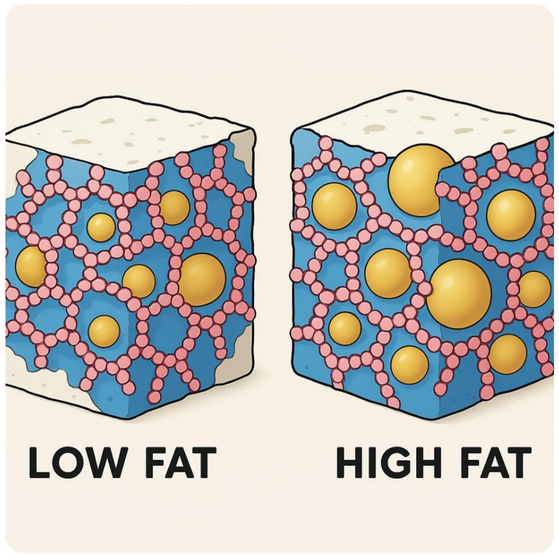
Impact of Fat Content Variation on Molecular Dynamics in Feta Cheese: A Time-Domain and Fast Field Cycling NMR Study

Neriman Ezgi Cifte[a], Furkan Erdem[a], Faisal Shah[b], Danuta Kruk[b] and Mecit Halil Oztop[a]

[a]*Middle East Technical University, Ankara, Turkey*, [b]*University of Warmia and Mazury, Olsztyn, Poland*

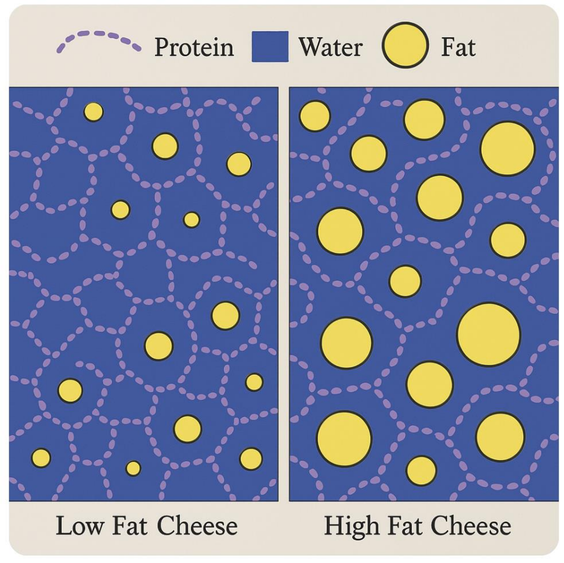
INTRODUCTION



- Feta is a semi-hard, brined white cheese made from sheep's milk, often blended with goat's milk
- Water is distributed in a continuous protein–fat matrix
- Fat exists in globular domains and influences both water mobility and proton relaxation behavior

Table 1. Compositional properties of the feta cheese samples

Nutritional Components	Low-Fat (% wb)	High-Fat (% wb)
Fat	6.00	18.00
Carbohydrates	1.50	3.50
Protein	17.70	15.00
Salt	2.34	2.00
Moisture	62	51



Low-fat cheese

- Texture is firmer and more elastic
- Less fat allows for greater water dispersion and potential mobility
- Less structural hindrance from fat leads to more mobile water fractions
- Water held less tightly by the matrix

High-fat cheese

- Leads to a softer and creamier texture
- Fat fills internal gaps in the protein strands, reducing available pathways for water
- Fat globules create physical barriers, limiting water movement
- Water tends to be more confined within the protein–fat matrix

METHODS

Time-Domain NMR measurements were conducted at four temperatures (283 K, 293 K, 303 K, and 313 K) to evaluate the influence of fat content on spin–lattice (T_1) and spin–spin (T_2) relaxation behavior using low field TD-NMR at 20 MHz. Fast Field Cycling NMR measurements were also performed over a frequency range of 10 kHz to 10 MHz at the same temperature interval.

RESULT AND DISCUSSION

TD-NMR: T_1 (Spin-Lattice Relaxation Time)

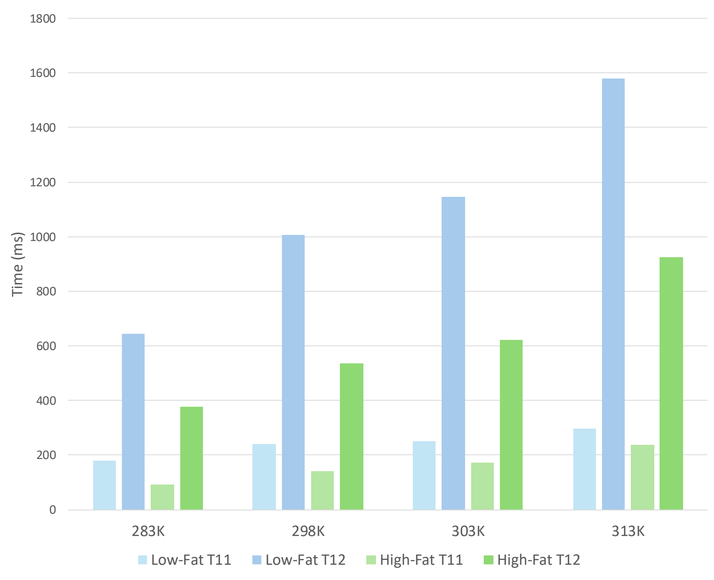


Figure 1

TD-NMR: T_2 (Spin-Spin Relaxation Time)

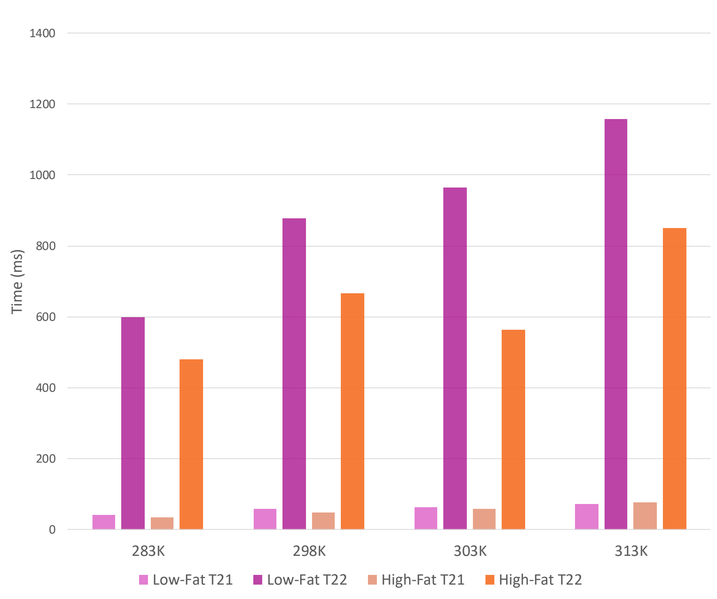


Figure 2

based on Fat Content

- **T_{11} and T_{21}**: Immboile water and fat entrapped in the protein matrix
- **T_{21} and T_{22}**: Mobile water and fat droplets
- In **High-Fat** Feta Cheese**: Relaxation times shorter**

- Less free water
- More fat globules are embedded in the protein matrix
- More interaction of water with fat-protein matrix
- Fat–protein interactions dominate the system: Restricted molecular motion

based on Temperature

- As **temperature increases**

- Protein chains gain flexibility
- Hydrophobic interactions, protein-fat matrix, weaken
- Fat begins to melt
- Viscosity drops
- Water–matrix interactions decrease

- **T_1 and T_2** relaxation times **increase**

FFC-NMR: T_1 Relaxation in High-Fat and Low-Fat Feta Cheese at 283K-313K

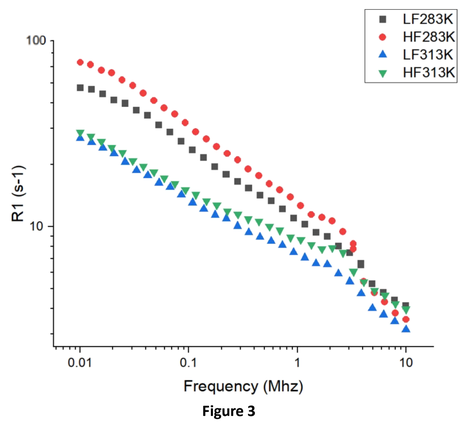


Figure 3

FFC-NMR: T_1 Relaxation in High-Fat Cheese

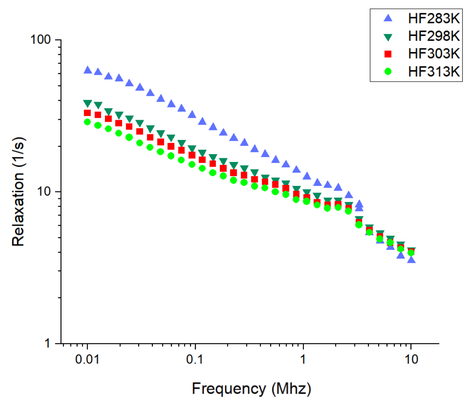


Figure 4

FFC-NMR: T_1 Relaxation in Low-Fat Cheese

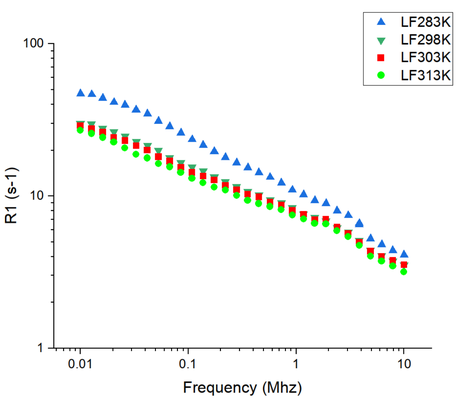


Figure 5

Low-fat cheese shows longer T_1 than high-fat cheese at the same T
Because water is less confined — it moves more freely in the matrix
- Fewer fat domains → less surface interaction with water → weaker dipole-dipole relaxation

Higher temperatures increase T_1 in both fat levels
- Heat increases molecular motion → faster reorientation of water
- Fast motion is less efficient at relaxing protons at low freq→ T_1 increases

At high frequencies, differences between samples diminish
- Because only very fast motions dominate relaxation

At **low frequencies**, T_1 is short and strongly dependent on temperature:
- Water is **confined** in fat–protein interfaces → slow motion → efficient relaxation.
- Temperature increase speeds up motion → T_1 increases.

At **high frequencies**, T_1 increases and differences between temperatures shrink:
- These frequencies evaluate more mobile portions. **T_1 curves converge**.

Fat's influence is most visible at low/intermediate frequencies, where molecular confinement matters most.

Water in low-fat cheese is **less confined** to begin with.
- Fat domains are fewer → less structural restriction.

At low frequencies, relaxation is still influenced by temperature and sample structure.
- T_1 increases with temperature as mobility increases.

At **high frequencies**, water motion is probed at very short timescales.

CONCLUSION

This study demonstrates that fat content significantly influences the molecular dynamics and microstructural organization of feta cheese. High-fat samples exhibited greater molecular confinement and stronger water–protein interactions, as reflected by lower relaxation times and steeper dispersion profiles. In contrast, low-fat cheese allowed greater water mobility due to its more open matrix.

ACKNOWLEDGEMENT

This study was supported by NMR-IMPROV project (EU HORIZON-MSCA, 101131564).

REFERENCES

Chen Y, MacNaughtan W, Jones P, Yang Q, Foster T. The state of water and fat during the maturation of Cheddar cheese. Food Chem. 2020;303:125390. Kruk D, Florek – Wojciechowska M, Masiewicz E, Oztop M, Ploch-Jankowska A, Duda P, et al. Water mobility in cheese by means of Nuclear Magnetic Resonance relaxometry. J Food Eng. 2021;298:110483.