NG7 2UH, UK; caroline.l.hoad@nottingham.ac.uk (C.L.H.); luca.marciari@nottingham.ac.uk (L.M.); hayfa.sharif@nottingham.ac.uk (H.S.)
  - <sup>7</sup> Department of Neuroscience, Karolinska Institutet, 171 77 Solna, Sweden
  - <sup>8</sup> Auckland Bioengineering Institute, The University of Auckland, Auckland 1010, New Zealand; peng.du@auckland.ac.nz (P.D.); armen.gharibans@auckland.ac.nz (A.A.G.); greg.ogrady@auckland.ac.nz (G.O.)
  - <sup>9</sup> Department of Surgery, Faculty of Medical and Health Sciences, University of Auckland, Auckland 1023, New Zealand
- \* Correspondence: a.milan@auckland.ac.nz; Tel.: +64-9-923-4785
- <sup>†</sup> Presented at the Annual Scientific Meeting of the Nutrition Society of New Zealand 2022, Wellington, New Zealand, 1–2 December 2022.



**Citation:** Milan, A.M.; Barnett, M.P.G.; McNabb, W.C.; Roy, N.C.; Coutinho, S.; Hoad, C.L.; Marciari, L.; Nivins, S.; Sharif, H.; Angeli-Gordon, T.R.; et al. Heat Treatment of Bovine Milk Impacts Gastric Emptying and Nutrient Appearance. *Med. Sci. Forum* **2023**, *18*, 8. <https://doi.org/10.3390/msf2023018008>

Academic Editors: Claire Smith, Sally Mackay, Shabnam Jalili-Moghaddan and Michelle Gibbs

Published: 8 March 2023



**Copyright:** © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

**Abstract:** Milk structural assemblies (e.g., casein micelles) occur naturally and can be altered during processing, and this may influence the milk's nutritional properties. Heat treatment of dairy ensures microbiological safety and extends shelf-life. Both pasteurisation and ultra-high temperature (UHT) processing are known to alter natural structural assemblies, but despite widespread use, only four human studies have addressed how heat treatment affects nutrient delivery. In vitro, animal, and human models have all shown more rapid nutrient release or appearance from UHT vs. pasteurised milk, with altered gastric emptying rate proposed as a mechanism. We hypothesised that differences in bovine milk structural assemblies arising from different processing methods would speed up gastric emptying and nutrient delivery following consumption of UHT relative to pasteurised milk. A randomised double-blind crossover trial assessed gastric emptying rate (using magnetic resonance imaging measuring gastric content volume) over 3 h and plasma amino acid appearance (using ultra-performance liquid chromatography) over 5 h following 500 mL of each milk in healthy women (n = 20). Gastric electrical activity was measured using body surface gastric mapping, and abdominal distension using stretch sensors. The time to empty 25% of the stomach contents was greater following UHT vs. pasteurised milk (45 ± 4 vs. 33 ± 4 min  $p < 0.05$ ). While gastric content remained greater for longer following UHT milk, the incremental area under the curve of plasma essential amino acids was greater than pasteurised milk (55324 ± 3809 vs. 36598 ± 5673  $\mu\text{mol}\cdot\text{min}\cdot\text{L}^{-1}$   $p < 0.05$ ). The greater amino acid appearance following UHT milk aligns with more rapid release of proteins from the gastric curd observed in vitro, yet the greater gastric content volume implies gastric content composition (e.g., solid vs. liquid) is an important determinant of nutrient release. Dairy processing using different heat treatments, which induced structural modifications, impacted gastric emptying

and plasma amino acid appearance, with implications for appetite regulation and nutrient utilisation for metabolism.

**Keywords:** milk; ultra-high temperature milk; pasteurised milk; food structure; digestion; gastric emptying; amino acids; magnetic resonance imaging; body surface gastric mapping

---

**Author Contributions:** Conceptualization, A.M.M., M.P.G.B., W.C.M., N.C.R. and R.F.M.; methodology, A.M.M., S.C., C.L.H., L.M., S.N., T.R.A.-G., P.D., A.A.G. and G.O.; formal analysis, A.M.M., C.L.H., L.M., S.N., H.S., P.D. and A.A.G.; investigation, A.M.M., M.P.G.B., S.C., P.S., A.S. and R.F.M.; software, C.L.H., L.M., P.D., A.A.G. and G.O.; resources, A.M.M., C.L.H., L.M. and G.O.; data curation, A.M.M., S.N., P.D., A.A.G., P.S. and A.S.; writing—original draft preparation, A.M.M., M.P.G.B. and R.F.M.; writing—review and editing, W.C.M., N.C.R., C.L.H., L.M., S.N., T.R.A.-G., P.D., A.A.G. and G.O.; visualization, A.M.M.; supervision, W.C.M., N.C.R. and R.F.M.; project administration, A.M.M., M.P.G.B., W.C.M., N.C.R. and R.F.M.; funding acquisition, W.C.M. and N.C.R. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Ministry of Business Innovation and Employment (MBIE) through the New Zealand Milks Mean More (NZ3M) Programme, grant number MAUX1803, and the High-Value Nutrition National Science Challenge funded by MBIE, grant number UOAX1902. The APC was funded by NZ3M.

**Institutional Review Board Statement:** The study was conducted in accordance with the Declaration of Helsinki and approved by the Central Health and Disability Ethics Committee of New Zealand (19/CEN/205, approved 13 December 2019).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

**Conflicts of Interest:** The authors declare no conflict of interest.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.