NMR Relaxometry for Quality and Authenticity Assessment of Dairy and Plant-Based Cheeses

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Abstract

This study explores the applicability of NMR relaxometry techniques for assessing quality and authenticity parameters in regular and plant-based cheese varieties. Cheddar, Gouda, and Greek white cheeses from both origins were analyzed using Fast Field Cycling (FFC) NMR, Time Domain (TD) NMR, and MRI. Experiments evaluated physicochemical, structural, and textural characteristics. Results showed that FFC-NMR and TD-NMR relaxation times (T_1 and T_2) varied based on temperature and composition. MRI visualized moisture distribution and apparent diffusion. Plant-based white cheese displayed higher T_1 and diffusivity due to moisture content, while regular cheeses showed stronger protein-related texture profiles. The combined NMR tools show promise for rapid, non-destructive cheese quality assessment and authentication.

Introduction

Cheese quality depends on composition, structure, and processing. Authenticity issues such as adulteration and mislabeling affect consumer trust and trade. Non-invasive tools like NMR relaxometry can provide molecular-level insight into water mobility, fat distribution, and structural differences between cheese types. Advanced analytical tools are vital for consumer safety, regulatory compliance, and product integrity in the cheese market. This study investigates how FFC-NMR, TD-NMR, and MRI can differentiate plant-based and dairy cheeses, contributing to better quality control and fraud detection.

Material and Methods

Material: Plant-based Cheeses: Cheddar, Gouda, Greek White (coconut oil, starch, salt, flavors), Animal-Based Cheeses: Cheddar, Gouda, White (milk, salt, rennet, calcium chloride) at room temperature

- **FFC-NMR**

T_1 measured at 10 kHz–300 MHz at 25–35-45 °C

- **TD-NMR**

T_1 and T_2 at 18.53 MHz

- **T1, T2, Mapping and Diffusivity Determination**

A benchtop MRI device (Pure Device) was used to conduct the experiments. The data were taken from MATLAB.

- **Color Measurement**

The color determination CIELAB values were measured via a portable spectrocolorimeter (Serlab SL400, İstanbul, Turkey).

Moisture Content (MC) and Water Activity (a_w)

The moisture content of the samples was determined gravimetrically The water activity was determined by a water activity meter (Decagon Devices Inc., Pullman, WA, USA) at room temperature.

- **Texture Analysis**

Texture profile analysis was executed with a texture analyzer (CT3 Brookfield, Middleboro, MA, USA) at a 25% deformation rate. Hardness (N), stringiness length (mm), cohesiveness, springiness (mm), gumminess (g*cm), and chewiness (g*cm) data were obtained.

- **Statistical Analysis**

MINITAB 19 (Minitab Inc., State College, PA, USA) was used ANOVA. The comparisons were made Tukey's test at a significance level of 0.05. Fitteia and Origin software were used for fitting and drawing the graphs.

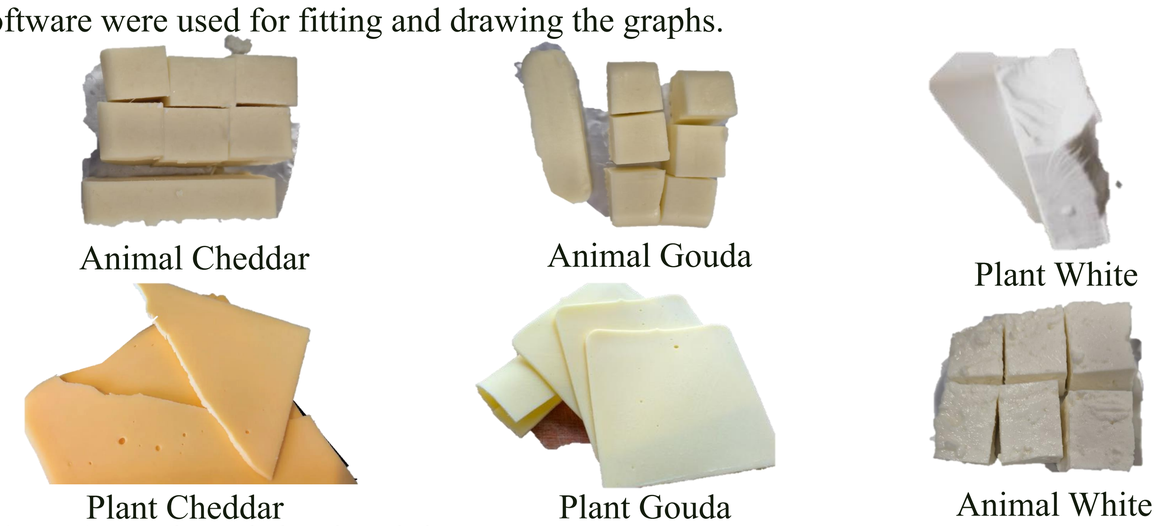

Figure 1. Regular and plant-based cheeses

Conclusions

NMR relaxometry is effective for differentiating cheese varieties based on composition and origin.
FFC-NMR and TD-NMR provide insight into water mobility and matrix rigidity.
MRI adds spatial distribution of moisture and structure.
These methods offer a non-invasive strategy for quality monitoring and fraud prevention in dairy and alternative cheese sectors.

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NMR-IMPROV

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REFERENCES

Results and Discussion

NMR Relaxometry:
T_1 values increased with temperature across all methods
FFC-NMR and TD-NMR revealed higher molecular mobility in plant-based cheeses, especially white
TD-NMR showed lower T_2 in starch-dense samples; MRI validated distribution patterns

MRI Mapping & Diffusion:
Plant-based white cheese had the highest T_1, apparent diffusivity, and moisture
T_1-/T_2-weighted maps showed structural variability (T_1-weighted: solid/fat effect, T_2-weighted: moisture effect) and overall uniformity
High diffusion = more mobile water; low diffusion = protein-fat matrix constraints

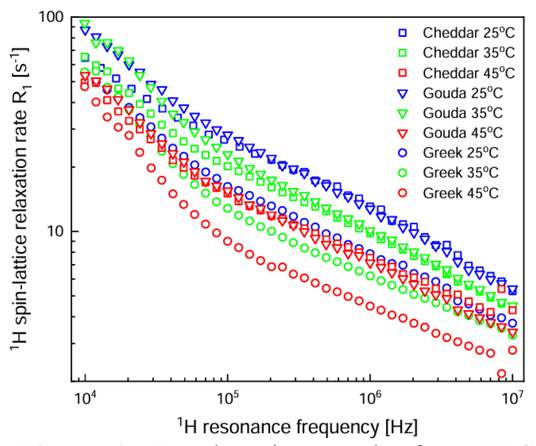

Figure 2. T_1 relaxation results from FFC-NMR of plant-based cheeses

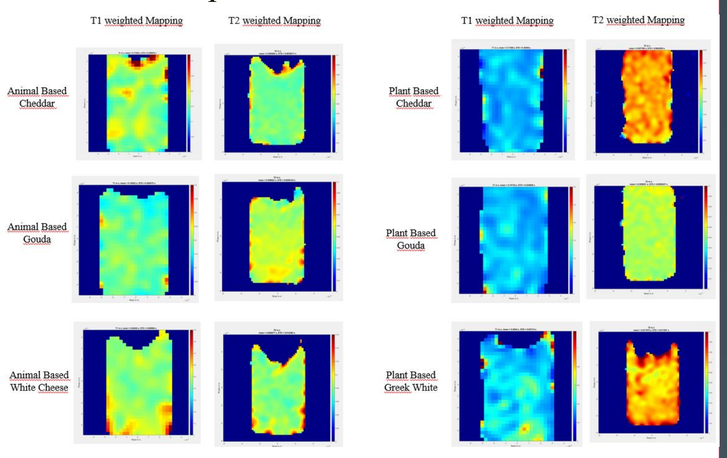

Figure 3. T_1 and T_2 weighted mapping of the cheeses

Table 1. T_1, T_2 and Diffusivity Results of all cheeses

Cheeses	T_1 (ms)	T_2 (ms)	Diffusivity (D× 10^{12} m^2/s)
A-Cheddar	157.9 ± 0.9^{e}	43.7 ± 1.1^{b}	5.3 ± 0.4^{bc}
A-Gouda	196.7 ± 5.1^{d}	47.1 ± 1.1^{b}	5.8 ± 0.5^{b}
A-White	447.0 ± 19.8^{b}	75.5 ± 1.9^{a}	5.2 ± 0.2^{bc}
P-Cheddar	280.4 ± 21.3^{c}	50.4 ± 11.3^{b}	5.5 ± 0.9^{bc}
P-Gouda	294.1 ± 2.8^{c}	38.4 ± 8.2^{b}	3.9 ± 1.0^{c}
P-White	580.2 ± 8.4^{a}	43.5 ± 2.0^{b}	9.4 ± 0.5^{a}

Moisture & Water Activity:
Moisture: Highest in white cheeses; lowest in cheddar. (correlated with T_1 value)
Water activity >0.98 in all samples; regular cheddar had lowest value due to fat repelling water

Color:
Plant-based cheddar had highest redness (a*) and yellowness (b*)

Texture:
Plant-based cheeses were harder due to starch
Animal-based cheeses had higher springiness and chewiness (protein effect)
White cheeses shared similar hardness regardless of origin
Moisture and hardness values are inversely proportional

Table 2. MC, a_w, and color measurement results

Cheeses	MC (%)	a_w	L* (lightness)	a* (redness)	b* (yellowness)
A-Cheddar	38.2 ± 0.2^{d}	0.98 ± 0.0^{b}	84.7 ± 0.4^{bc}	0.67 ± 0.4^{c}	19.4 ± 0.5^{c}
A-Gouda	43.1 ± 0.2^{cd}	0.99 ± 0.0^{b}	87.8 ± 1.2^{b}	-0.60 ± 0.0^{e}	16.2 ± 1.9^{d}
A-White	65.2 ± 0.3^{a}	1.00 ± 0.0^{a}	95.8 ± 0.4^{a}	-0.50 ± 0.0^{de}	7.9 ± 0.3^{e}
P-Cheddar	46.2 ± 4.8^{bc}	0.99 ± 0.0^{a}	78.0 ± 0.4^{d}	22.0 ± 0.2^{a}	53.0 ± 0.7^{a}
P-Gouda	48.7 ± 0.8^{b}	1.00 ± 0.0^{a}	85.8 ± 0.3^{bc}	3.83 ± 0.3^{b}	40.4 ± 0.4^{b}
P-White	60.7 ± 0.4^{a}	1.00 ± 0.0^{a}	83.4 ± 2.4^{c}	-0.03 ± 0.1^{d}	2.2 ± 0.5^{f}

Table 3. Texture Profile Analysis Results

Cheeses	Hardness (N)	Stringiness Length (mm)	Cohesiveness	Springiness (mm)	Gumminess (g*cm)	Chewiness (g*cm)
A-Cheddar	8.9 ± 0.6^{ab}	0.22 ± 0.0^{c}	0.69 ± 0.0^{c}	3.9 ± 0.1^{a}	6.1 ± 0.4^{b}	247 ± 20.8^{a}
A-Gouda	7.1 ± 1.2^{c}	0.32 ± 0.0^{c}	0.69 ± 0.0^{c}	4.4 ± 0.1^{a}	4.9 ± 0.8^{c}	219 ± 37.9^{a}
A-White	2.2 ± 0.3^{d}	6.4 ± 4.8^{b}	0.79 ± 0.0^{a}	3.4 ± 0.3^{b}	1.8 ± 0.2^{d}	61.50 ±12.0^{c}
P-Cheddar	8.1 ± 0.9^{bc}	14.2 ± 1.2^{a}	0.79 ± 0.0^{ab}	2.1 ± 0.0^{c}	6.3 ± 0.6^{b}	136 ± 15.2^{b}
P-Gouda	10.3 ± 0.3^{a}	3.5 ± 1.9^{bc}	0.74 ± 0.0^{b}	2.0 ± 0.0^{c}	7.6 ± 0.2^{a}	156.75 ±6.2^{b}
P-White	3.6 ± 0.5^{d}	3.2 ± 3.4^{bc}	0.56 ± 0.0^{d}	1.9 ± 0.4^{c}	2.0 ± 0.2^{d}	40.25 ±10.8^{c}