Quantitative sodium MRI in foods : addressing sensitivity issues using single quantum Chemical Shift Imaging at high field

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AgroResonance

NMR platform for agronomy, food science and nutrition

23Na MRI, a good tool for food science

MRI allows to achieve 3 key parameters

- **Nucleus density**
  - → Technological food properties (sanitary issues, public health …)
  - → Numerical modelling → optimize processes
- **Localisation**
  - → Salting process = heterogeneous process:
    - Diffusion from surface to center
    - Food intrinsic heterogeneities= salt barriers
  - → Control of sensory properties:
    - salt heterogeneity enhances saltiness
- **Nucleus/matrix interaction**
  - → Na+ release drives saltiness perception
  - → Technological properties ? Salt diffusion?


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Heterogeneous salt distribution in hot snacks enhances saltiness without loss of acceptability

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Non-destructive: longitudinal following of processes, no inter products variability bias

23Na MRI is not easy

Two main constrains: sensitivity and relaxation

Food products [salt] ≈ 100mM to 800mM

Spatial resolution needed ≈ 1-x mm

Temporal resolution needed ≈ depends on the process

Rice cooking = 10 minutes
Ham drying =9 months

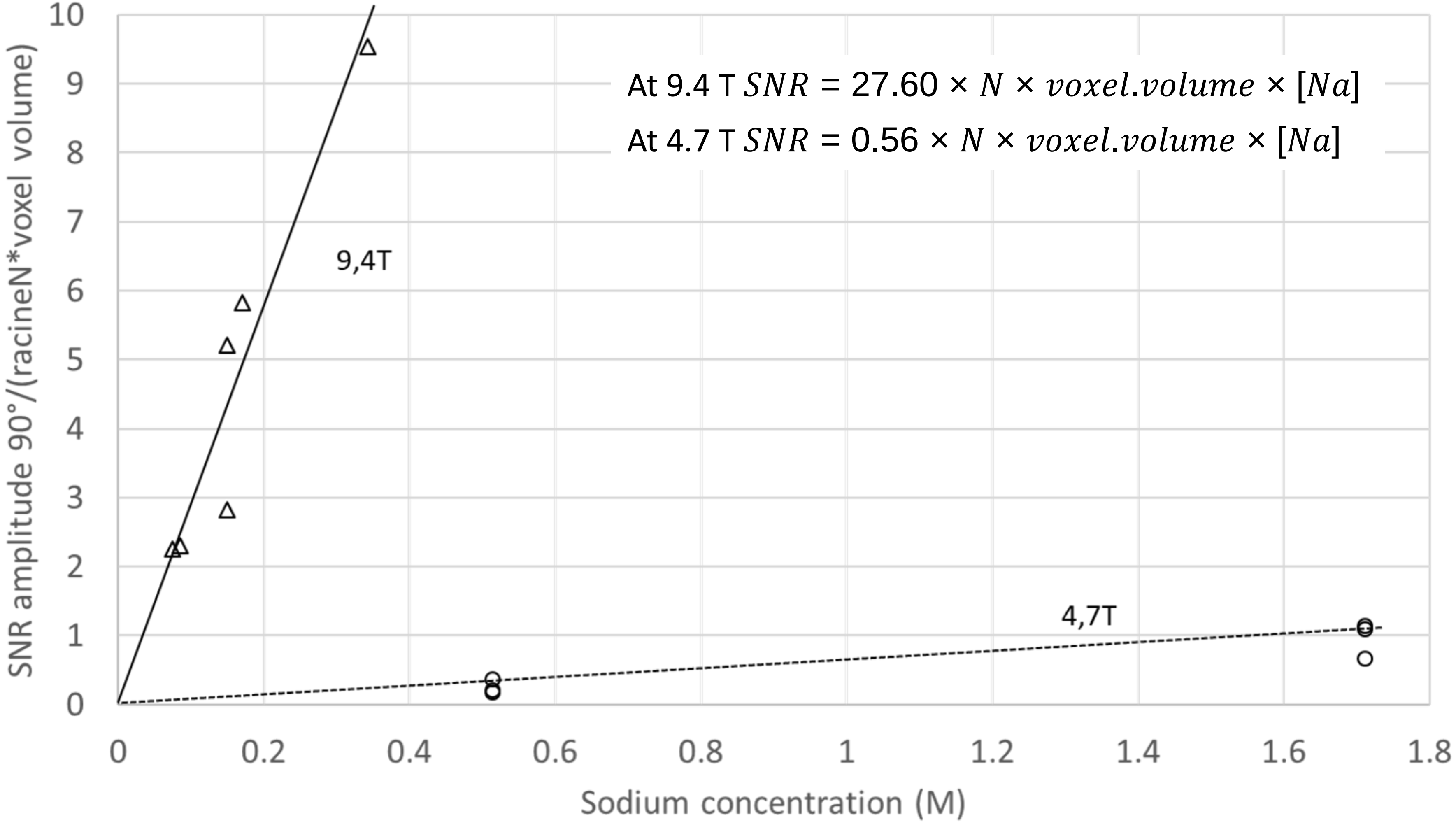
Is it possible to see sodium repartition in my [choose a food product] during the [choose a food process]?

"It depends" is not a satisfactory response → abacus

Sensitivity

23Na MRI is not easy

Two main constrains: sensitivity and relaxation



At 9.4 T $SNR = 27.60 \times N \times voxel.volume \times [Na]$

At 4.7 T $SNR = 0.56 \times N \times voxel.volume \times [Na]$

0.17 M
9.4 T MRI device
1 mm^3
SNR=10
1h16 total acquisition duration

0.17 M
9.4 T MRI device
0.5x0.5x1 mm^3
SNR=10
4h50 total acquisition duration

Experimental designs

In our given experimental conditions (coil, filling ratio …)

23Na MRI is not easy

Two main constrains: sensitivity and relaxation

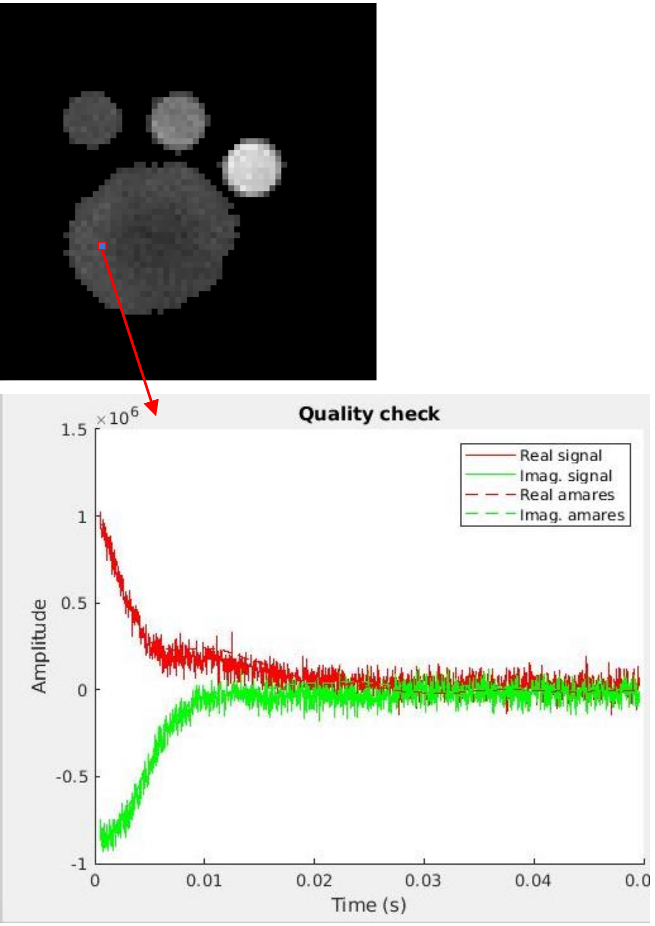
Nucleus	Spin (I)	Sensitivity/1H	γ (10^7 rad $T^{-1}s^{-1}$)	Resonance (MHz) à 4,7T	Resonance (MHz) à 9,4T	Resonance (MHz) à 11,7T
1H	1/2	1	26,75	200	400	500
23Na	3/2	0,0925	7,08	53	106	132

→ Possible quadripolar interaction → Multi exponential NMR signal decay?

→ Short T2* → Need to correct sodium NMR signal lost in fast relaxation.

→ Short T1 → Save time thanks to short repetition time

Our MRI solution: Chemical Shift Imaging (CSI) sequence



Spectroscopic imaging:
one pixel = one full FID

By adjusting the experimental FID

1. We can extrapolate the amplitude well before the echo time
2. We access the B0 variations, locally, in each pixel
3. We access the T2* value, locally, for each pixel

Because CSI is a cartesian filling sequence, there are no relation between relaxation and resolution. Localization is not biased.

We wanted
- Nucleus density ✓
- Localisation ✓
- Interactions ✓

We had to manage
- Poor sensitivity ✓
- Fast relaxation ✓

M&M: the food products

Two very different real food products in terms of **salt content**, **size** and **tissu type**.

Cooked carrot

Peeled carrot

Cylinder lenght 80 mm x diam. 20 mm

Cooked 25 minutes in boiling salted water (171mM)

Reference tubes: 85, 171 and 342 mM of NaCl in gelatin from porcine skin

Norvegian dry cured ham

Entire Norwegian dry cured ham

End of process, 9 months drying

Length 33 cm x width 12 cm x height 8 cm

Reference tubes: 2x513 and 2x1710 mM of NaCl in gelatin from porcine skin

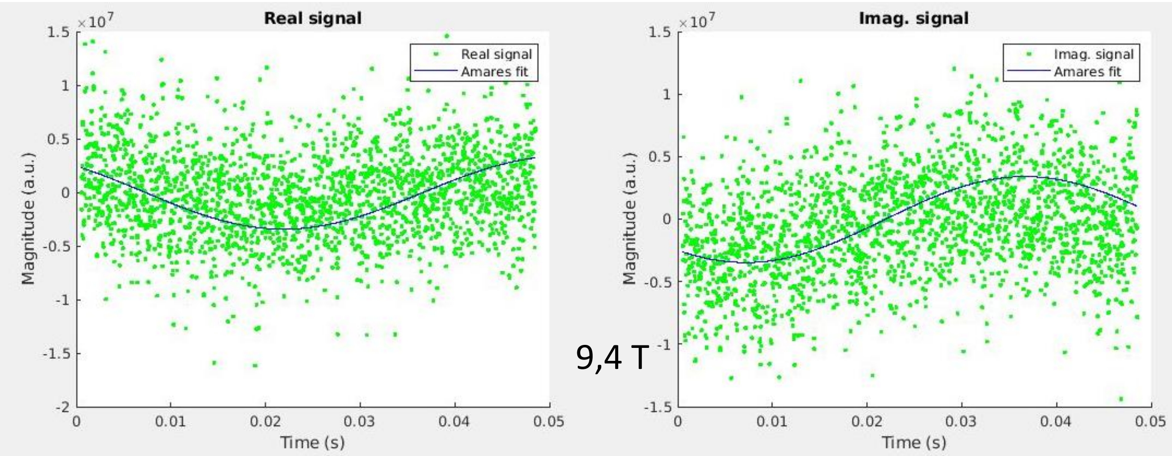
M&M: 2D CSI parameters and adjustments

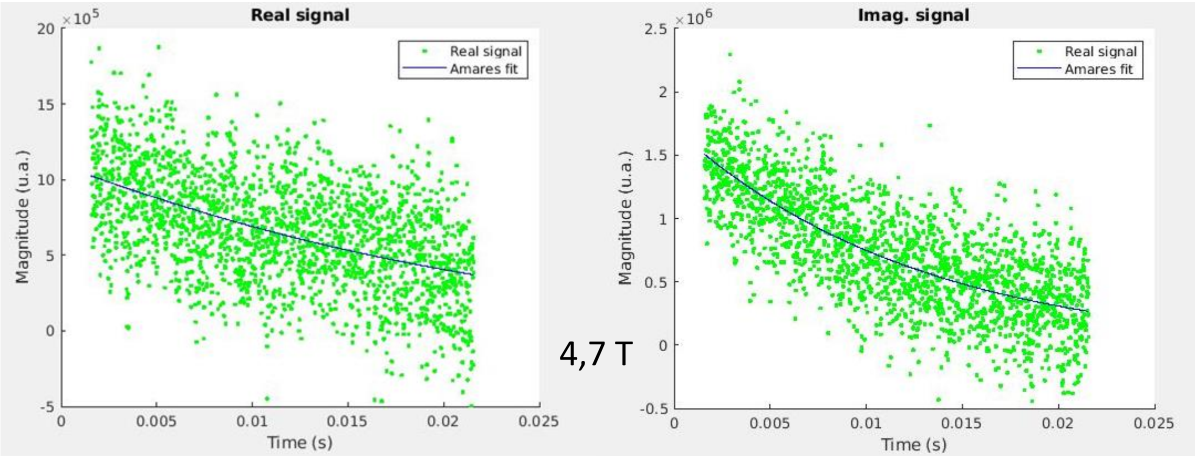
CSI parameters

B0 (T)	Object	In plane vox. size (mm)	Matrix size	Slice thickness (mm)	FID Nb points Temporal resol. (µs)/duration (ms)	TE/TR (ms/ms)	Total duration
9.4	Carrot and tubes	0.5*0.5	64 x 64	8	4096/12/49	0.95/500	1h30
4.7	Ham and tubes	2*2	64 x 64	8	8192/5/41	5.4/200	2h15

Adjustment

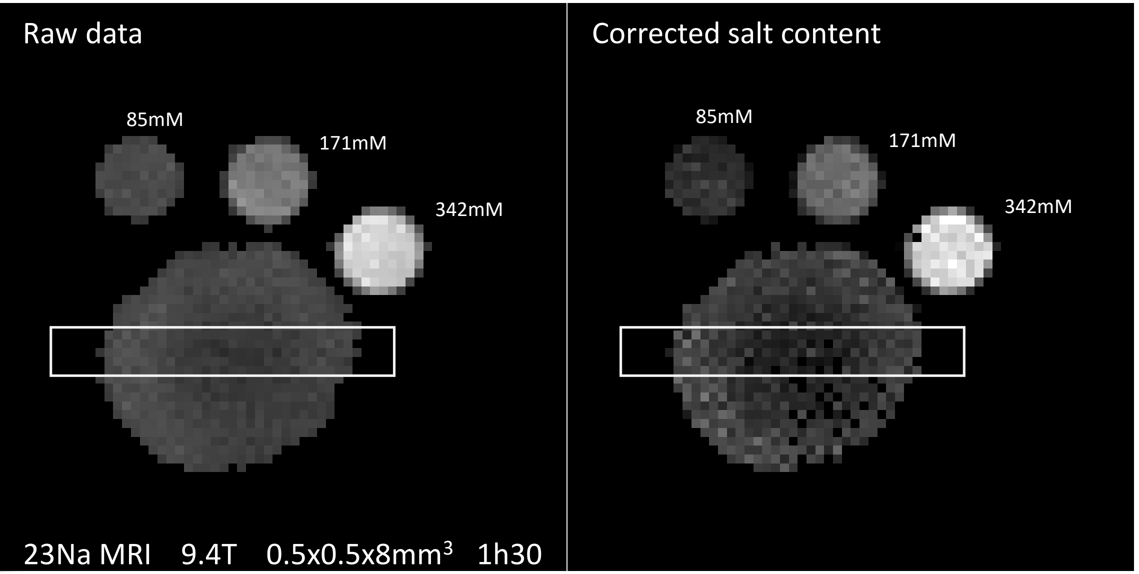
Voxel wise adjustment is done in the frequency domain with a single Lorentzian peak.

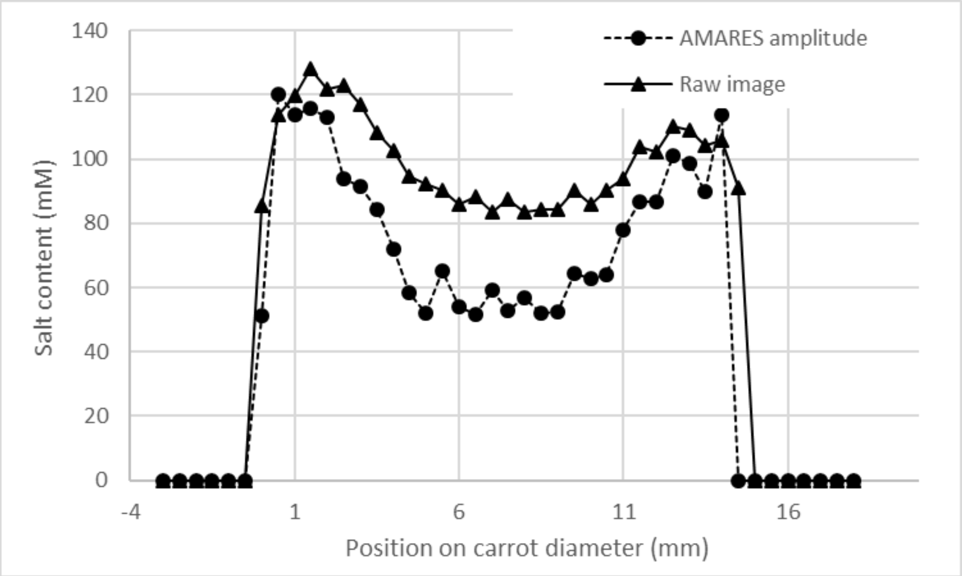




A, T2*, B0 ⟹ Amplitude = [Na] independent of T2*, B0

Results: salt gradient in the cooked carrot





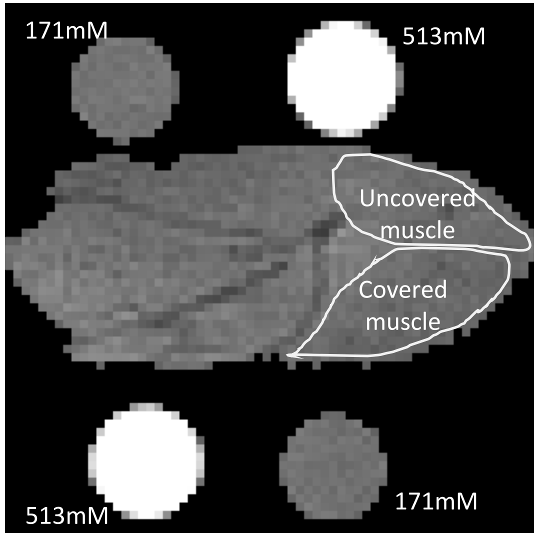
- Salt content decreases from the edge to the center
- Maximun salt content (120mM) is coherent with the [Na]=171mM in the boiling water
- Correction enhances the gradient

Because relaxation differences between the center and the edge (salt, tissue…)

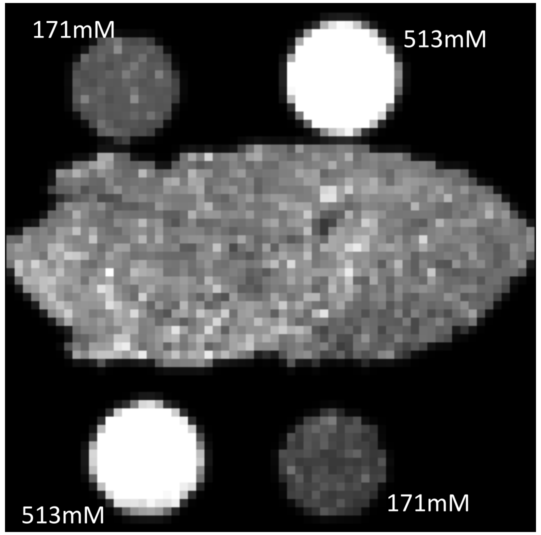
Relaxation must be corrected to access sodium map independant to local relaxation properties

Results: different salt content in different ham muscles

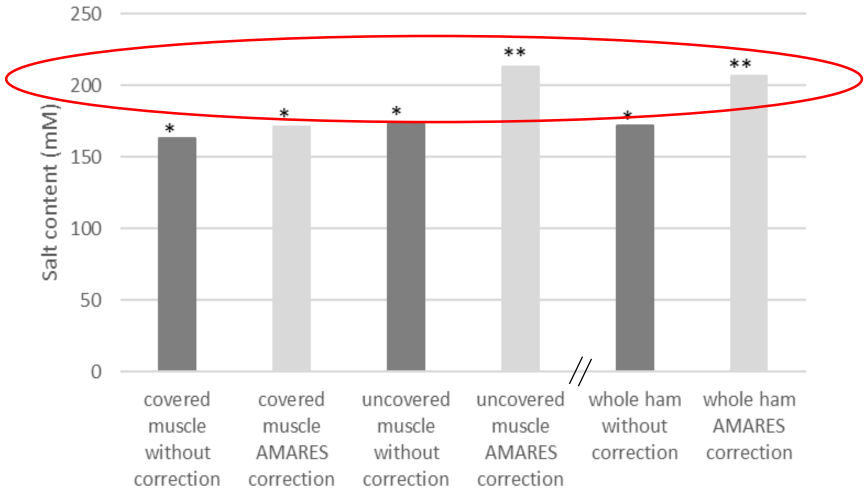
Raw data



Corrected salt content



23Na MRI 4.7T $2x2x8mm^3$ 2h15



- Before correction no difference
- After correction
covered muscle [Na] < uncovered muscle [Na]
- Relaxation correction significantly enhances the whole ham salt content

Relaxation must be corrected to access sodium map independant to local relaxation properties

[Na] ≈ 200mM << real [Na] ≈ 800mM

Adjustment = mono exponential decay, if bi exponential decay 3/5 of the signal is not visible

Correction : [Na]=200mM*5/2=**500mM** … still far away

More complicated: **Nour El Sabbagh** showed a mix of relaxation behaviours in food products

Perspectives, quantitative sodium MRI improvement

1. Taken into account all relaxation behaviors

2. b1+ inhomogeneities correction

Why?

1. High fields increases these inhomogeneities (because spatial wavelenghts shortens)
2. Salt causes conduction lost → local lost of excitation power (b1+ inhomogeneities)
3. Reference tubes are often placed close to the coil, were inhomogeneities are high

How?

Double Angle Method CSI protocole at 90° and 30°

Double the total acquisition time

Introduce propagated noise from the 30° 23Na MRI

Cost/benefit ratio

Perspectives, application to food science and health

Inhomogeneous spatial distribution of NaCl → saltiness enhancement

ces saltiness without loss

Sal&Mieux ANR	MRI/NMR	Sensory evaluation *in vivo* measurement
• Real food matrices Carrot Chicken Patatoes Pasta • Different food structures (intact, purée, soup) • Different salting domestic practices	Salt localisation Salt diffusion Interactions 23Na/food matrix	Saltiness sensory evaluation In mouth Na+ release measurement

Health: find **domestic** practices to reduce salt consumption without reducing saltiness

Thanks for your attention

AgroResonance

NMR platform for agronomy, food science and nutrition

Founding:

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