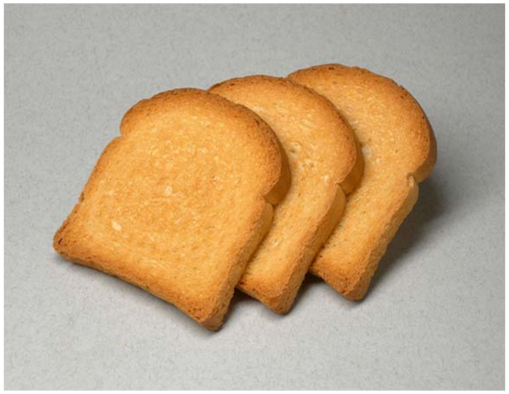
Don’t lose your crunch!

Plasticization of crunchy snacks based on Fermi’s distribution

https://media.giphy.com/media/33Hr4TJYUwM2lUDRaJ/giphy.gif

Nathan Fredman
April Futch
Vishal Ganesan
Shubhang Goswami



https://en.wikipedia.org/wiki/Zwieback#/media/File:Zwieback-1.jpg

Wollny M and Peleg M. “A Model of Moisture-Induced Plasticization of Crunchy Snacks Based on Fermi’s Distribution Function”. *J Sci Food Agric*, **64**, 1994. 467-473.

Motivation

https://www.cookwithmanali.com/wp-content/uploads/2017/02/Rusk-Recipe-2.jpg

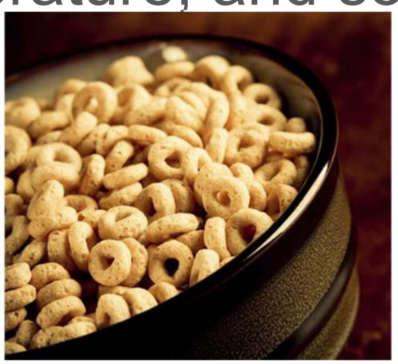
- Rusk: Tasty tea accompaniment
- But what’s the optimum dipping time to enjoy your rusk?
- Similar analysis with cheese balls!

The Recipe: Procedure of Experiment

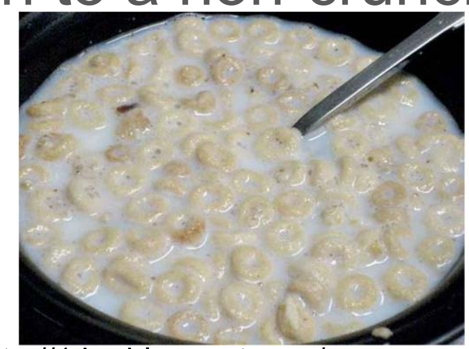
- Quantify the amount of water the rusk soaks, i.e., the water activity (humidity)
- Measure the stiffness (amount of force required to cause a particular strain) and jaggedness (the fractal dimension quantifying the self-similarity of the curve) at different water activities
- Model the resulting stiffness and jaggedness by fitting corresponding fitness curve

The Recipe: Procedure of Experiment

- The stiffness, jaggedness and water activity help understand the plasticization of the snacks
- The plasticization changes the snacks’ glass transition temperature, and so its transition to a non-crunchy snack



https://img.aws.livestrongcdn.com/ls-article-image-673/ds-photo/getty/article/241/15/184665949.jpg



http://1.bp.blogspot.com/-pVkufhiFjCE/UKsOzBNhyKI/AAAAAAAABRg/qM90iLm8pmA/s1600/Soggy+Cereal.jpg

How is the Glass Transition Characterized?

http://www.aimil.com/Resources/Products/Original/267_Universal_Testing_Machine.jpg

- Desiccators with saturated solutions determine water activity (LiCl, NaCl,...)
- Universal Testing Machine to measure stiffness
- Quadratic polynomial for force-strain relationship

$$F(\varepsilon) = k_0 + k_1\varepsilon + k_2\varepsilon^2 + k_3\varepsilon^3 + k_4\varepsilon^4$$

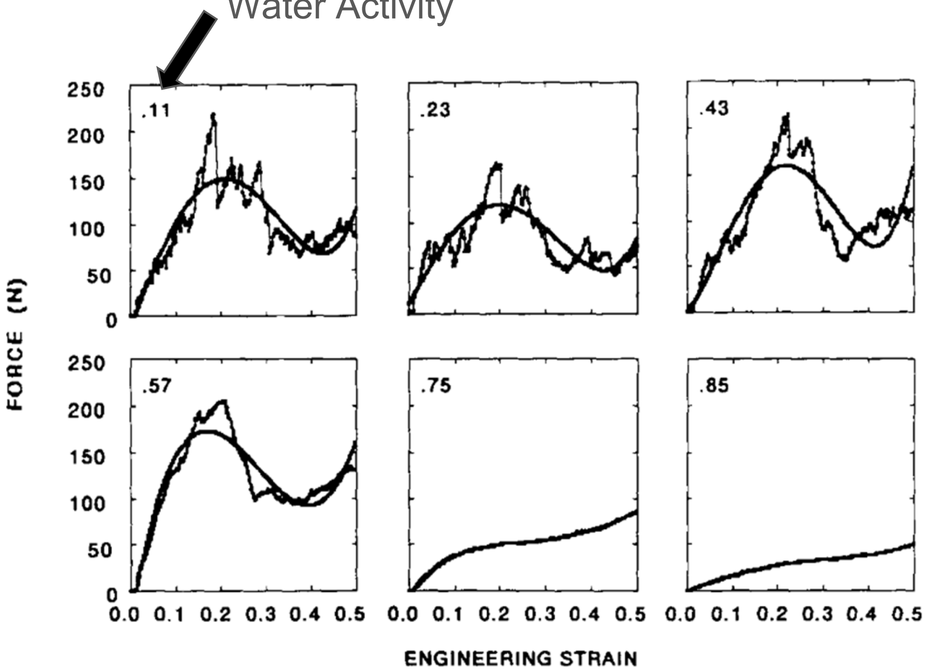
- Model using previous work in field (*Peleg 1994)*
    - A fermi distribution used to model the transition from crispy to soggy

$$E(a_w) = \frac{E_s}{1 + e^{(a_w - a_{wc})/b}}$$

Force vs. Strain

Experiment and Model

Water Activity

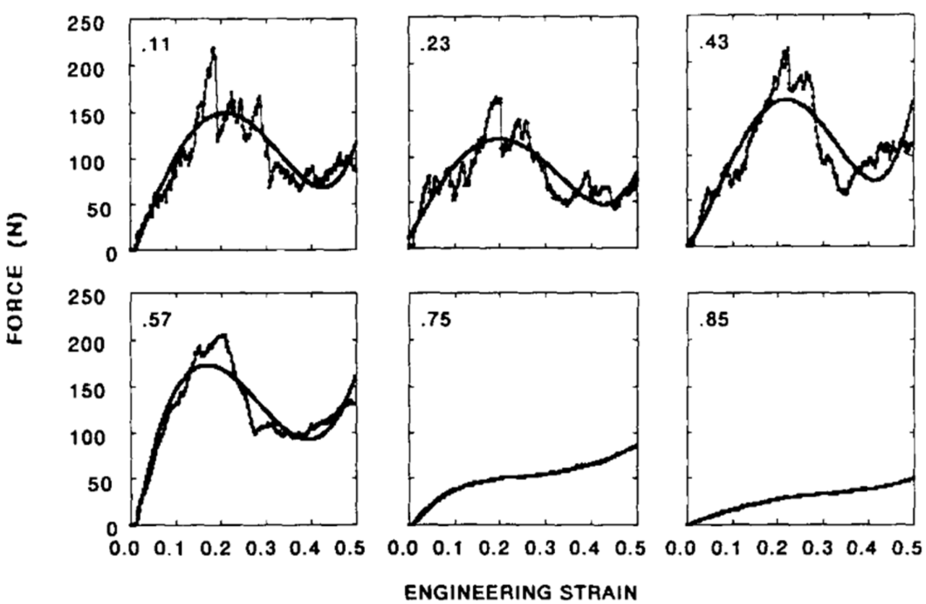


Rusk

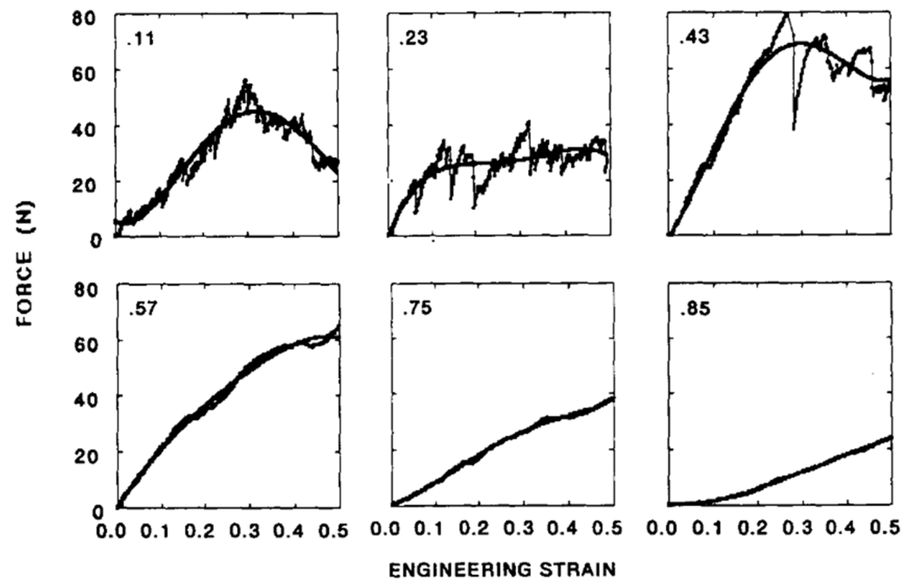
- Polynomial fit works well with the rusk
- Because of variation between force and strain, authors chose to focus on the strains at 0.1 and 0.2

Force vs. Strain

Experiment and Model



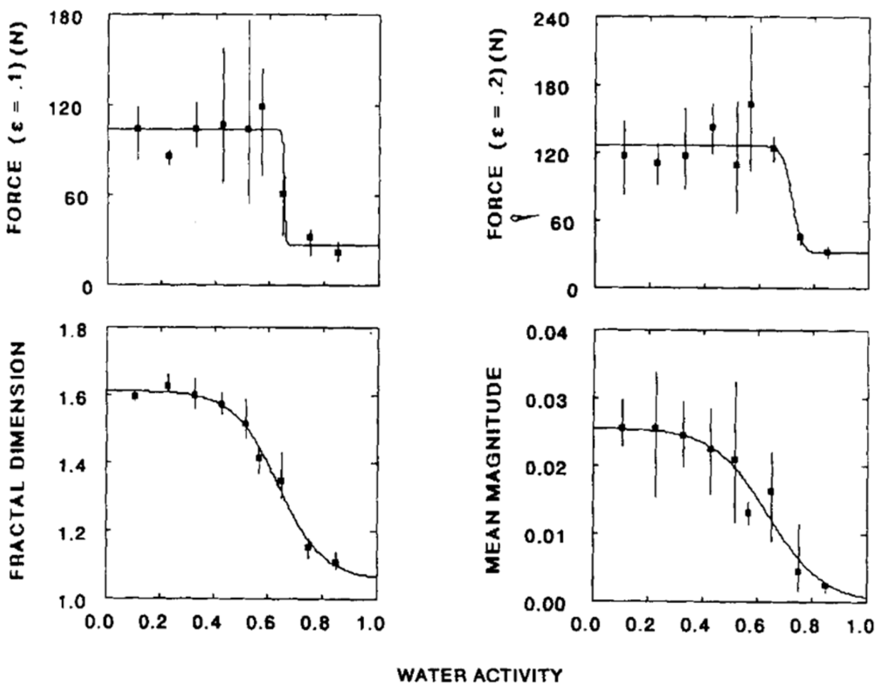
Rusk



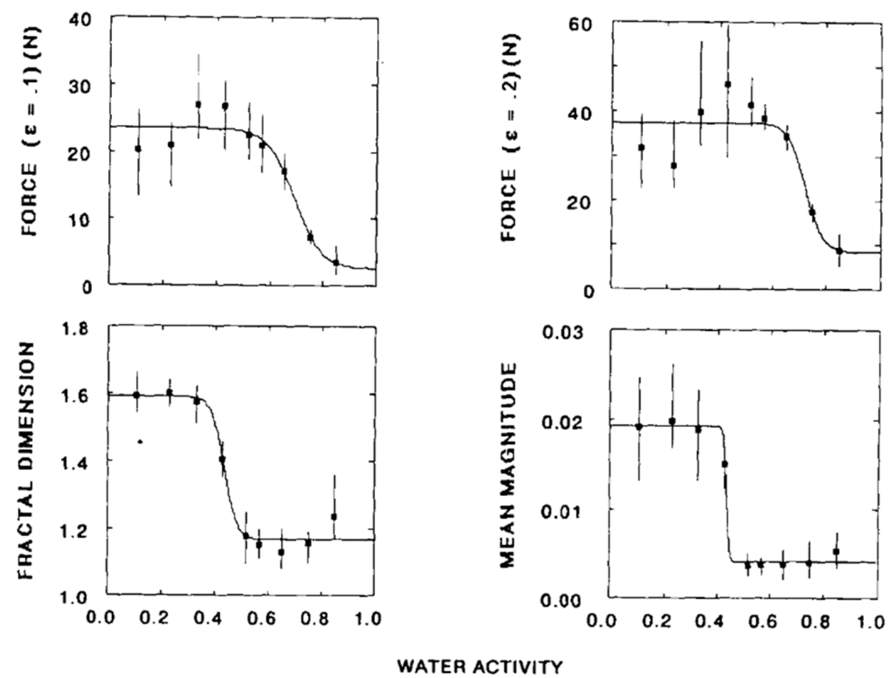
Cheese ball

Works for cheeseballs too

Fermi Distributions

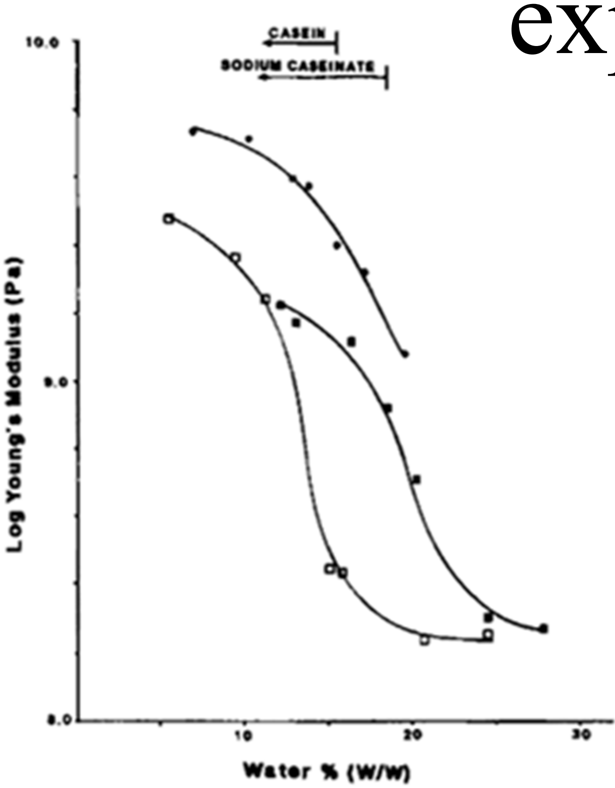


Rusk



Cheese ball

Provides mathematical model for experimental data



(Kalichevsky 1993)

Past *experimental* work has studied stiffness-moisture relationships of various foods/compounds at the glass-transition region [1,2]

Wollny and Peleg provide a *mathematical* description of how mechanical properties change

[1] Kalichevsky MT, Blanshard JMV, Tokarczuk PF. "Effect of water content and sugars on the glass transition of **casein and sodium caseinate**". *Int. J. of Food Sci. and Tech.*. 28(2), 1993

[2] McNulty PB, Flynn DG. "Force-deformation and texture profile behavior of **aqueous sugar glasses**". *J. of Text. Studies*. 8(4), 1977.

New model applicable in glass transition region

Other mathematical models describing how food properties change:

- WLF model [1] $\log_{10} a_T = -C_1(T - T_s)/(C_2 + T - T_s)$
  - Describes the ratio of time scales for the relaxation of mechanical parameters (a_T) at two temperatures (T, T_s)

- Arrhenius (or Frenkel) model [2] $(x/a)^2 = (3/2)(\sigma t/a\mu)$
  - Relates particle separation (x), viscosity (μ), and surface tension (σ)

These do not work in the glass transition region [3], but the Fermi distribution function does

[1] Williams ML, Landel RF, Ferry JD. "The Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-forming Liquids". *J. of Amer. Chem. Soc.* 77(14), 1955.
[2] Wallack DA, King, CJ. "Sticking and Agglomeration of Hygroscopic, Amorphous Carbohydrate and Food Powders". *Biotech. Prog.* 4(1), 1988.
[3] Peleg, M. "Glass transitions and the physical stability of food powders". In *Glassy states in foods*. Blanshard, JMV, Lillford, PJ, Eds. Nottingham University Press: Nottingham, UK, 1993.

Expands the applicability of the model

First paper presenting the Fermi distribution model used it to describe the elasticity/stiffness of various materials as a function of temperature and water activity [1]

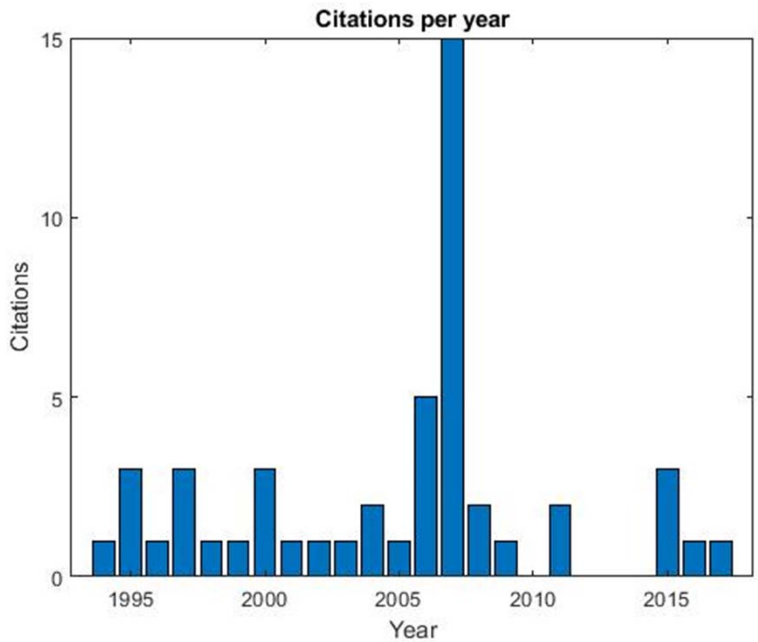
This paper validates the model and applies it to new situations

- Tests the model more rigorously using newly collected data
- Focuses on a different type of food (crunchy snacks)
- Applies model to non-conventional mechanical parameters that are related to textural properties

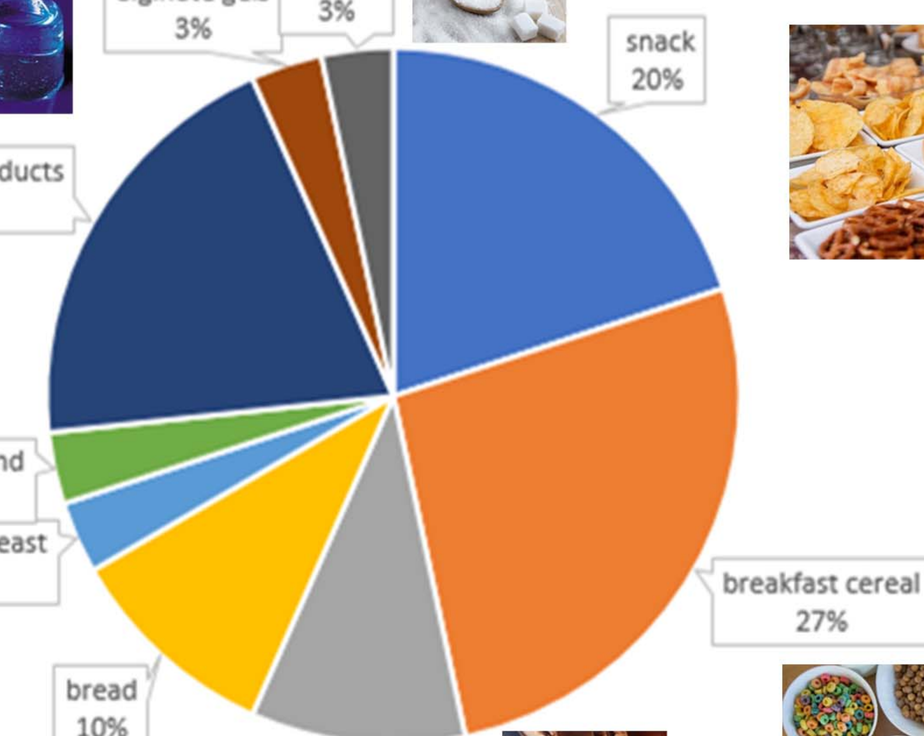
[1] Peleg M. “A Model of Mechanical Changes in Biomaterials at and around Their Glass Transition”. *Biotechnol. Prog.* 10(4), 1994.

Citation Analysis

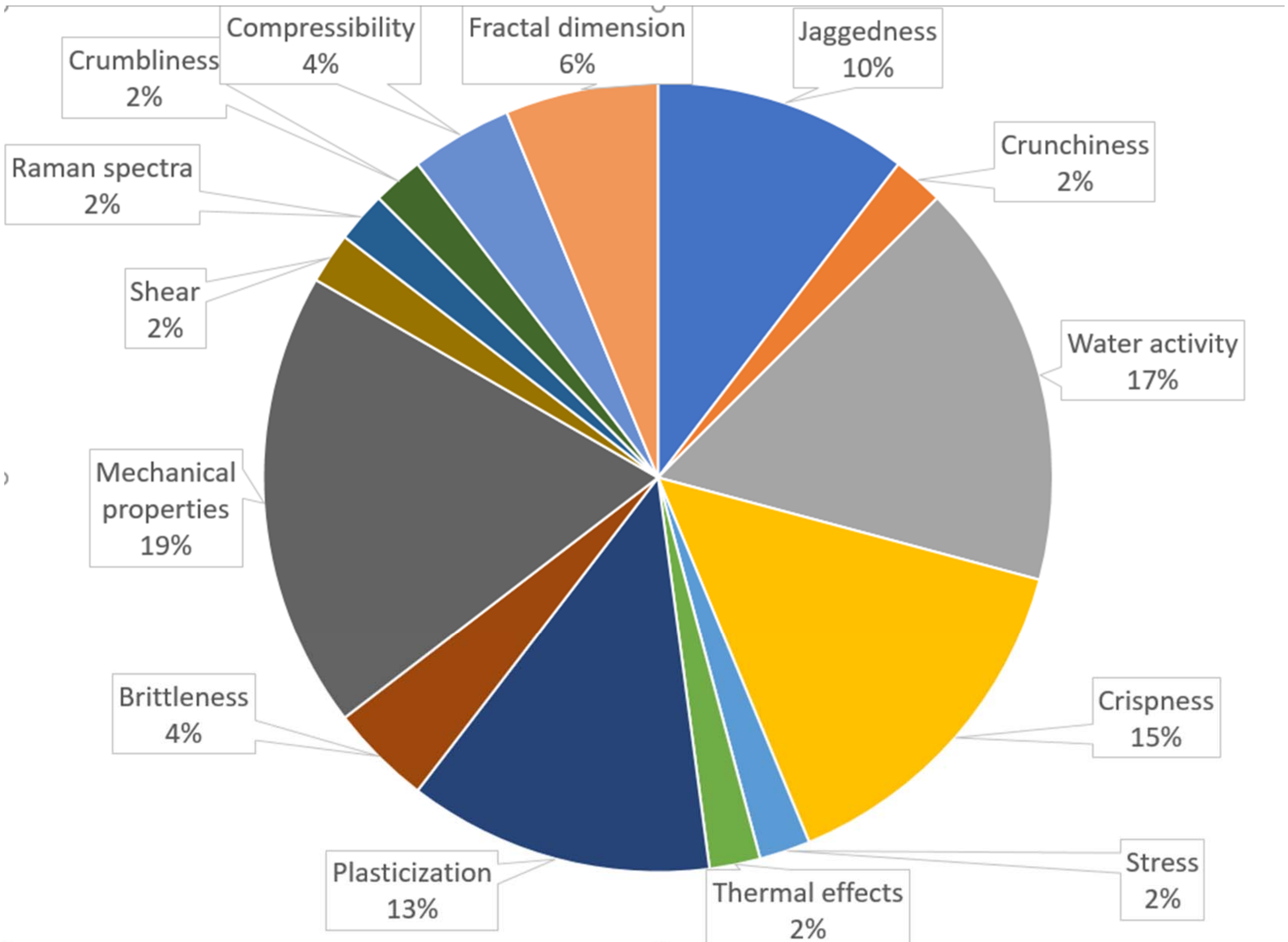
- 49 Citations since published in 1994 (according to Web of Science)
  - 18 are self-citations
  - 8 are review articles



Food Types


alginate gels
3%
glucose
3%
snack
20%
cereal products
20%
breakfast cereal
27%
pork rind
3%
turkey breast
4%
bread
10%
coffee beans
10%


PALEO LEAP

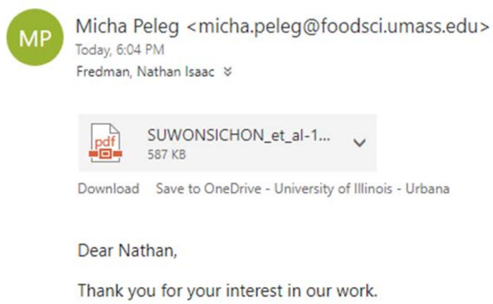


Compressibility 4%
Fractal dimension 6%
Jaggedness 10%
Crumbliness 2%
Crunchiness 2%
Raman spectra 2%
Shear 2%
Water activity 17%
Mechanical properties 19%
Brittleness 4%
Crispness 15%
Stress 2%
Plasticization 13%
Thermal effects 2%

Development of ‘Soft’ Physics

- Better measurements of glass temperature (Höhne et al 2003)
- Water activity has been correlated with food safety (Troller and Christian 2012)
- Knowledge of glassy states been used to “to get light and crispy textures of different tastes." (Vilgis 2015)
- Jaggedness applied to test food textures
- Not very much literature on fractal dimension

Remarks from Dr. Peleg


Micha Peleg <micha.peleg@foodsci.umass.edu>
Today, 6:04 PM
Fredman, Nathan Isaac

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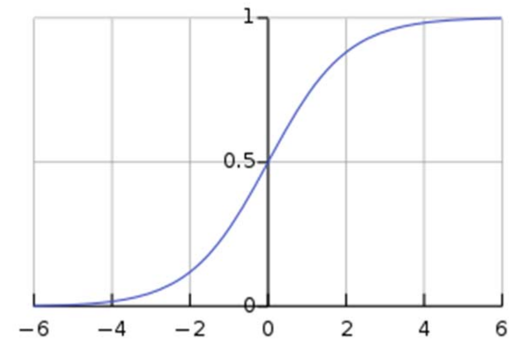
587 KB
Download Save to OneDrive - University of Illinois - Urbana

Dear Nathan,

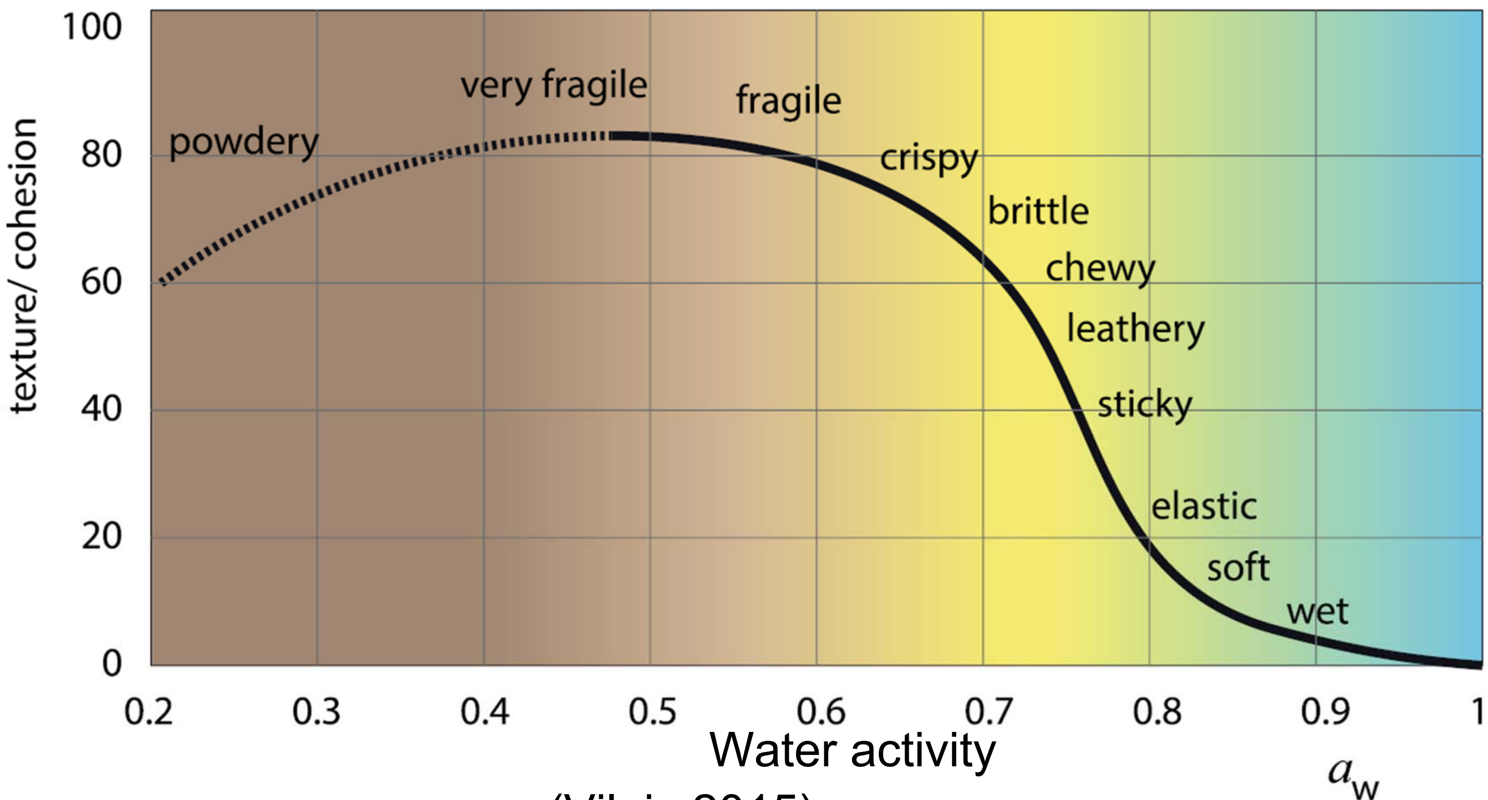
Thank you for your interest in our work.



Sigmoid
https://upload.wikimedia.org/wikipedia/commons/thumb/8/88/Logistic-curve.svg/1920px-Logistic-curve.svg.png

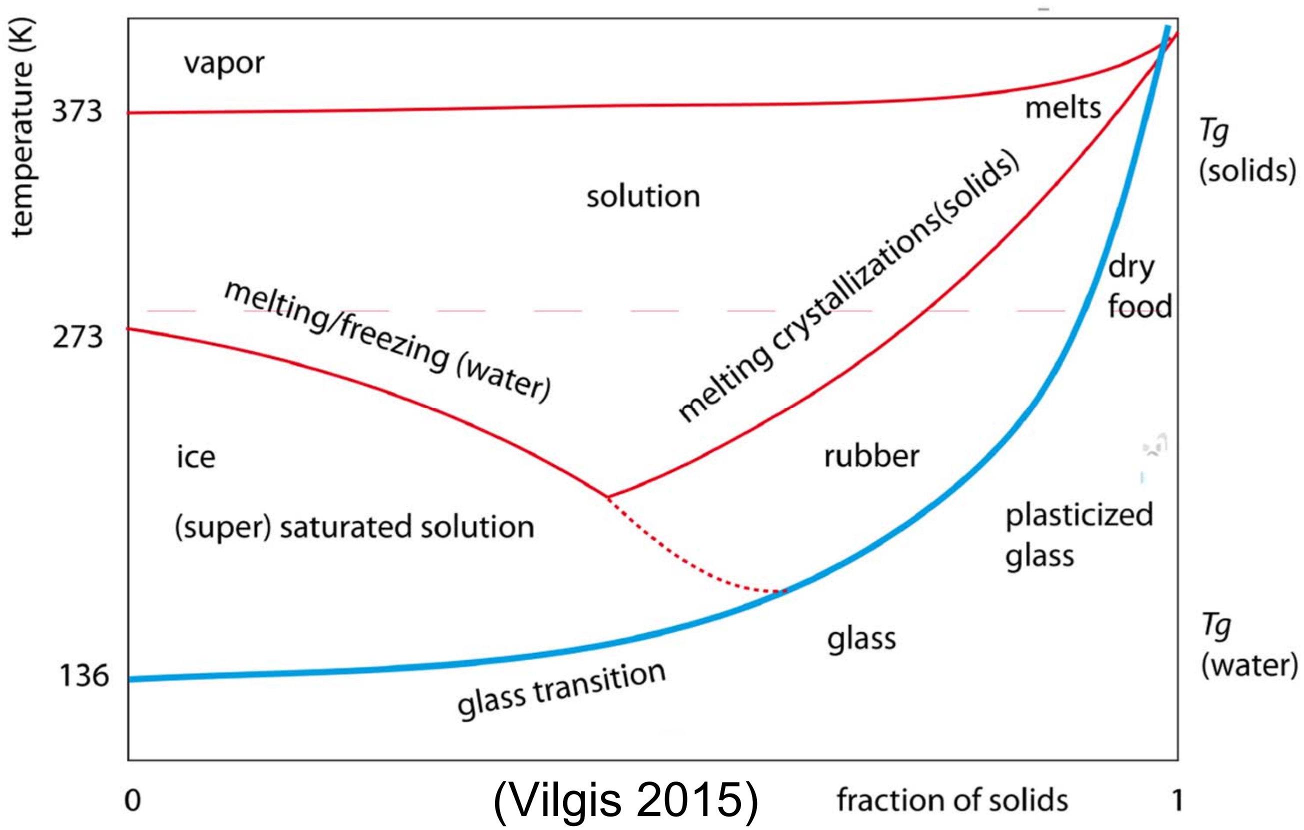
- The most significant impact is that brittleness ("crunchiness") vs. moisture (or a_w) relationship
  - is sigmoid, not linear as was previously reported (on the basis of too few data points)
  - Is not ruled by the WLF (Williams–Landel–Ferry) equation which would require monotonic rise all the way to zero moisture or the (in his opinion fictitious) "Tg." (glass-transition temperature)

Water activity and texture



(Vilgis 2015)

Phases of Foods



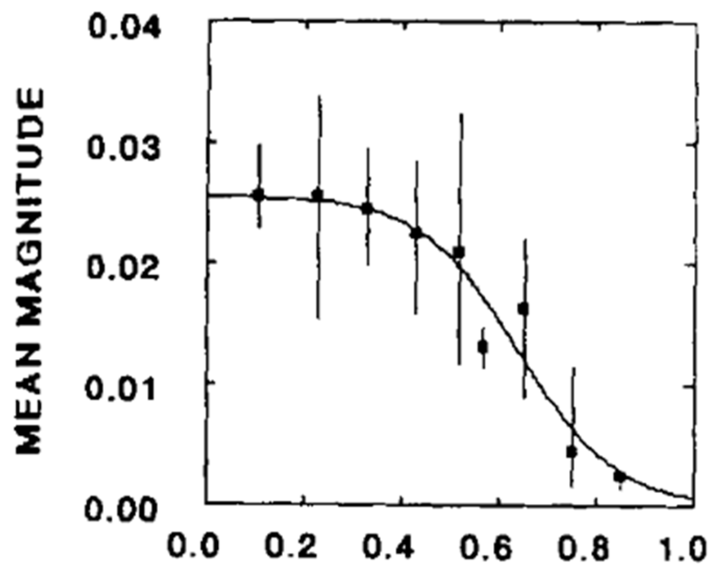
(Vilgis 2015)

Negative Critiques

- Tpyos!

cannot be meaninfully determined

- Large error bars
    - Only 5 cheeseballs used for each data point!



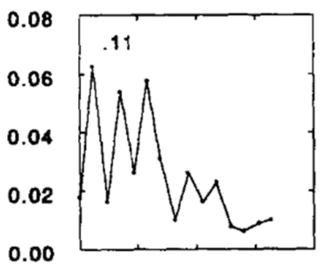
More Negative Critiques

- **What's the significance of using Fermi distribution?**
    - Response by email from Dr. Peleg "The main advantages of the Fermi Distribution function is that it can describe **both** sharp and moderate sigmoid drops and its inflection point is explicitly marked by the Xc parameter in its formula."
- **What is the reason cheeseballs and rusks were chosen?**
    - Response by Dr. Peleg "because they are of more or less uniforms size and shape and could be tested individually."
    - "The Cheeseballs were also used to demonstrate the possibility of extracting the properties of individual particles from the compressibility of their bulk"

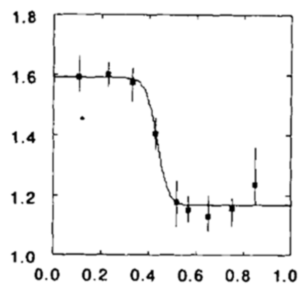
https://www.youtube.com/watch?v=VYJfgEnJTvc

Positive Critiques

- Characterized jaggedness using two methods, giving consistent results

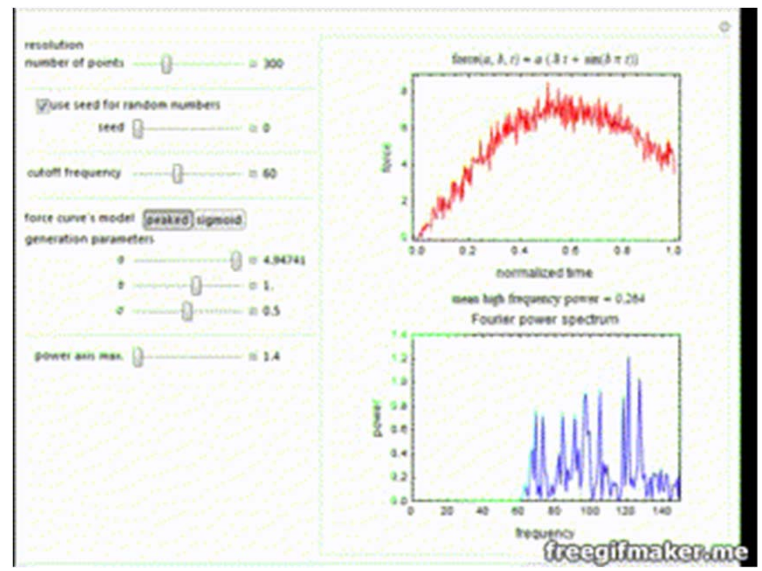


Power spectra



Fractal Dimension

- Model applicable to a wide range of studies



https://demonstrations.wolfram.com/FourierPowerSpectrumAsAMeasureOfLineJaggedness/

Conclusion

- Uses Fermi-distribution function to model the glass transition phase of crunchy snacks undergoing water absorption
- Applies model to new parameters - stiffness and jaggedness of stress-strain relationship
- Strong methods, but lacking in statistics (and full of typos)
- The paper is frequently cited in future food science studies

https://www.youtube.com/watch?v=gyxaNIoze68

Extra Slides

A Model of Moisture-Induced Plasticization of Crunchy Snacks Based on Fermi's Distribution Function

Mathis Wollny and Micha Peleg*

Department of Food Science, University of Massachusetts, Amherst, Massachusetts 01003, USA

(Received 9 June 1993; accepted 12 November 1993)

Abstract: The irregular force-deformation relationships of commerical cheese balls and Zwiebacks at nine levels of water activity in the range 0·11–0·85 were recorded with a computer-interfaced Universal testing machine. They were characterized by two empirical stiffness parameters, the force at 10 and 20% deformation, and two jaggedness measures, the apparent fractal dimension of the normalized force–deformation curve and the mean magnitude of its power spectrum. The plots of all four parameters versus the water activity had a stable region followed by a substantial drop at a characteristic water activity level, of the kind expected when a material undergoes a glass transition. The phenomenon over the entire experimental water activity range, could be described by a model whose mathematical format is a slightly modified version of Fermi's distribution function that is $P(a_w) = P_s/\{1 + \exp[(a_w - a_{wcp})]/b_P\} + c_P$ where $P(a_w)$ is any of the stiffness or jaggedness parameters, P_s and c_P constants whose sum is the magnitude of the parameter when the material is in the dry state (c_P is the residual level after plasticization), a_{wcp} is a characteristic water activity level representing the region where the major textural changes take place, and b_P a constant representing the steepness of the relationship at the transition region.

https://www.youtube.com/watch?v=VYJfgEnJTvc

Key words: glass transition, texture, rheology, brittleness, fractals.