BCCC “Drivers for Success”
March 26 and 27 2009

UNIVERSITY OF LEEDS

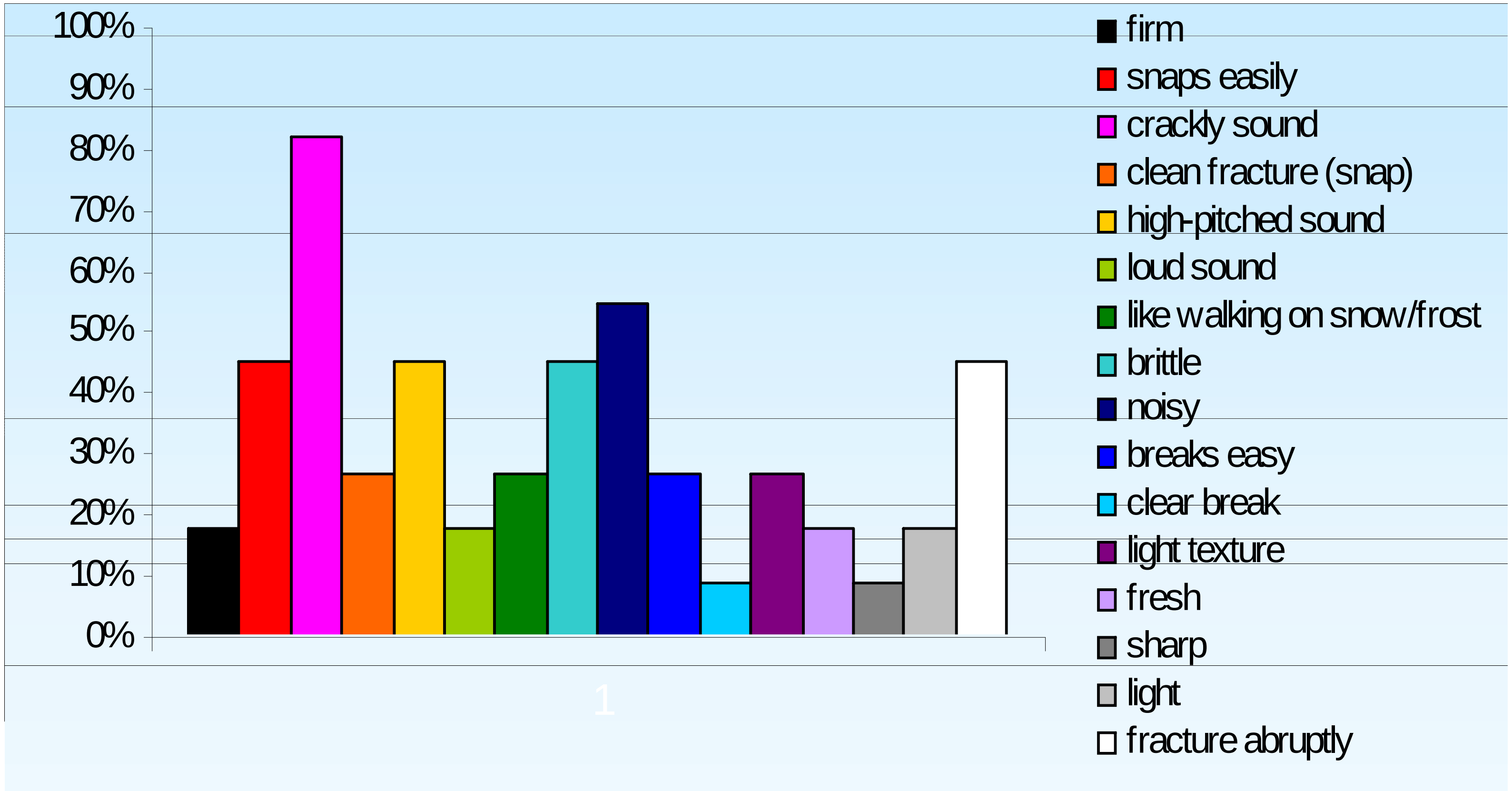
Assessment of Crispness & Crunchiness by Acoustics

Malcolm Povey

University of Leeds

Definition of crispness.

UNIVERSITY OF LEEDS

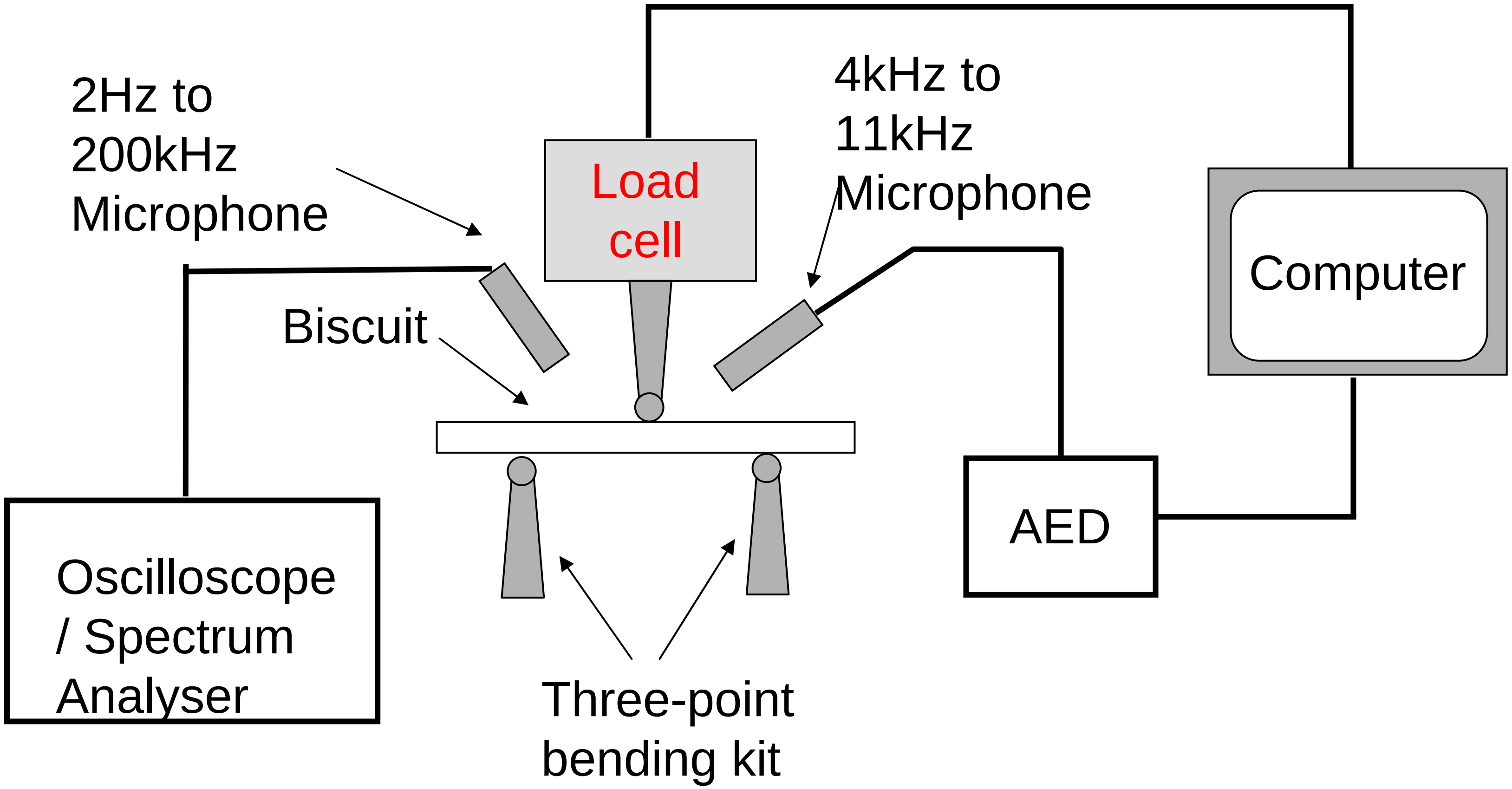


An objective measure of crispiness and crunchiness is needed

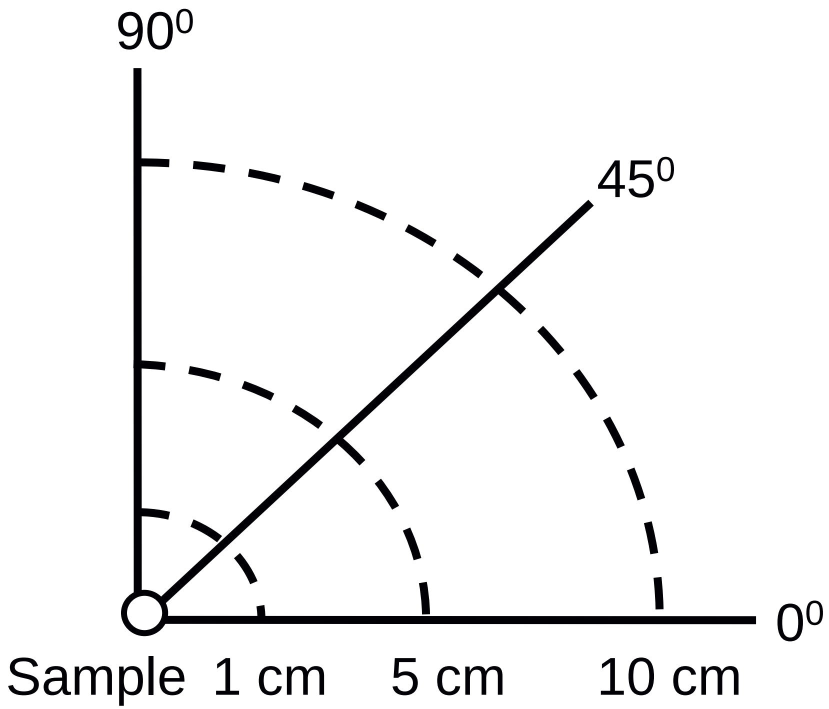
UNIVERSITY OF LEEDS

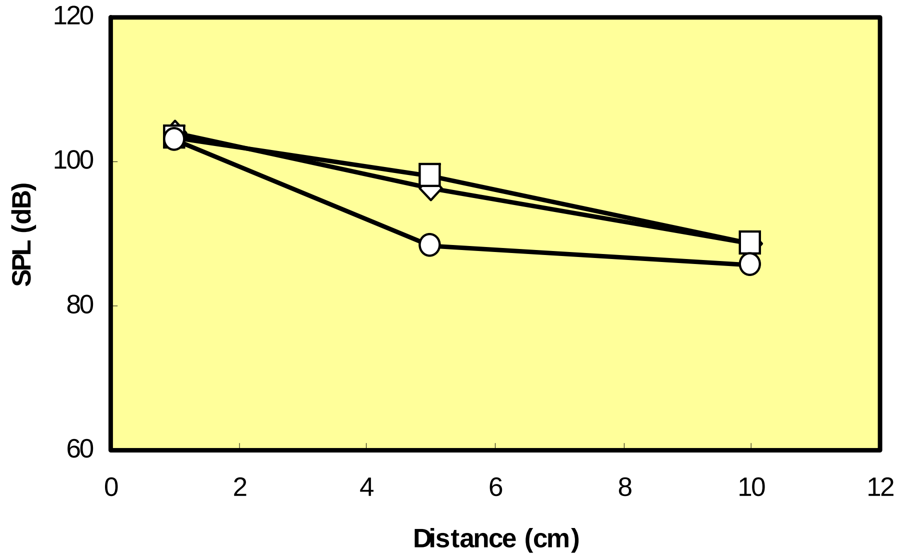
Experimental Set-up

UNIVERSITY OF LEEDS



Position of Microphone





Positioning of the microphone is not critical

Materials tested

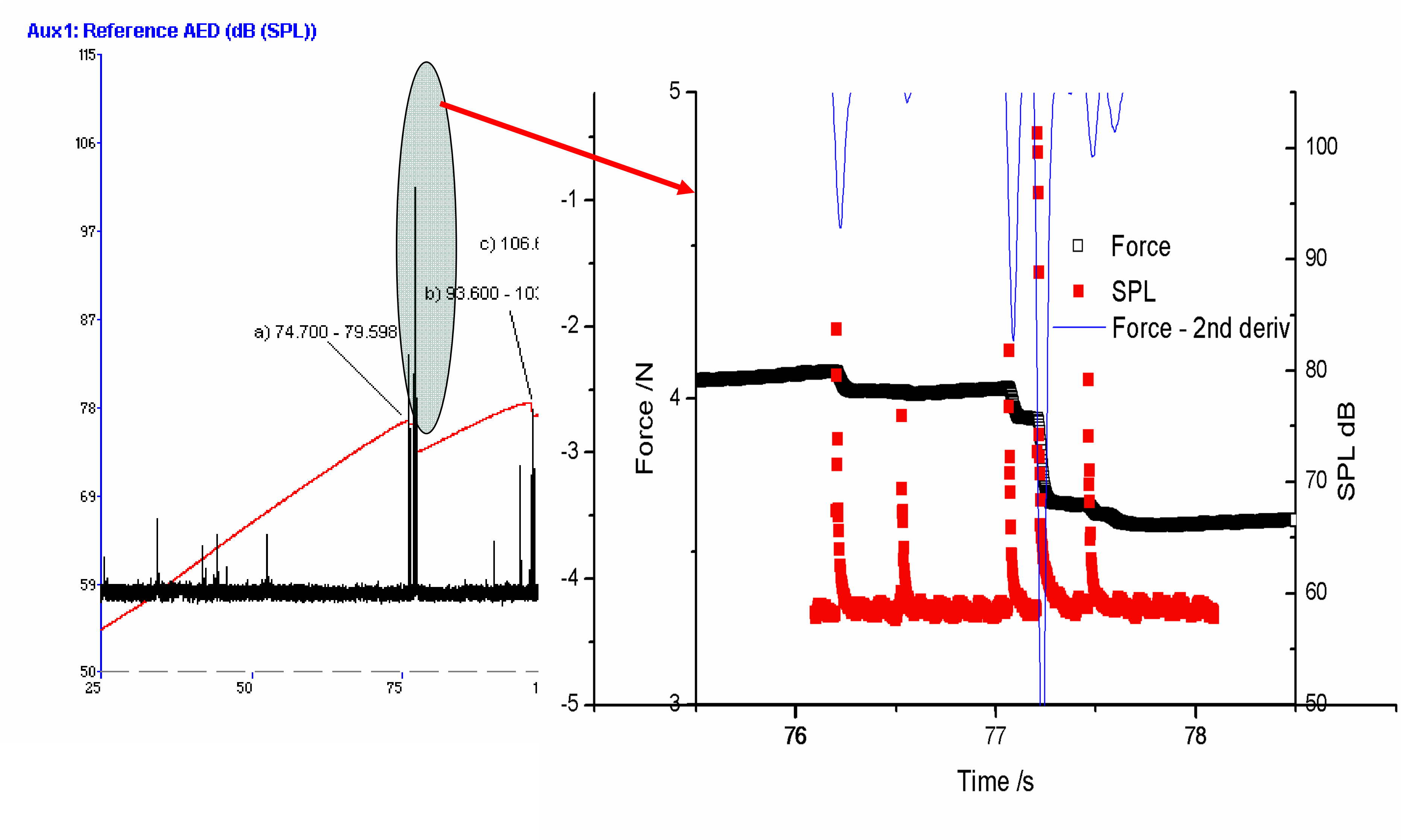
UNIVERSITY OF LEEDS

- *Carr's Table Water* (CTW)
- *Rich Tea Fingers* (RTF)
- *Mac Vitie's Digestive* (MVD)
- *Short Bread* (SB)
- *Crackbread* (CB)
- *Rye Crispbread* (RCB)
- *Dutch Crispbakes* (DC)

  Also
- Apples, Celery and Carrots

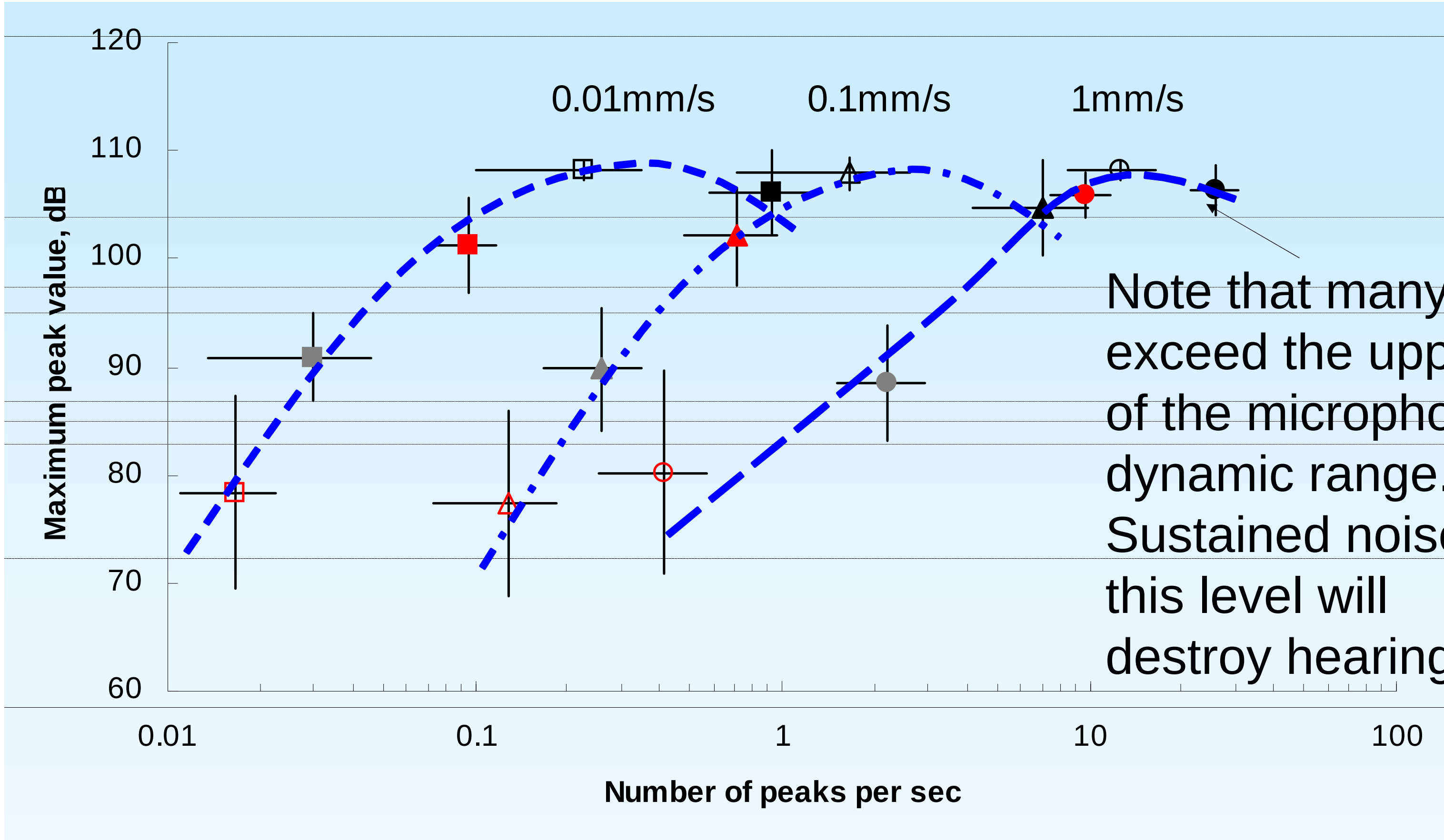
Force-displacement and acoustic measurements

UNIVERSITY OF LEEDS



Acoustic peak rate vs. peak max

UNIVERSITY OF LEEDS



Note that many peaks exceed the upper limit of the microphone dynamic range. Sustained noise at this level will destroy hearing.

Summary points/hypotheses

UNIVERSITY OF LEEDS

•Crispness/crunchiness is related to crack propagation

•Some of the elastic energy stored and then released by cracking is emitted as a sound pulse

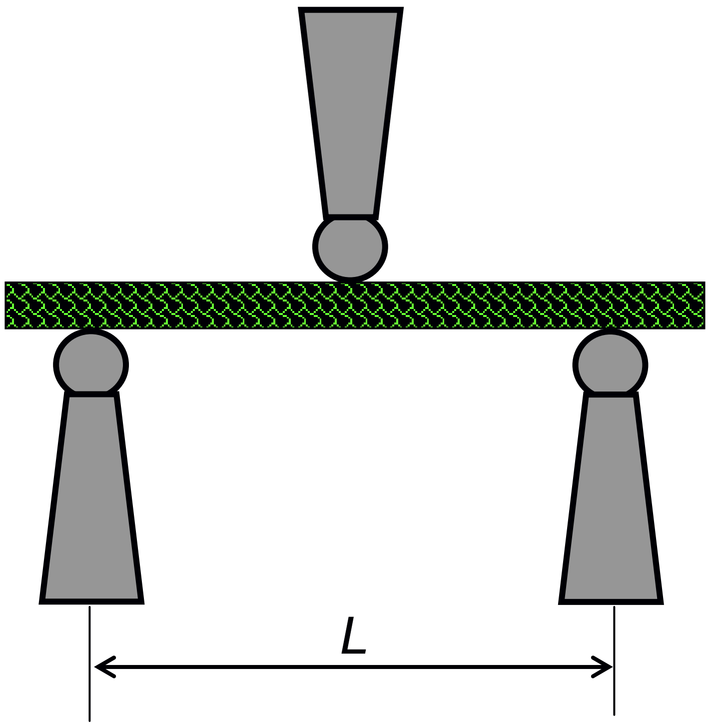
•The magnitude of each sound pulse is related to the energy release in the crack event

•The rate at which crack events occur is related to perception of crispiness/crunchiness

•Acoustic pulse rate is a very robust discriminator between different types of biscuit

•Acoustic pulse rate can be used as an objective measure of crispy/crunchiness

Three-Point Bending



$$E = \frac{FL^3}{4wt^3 d}$$

$$\sigma_{max} = \frac{FL}{4wt^3 d}$$

F: measured force

L: length between the supports

w: width of biscuit

t: thickness of biscuit

d: deflection at the centre of the beam.

The ratio of the length to the thickness of biscuit was set to close to 9 (between 8.3 and 9.8).

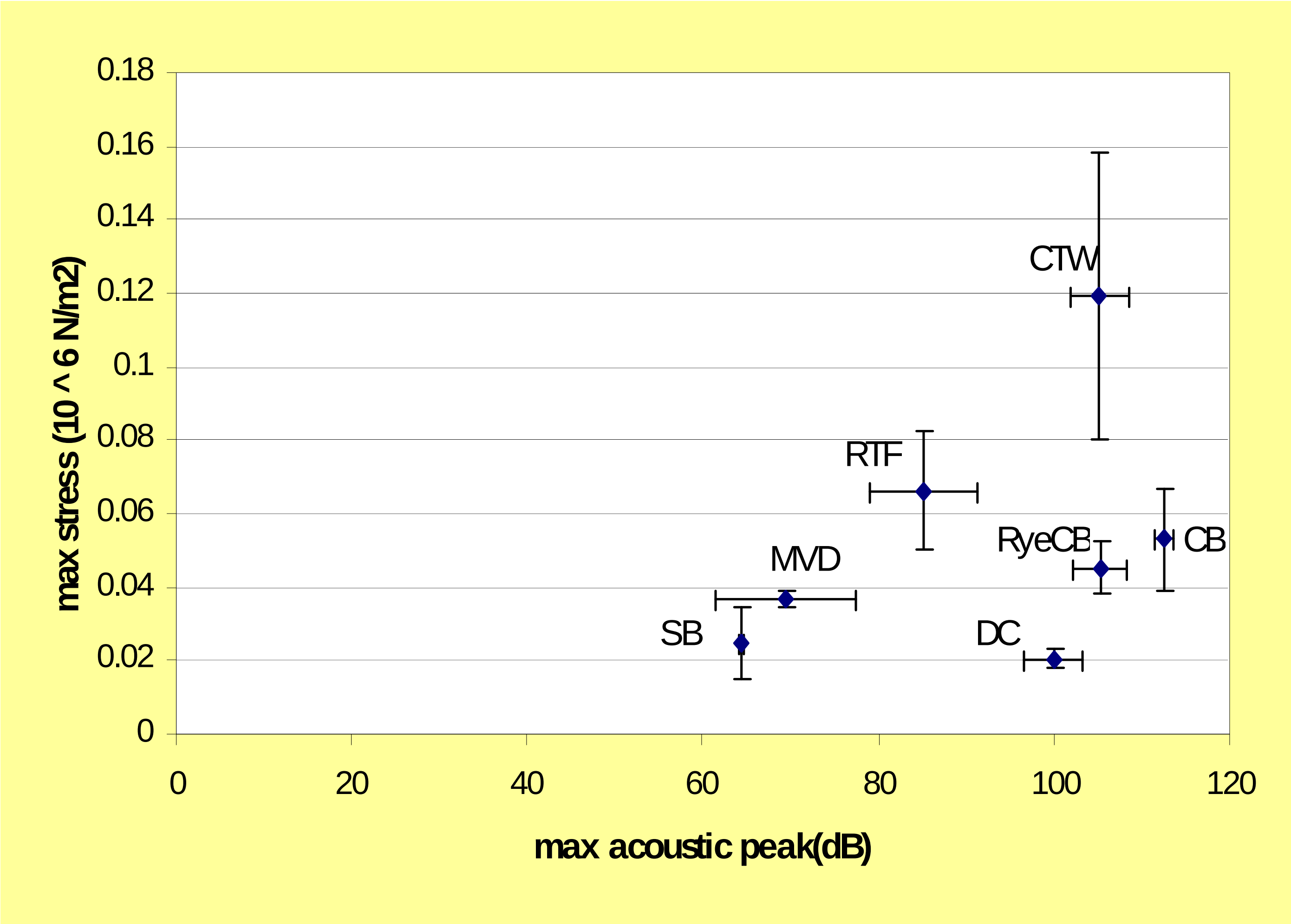
Parameters Available for Analysis

UNIVERSITY OF LEEDS

Mechanical properties	Acoustic properties
•Young's modulus •Maximum stress	• Number of peaks per newly created area • Maximum acoustic peak • Total number of acoustic peaks

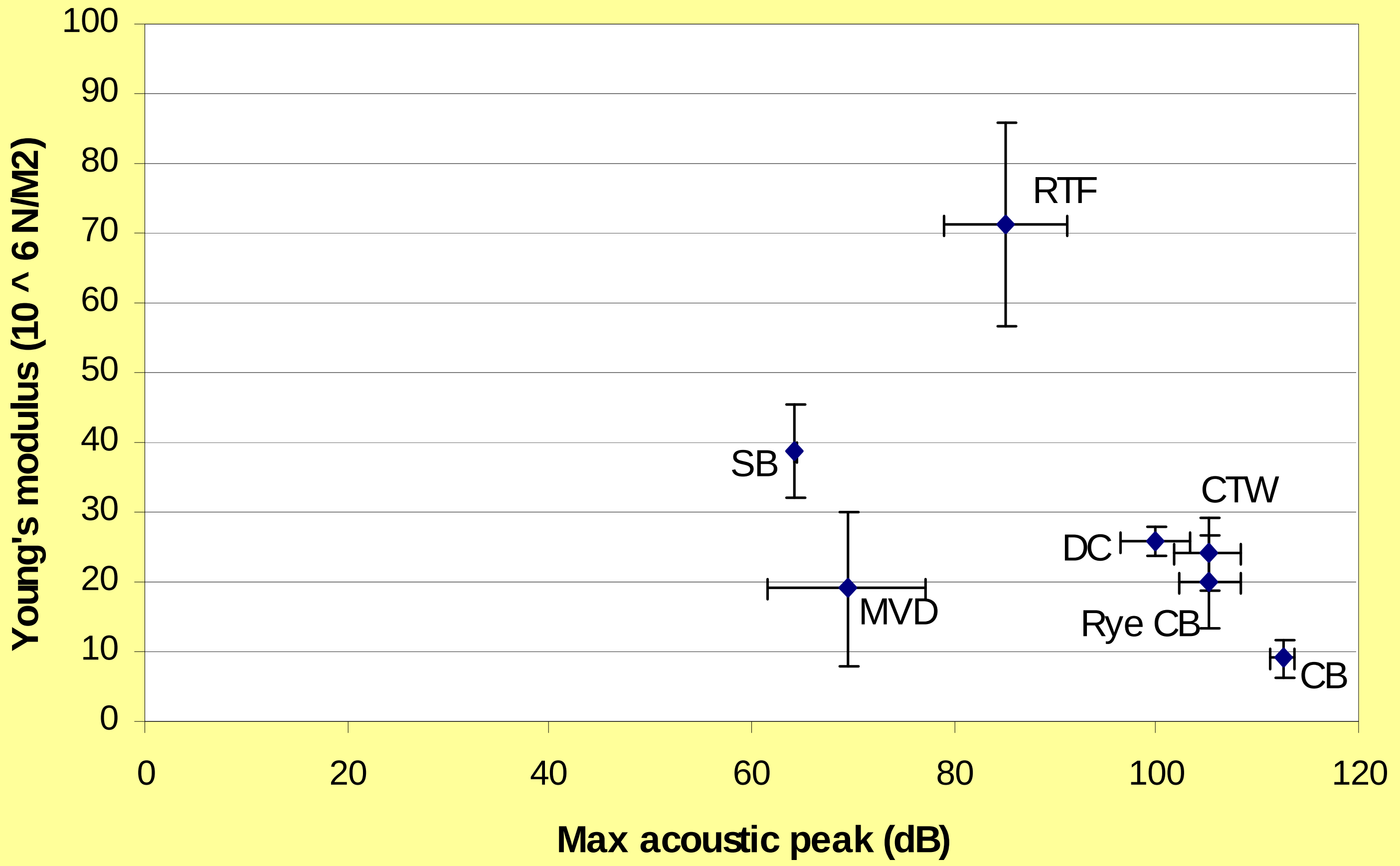
Maximum stress against the maximum acoustic peak.

UNIVERSITY OF LEEDS



Young’s modulus against max acoustic peak.

UNIVERSITY OF LEEDS



Statistical analysis

UNIVERSITY OF LEEDS

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**2.989**	**59.772**	**59.772**	**2.989**	**59.772**	**59.772**	**2.906**	**58.120**	**58.120**
2	**1.149**	**22.971**	**82.743**	**1.149**	**22.971**	**82.743**	**1.231**	**24.624**	**82.743**
3	.580	11.604	94.348						
4	.177	3.537	97.885						
5	.106	2.115	100.000						

The first two component axes have the cumulative percentage of the variance of 82.7%, which is satisfactorily high to describe the properties of biscuits.

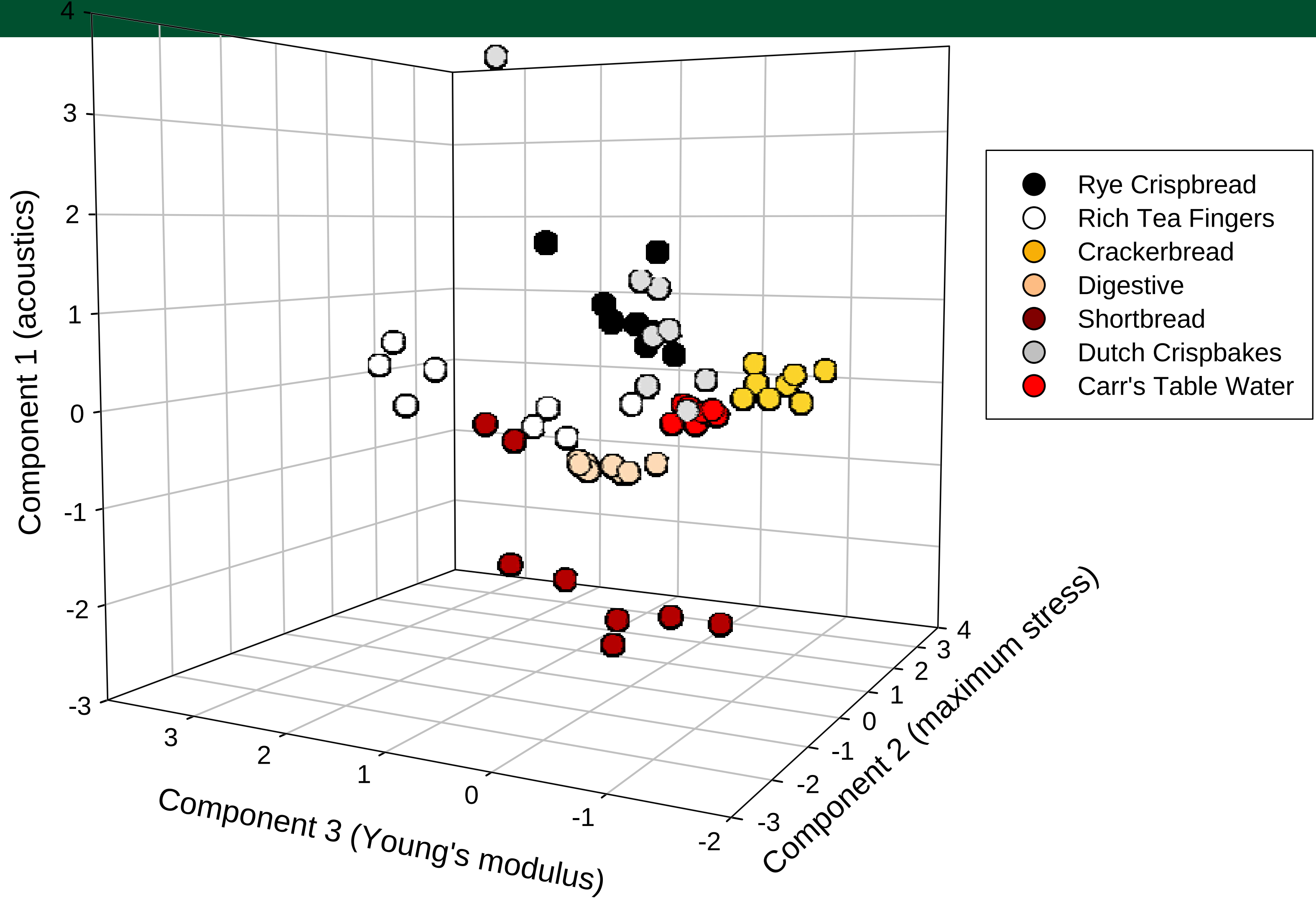
Component matrix of the first two axes

UNIVERSITY OF LEEDS

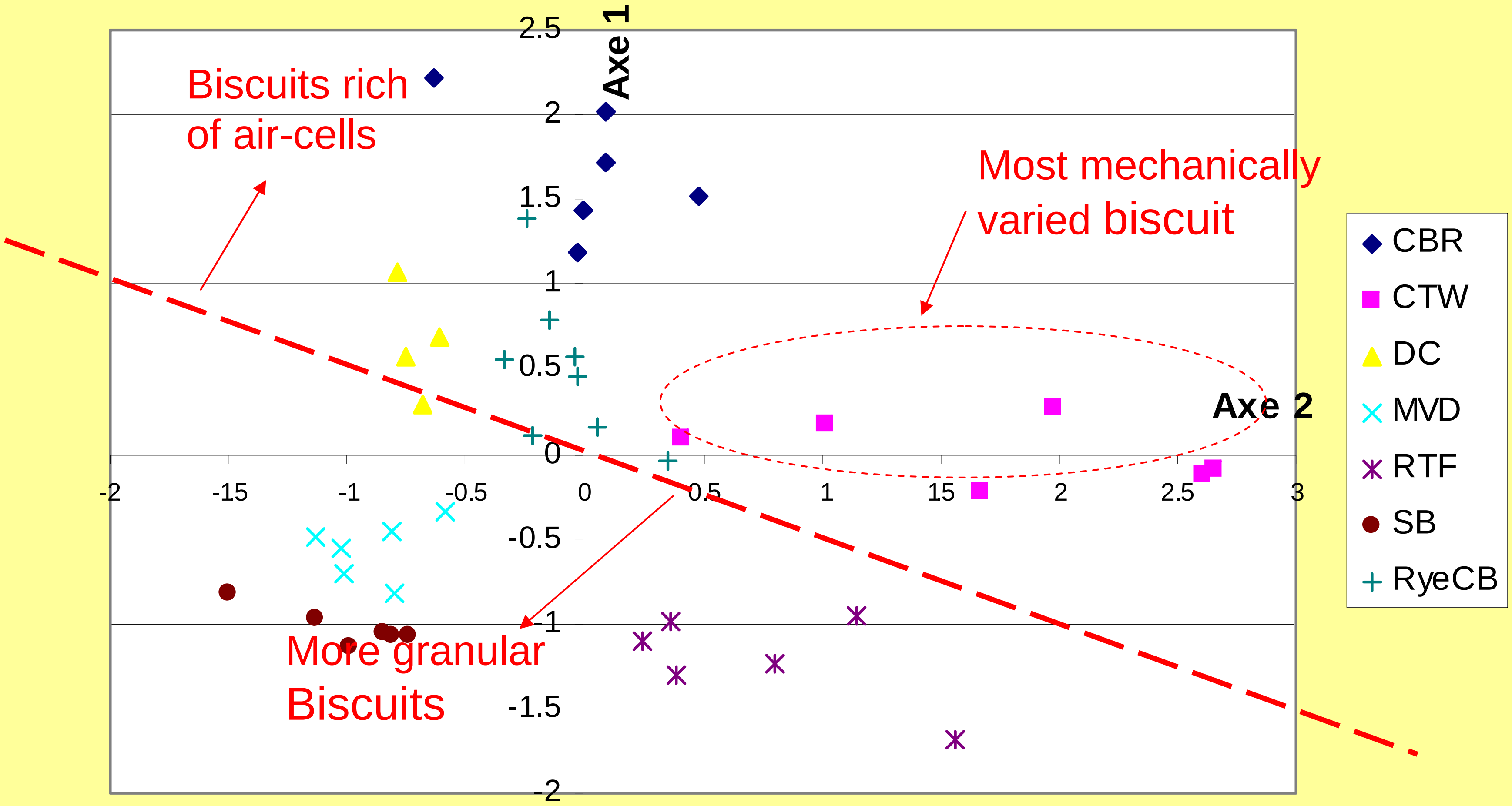
	Component	
	1	2
Young's modulus	-.732	.211
Maximum stress	-.017	.958
Number of peaks per mm2 of created area	.924	.083
Maximum acoustic peak	.786	.504
Total number of peaks	.948	.083

principal component analysis

UNIVERSITY OF LEEDS



Created, using Sigma Plot

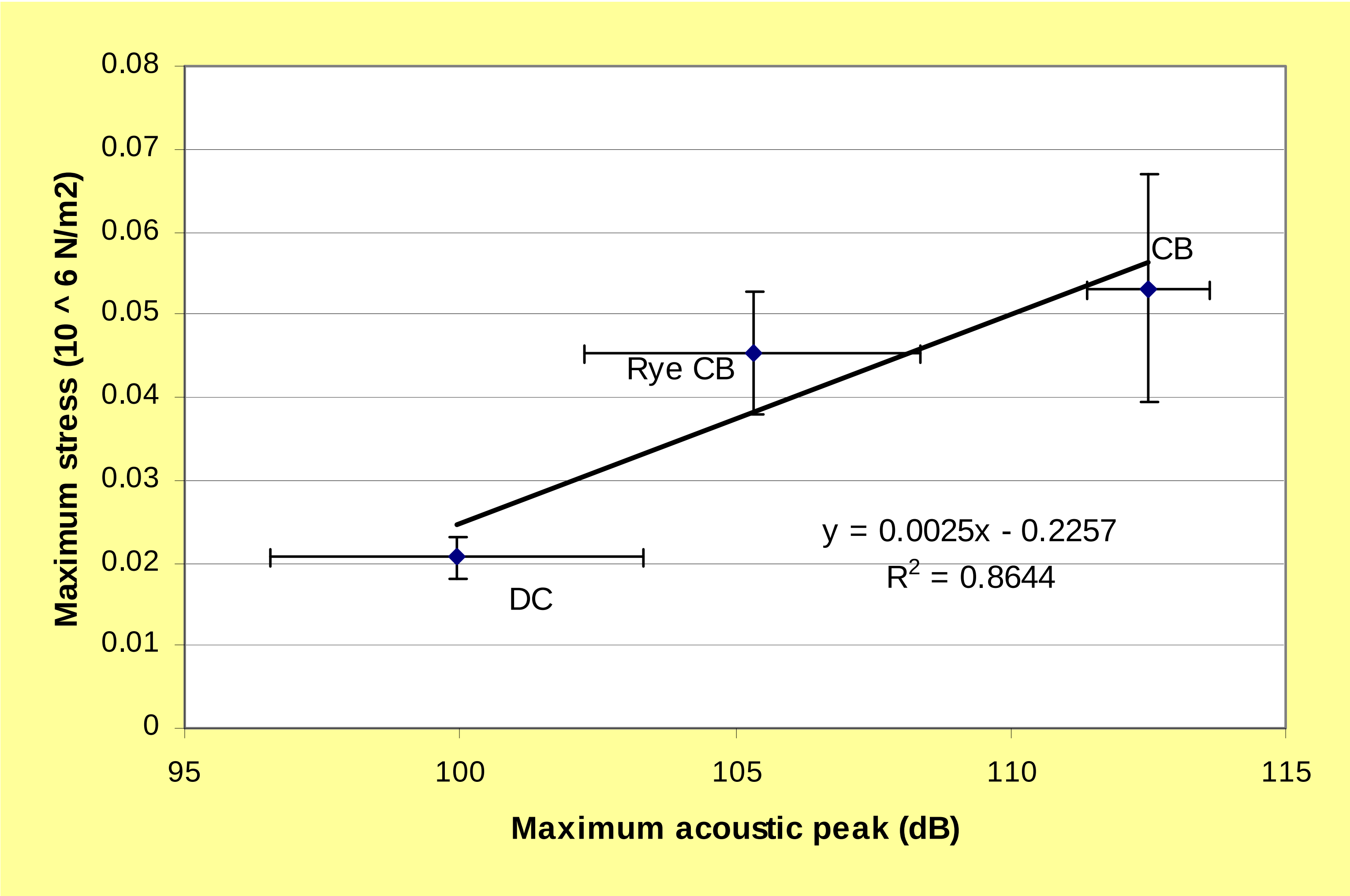

Biscuits rich
of air-cells
Most mechanically
varied biscuit
More granular
Biscuits
Axe 1
Axe 2
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
-15
-1
-0.5
0
0.5
1
15
2
2.5
3
CBR
CTW
DC
MVD
RTF
SB
RyeCB

Hierarchical cluster analysis

```
C A S E        0         5         10        15        20    25
  Label         Num  +---------+---------+---------+---------+-----+
  SB 1           29   òø
  SB 2           30   òôòø
  SB 4           32   ò÷ ó
  MVD 2          18   òø ó
  MVD 3          19   òú ó
  MVD 5          21   òú ùòòòòòòòòòòòòø
  MVD 6          22   òú ó            ó
  SB 3           31   òú ó            ó
  SB 5           33   òú ó            ó
  SB 6           34   òôò÷            ó
  MVD 1          17   òú              ó
  MVD 4          20   ò÷              ùòòòòòòòòòòòòòòòòòòòø
  CTW 3           9   òø              ó                   ó
  Rye CB 7       38   òú              ó                   ó
  Rye CB 10      41   òôòòòø          ó                   ó
  Rye CB 9       40   ò÷   ùòòòø      ó                   ó
  CTW 6          12   òòòòò÷   ó      ó                   ó
  RTF 7          27   òûòòòø   ùòòòòòò÷                   ó
  RTF 8          28   ò÷   ó   ó                          ó
  RTF 1          23   òø   ùòòò÷                          ó
  RTF 5          25   òú   ó                              ó
  RTF 2          24   òôòòò÷                              ùòòòòòòòòø
  RTF 6          26   ò÷                                  ó        ó
  Rye CB 4       36   òø                                  ó        ó
  Rye CB 5       37   òú                                  ó        ó
  Rye CB 1       35   òôòòòø                              ó        ó
  Rye CB 8       39   ò÷   ùòø                            ó        ó
  DC 1           13   òø   ó ó                            ó        ó
  DC 3           15   òôòòò÷ ùòòòòòòòø                    ó        ó
  DC 2           14   ò÷     ó       ó                    ó        ó
  DC 4           16   òòòòòòò÷       ó                    ó        ó
  CB 2            2   òûòø           ùòòòòòòòòòòòòòòòòòòòò÷        ó
  CB 6            6   ò÷ ùòø         ó                             ó
  CB 4            4   òûòú ó         ó                             ó
  CB 5            5   ò÷ ó ùòòòø     ó                             ó
  Rye CB 11      42   òòò÷ ó   ùòòòòò÷                             ó
  CB 3            3   òòòòò÷   ó                                   ó
  CB 1            1   òòòòòòòòò÷                                   ó
  CTW 2           8   òûòòòø                                       ó
  CTW 5          11   ò÷   ùòø                                     ó
  CTW 4          10   òòòòò÷ ùòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòòò÷
  CTW 1           7   òòòòòòò÷
```

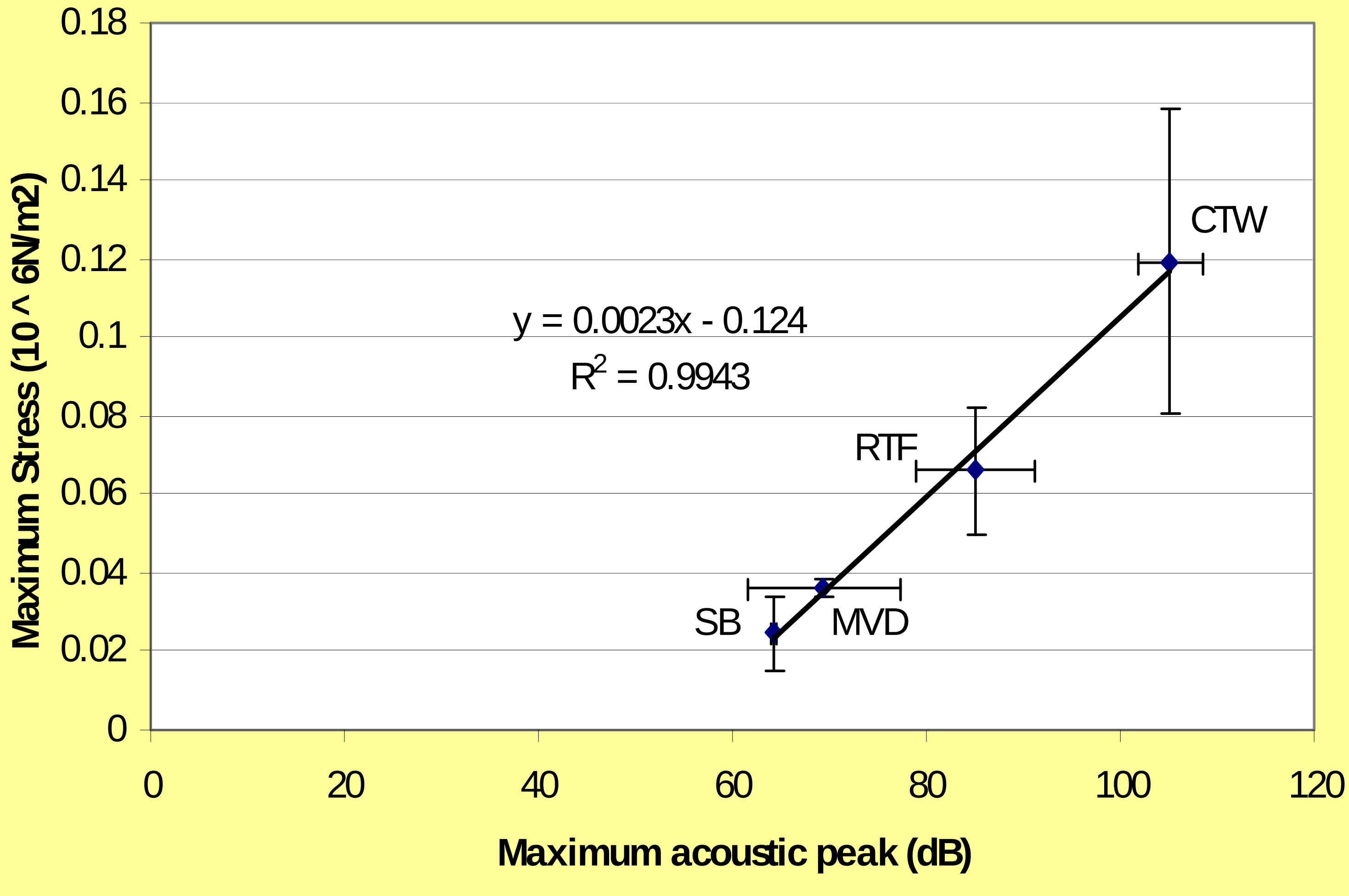
Maximum stress against maximum acoustic peak for the group of air-cell rich biscuits

UNIVERSITY OF LEEDS



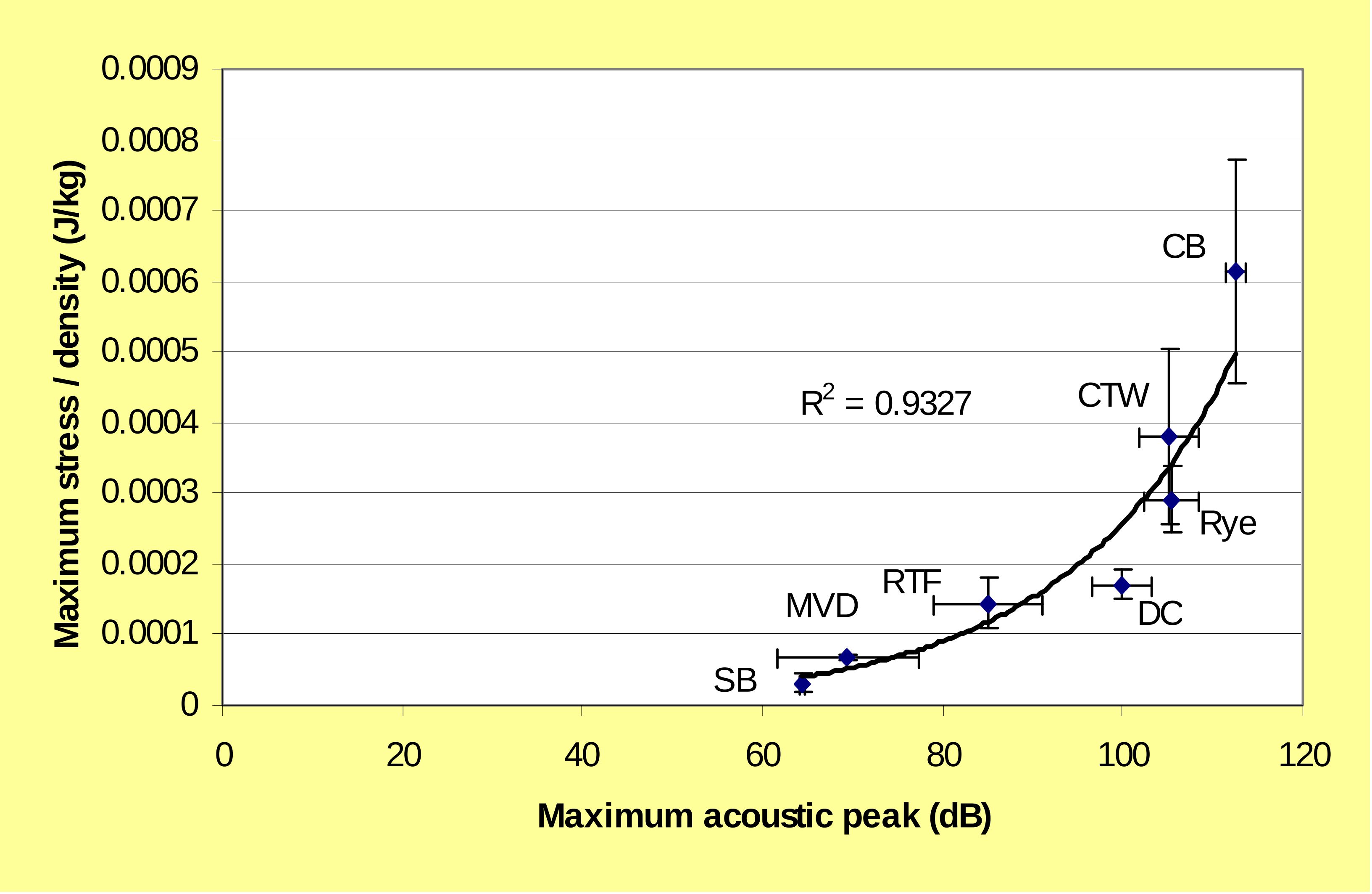
Maximum stress against maximum acoustic peak for the group of more granular-structured biscuits

UNIVERSITY OF LEEDS



Ratio of the max stress and density against max acoustic peak for all tested biscuits.

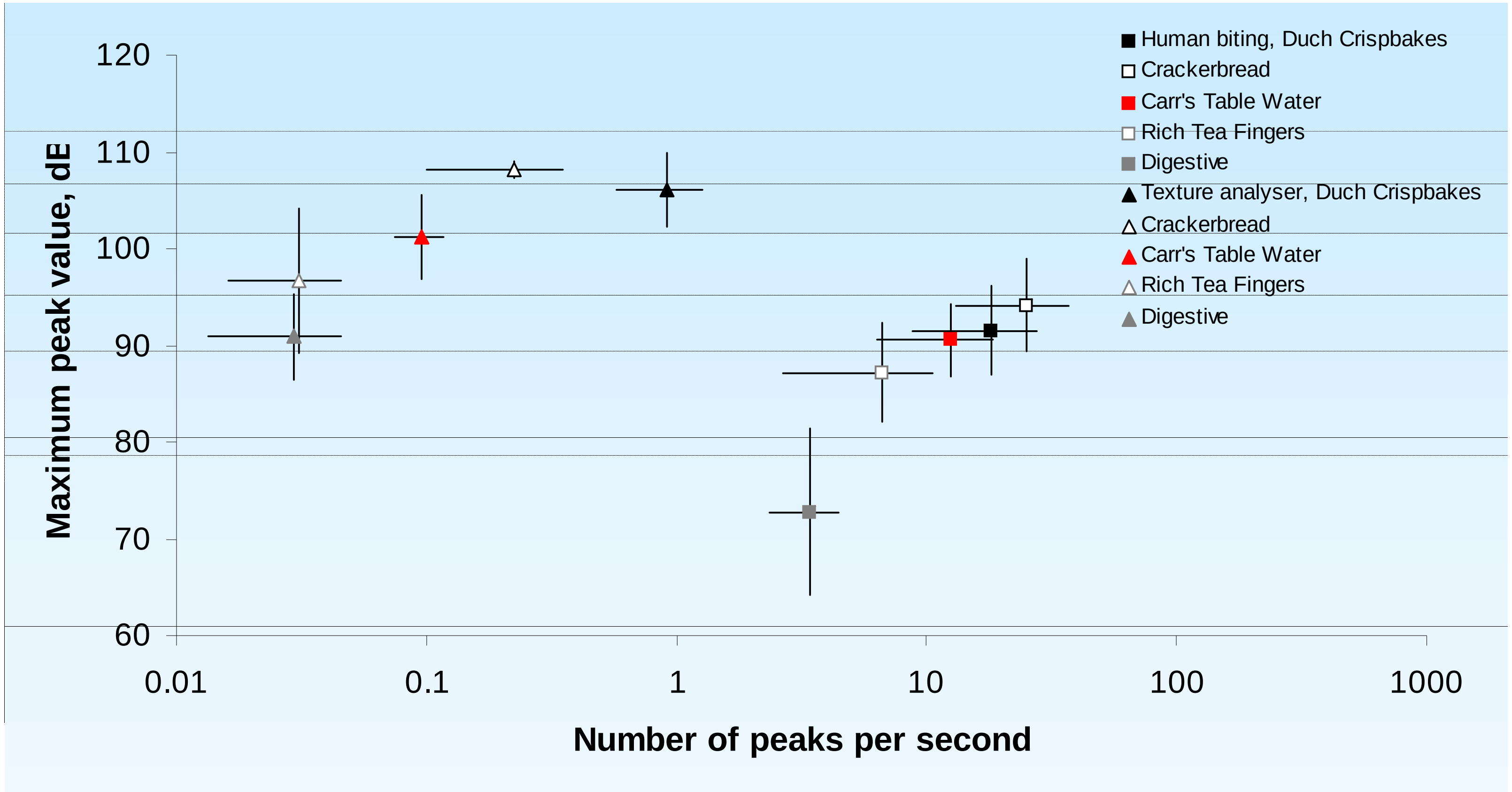
UNIVERSITY OF LEEDS



We can make these measurements during human biting

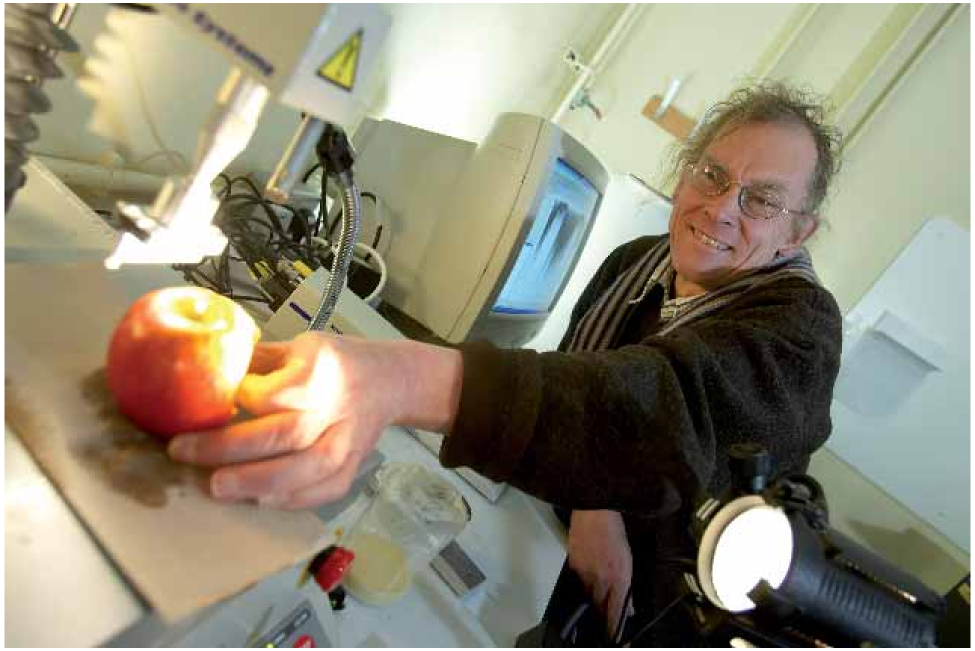
UNIVERSITY OF LEEDS

First bite and 3 point bending (0.01 mm/s) comparison



Biting apples

UNIVERSITY OF LEEDS

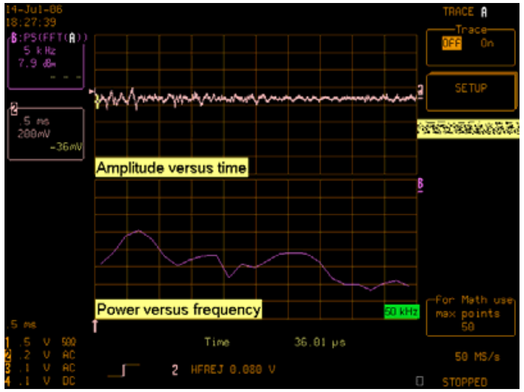


Apples and Ultrasound

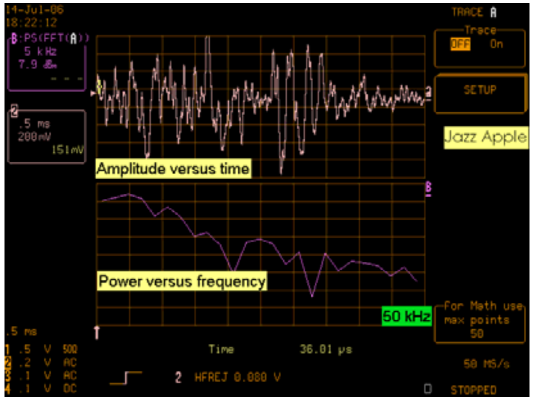
UNIVERSITY OF LEEDS

Crisp apples produce much more ultrasound than either the biscuit or the crisps

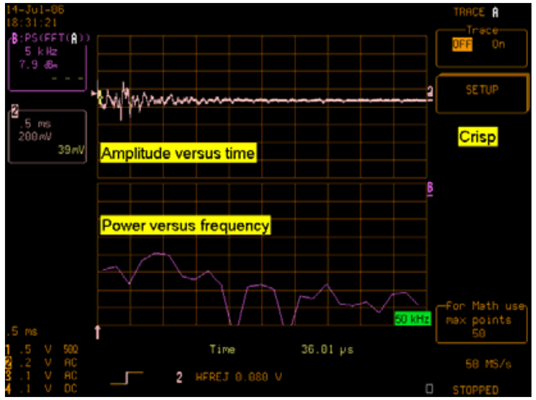
- Examination of the three ultrasound recordings below indicate that crisp apples (middle recording) produce much more ultrasound.



Rich tea biscuit



Jazz apple



High quality crisp

Conclusion

UNIVERSITY OF LEEDS

- Acoustic envelope detection is an economical and objective method for the acoustical evaluation of crispy/crunchy foods
- The technique is robust because it is easy to desensitise it to ambient noise when a ‘peak counting’ method is used. It has a sound physical basis
- Acoustic peak counting provides an objective measure of the ‘cracking’ of foods
- Acoustic peak counting provides an objective measure of sensory ‘crispiness’ and ‘crunchiness’
- Ultrasound assessment can be carried out in ‘noisy’ environments

Chemometric approach

UNIVERSITY OF LEEDS

JOURNAL OF CHEMOMETRICS, J. Chemometrics 2006; 20: 311–320, Published online in Wiley InterScience, (www.interscience.wiley.com) DOI: 10.1002/cem.1029

Crispness assessment of roasted almonds by an integrated approach to texture description: texture, acoustics, sensory and structure

P. Varela[1], J. Chen[2], S. Fiszman[1] and M. J. W. Povey[2*]

1Instituto de Agroquı´mica y Tecnologı´a de Alimentos (CSIC) Apartado de Correos 73, 46100 Burjassot, Valencia Spain

2Procter Department of Food Science, University of Leeds, Leeds LS2 9JT, UK

Crushing almonds

UNIVERSITY OF LEEDS

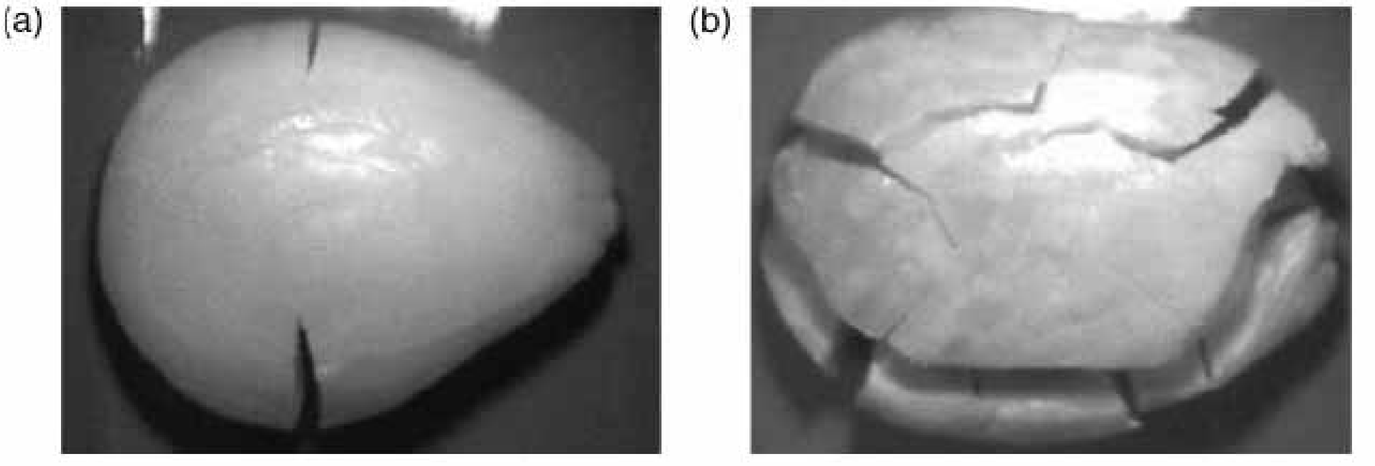
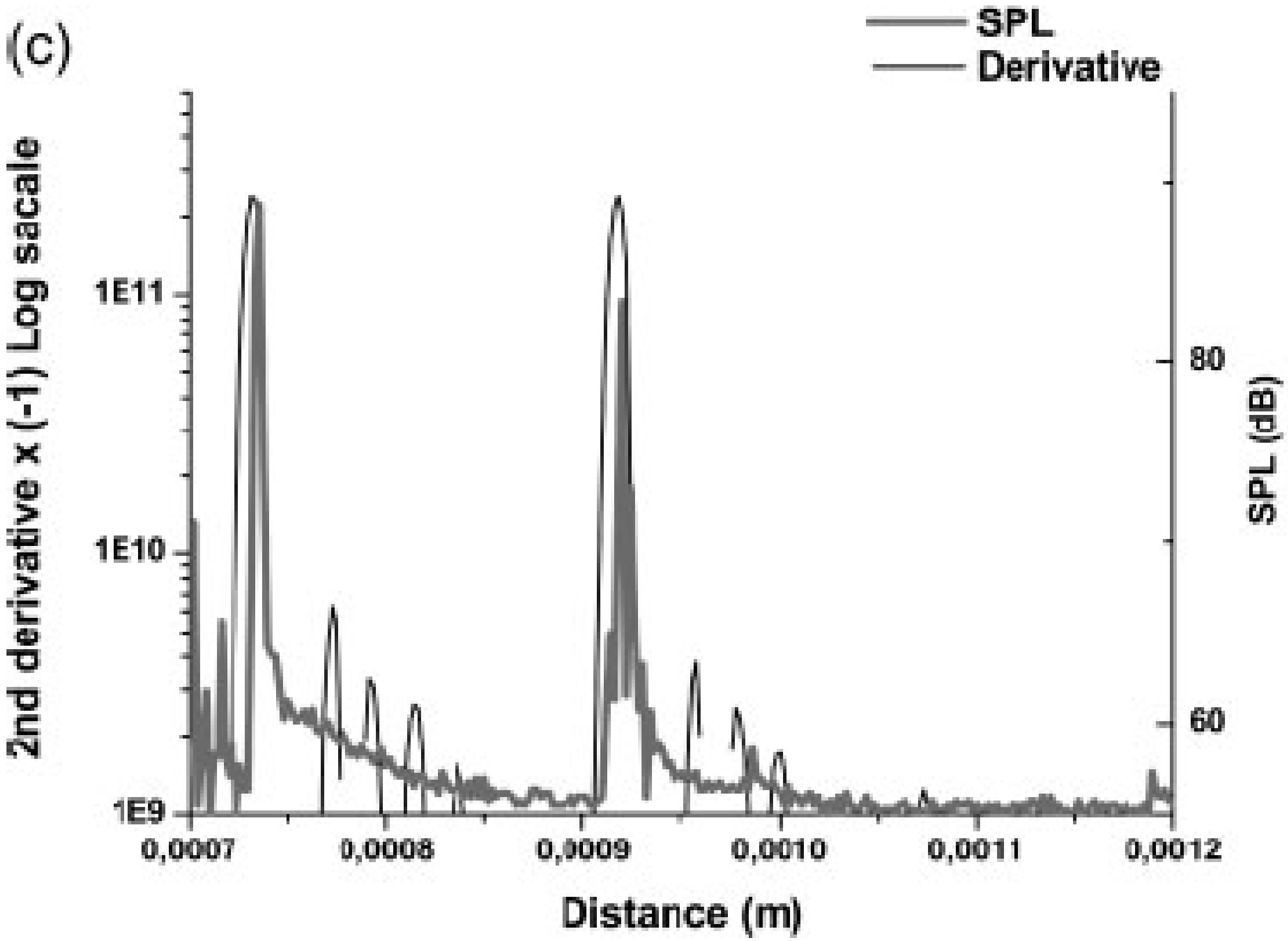


Figure 4. Photographs of the almond samples fractured after compressing in the texture analyser, examples of (a) raw and (b) 6-min roasted.

Almonds fail by cracking and extrusion

UNIVERSITY OF LEEDS



Recording directly an assessor

UNIVERSITY OF LEEDS

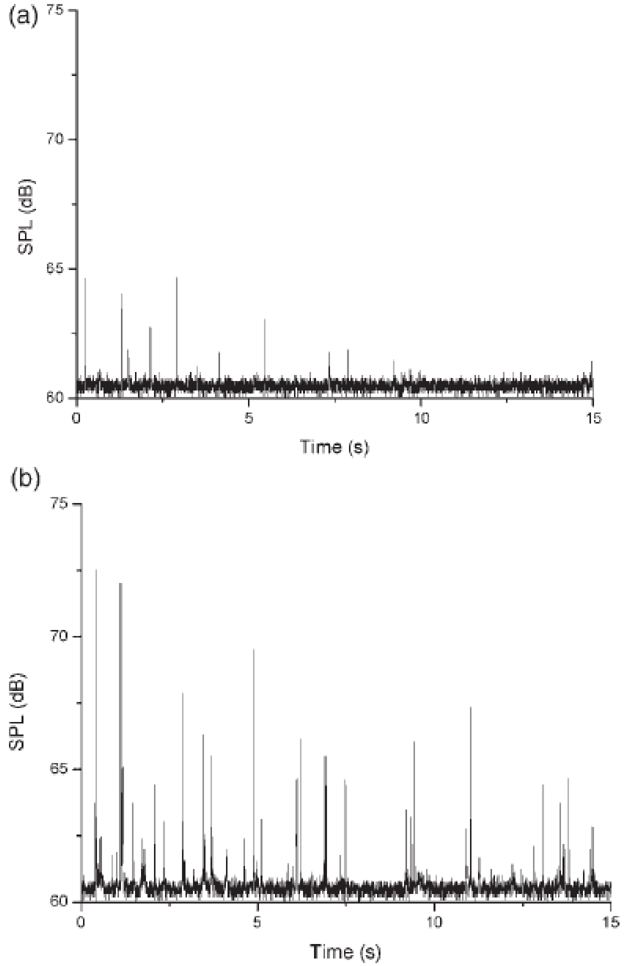


Figure 6. Sound pressure level. Example of a recording from one of the assessors while chewing the samples: (a) raw sample and (b) 6-min roasted sample.

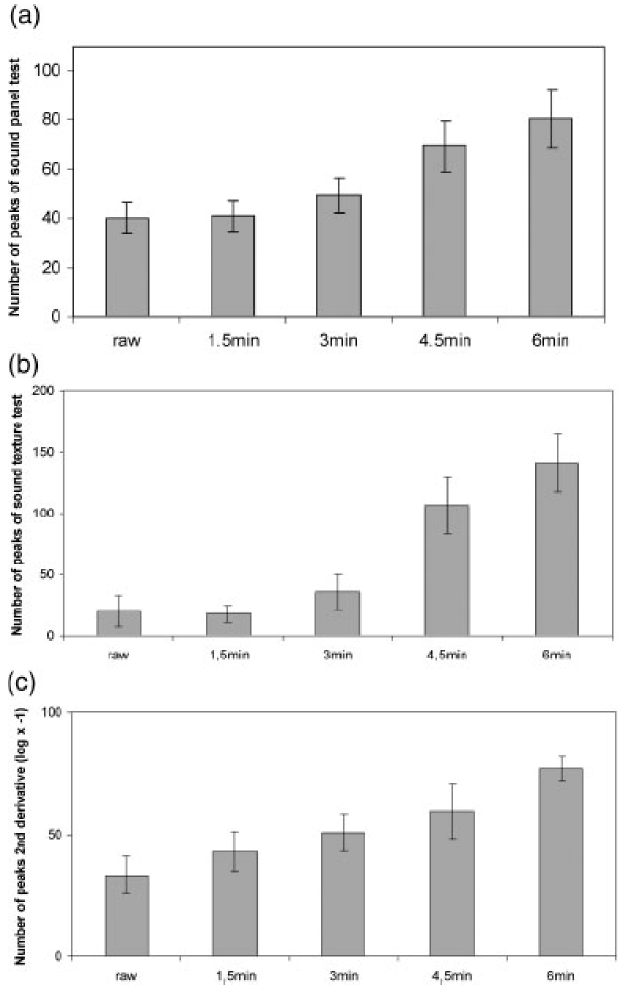


Figure 7. Effect of roasting time on the number of acoustic signal peaks: (a) sensory texture evaluation, (b) instrumental texture evaluation, (c) second derivative of force curve.

The measureables

UNIVERSITY OF LEEDS

Table IV. Principal component analysis

	PC1 (39.1%)	PC2 (16.8%)	PC3 (9.7%)	PC4 (8.6%)	PC5 (7.7%)
Área	−0.298	**0.788**	0.360	−0.144	−0.001
$Slope_{Fmax}$	0.358	**0.666**	−0.139	−0.219	−0.042
Number of force peaks	**0.935**	−0.112	0.164	0.067	−0.013
Average gradient	−0.178	0.102	−0.002	−0.037	**0.922**
Fit distance	0.065	−0.067	−0.226	**0.854**	0.066
Average drop off	−0.446	−0.074	0.126	**0.656**	−0.349
Linear distance	−0.072	**0.823**	0.241	0.214	0.332
Force at failure	**−0.868**	0.174	0.028	0.303	0.230
Distance at failure	**−0.736**	−0.019	0.065	0.430	0.161
Number of peaks of the derivative	**0.859**	0.261	0.289	0.146	0.068
Number of sound peaks	**0.905**	0.036	0.306	−0.075	0.043
Max SPL	0.534	0.559	−0.214	−0.056	−0.077
Panel sensory crispness	**0.780**	0.248	0.256	−0.046	−0.194
Panel number of sound peaks	0.448	−0.098	**0.727**	−0.074	0.230
Panel Max SPL	0.210	0.273	**0.777**	−0.114	−0.164

Rotated component matrix. Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser normalization. Rotation converged in 16 iterations. Correlations were taken into account if their absolute values were >0.6 (numbers in bold print).

Almond roasting

UNIVERSITY OF LEEDS

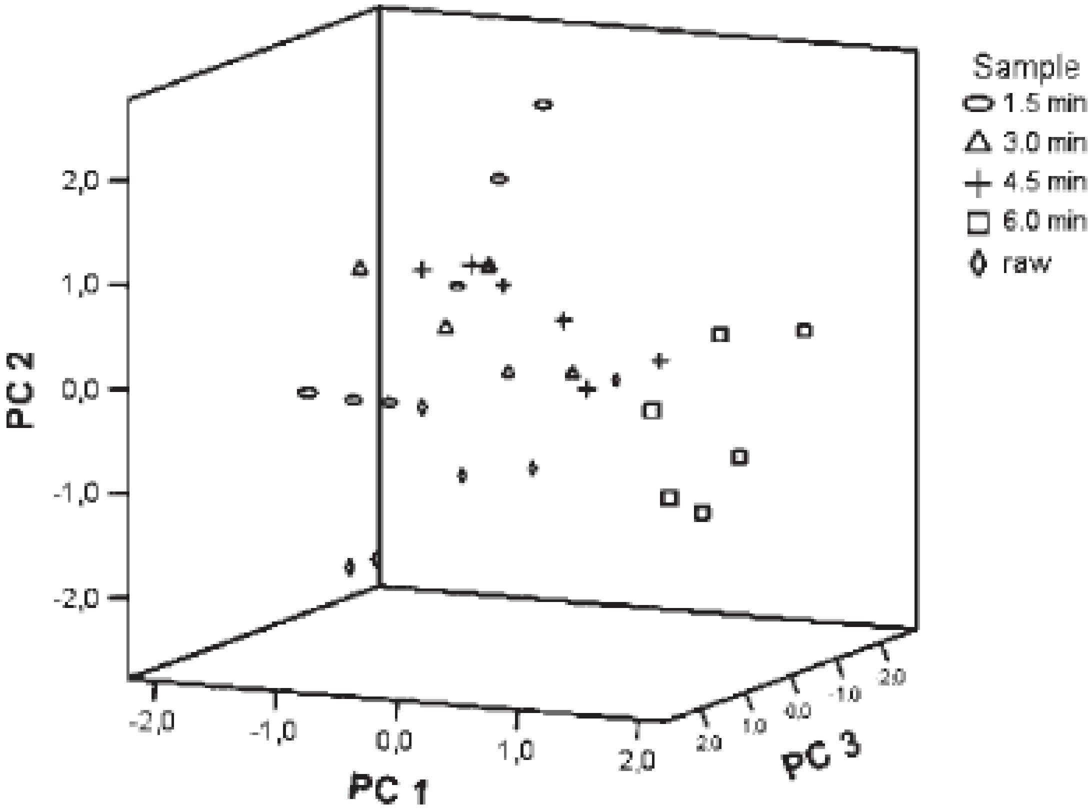


Figure 8. PCA. 3D-loading plot of the samples in the first three principal components, together they explain 65.7% of the variance.

Acknowledgements

UNIVERSITY OF LEEDS

The loan of an acoustic envelope detector by Stable Microsystems (Jade Bank) is gratefully acknowledged.

Technical support from Pete Jardine of Stable Microsystems is gratefully acknowledged

Acknowledgements

UNIVERSITY OF LEEDS

•The following colleagues and students played an important role in these studies

•Dr Jianshe Chen, Cathrine Karlsson, Paula Varela, Bertrand Simon

Published papers include

• Chen JS, Karlsson C, Povey M, Acoustic Envelope Detector for crispness assessment of biscuits, JOURNAL OF TEXTURE STUDIES 36 (2): 139-156 APR 2005

•Varela P, Chen J, Fiszman S, et al.
Crispness assessment of roasted almonds by an integrated approach to texture description: texture, acoustics, sensory and structure
JOURNAL OF CHEMOMETRICS 20 (6-7): 311-320 JUN-JUL 2006

•See also Discovery Channel
http://www.exn.ca/dailyplanet/view.asp?date=4/19/2006

•THANK YOU FOR YOUR ATTENTION!