Statistical Laws for Food Fragmentation by Human Mastication

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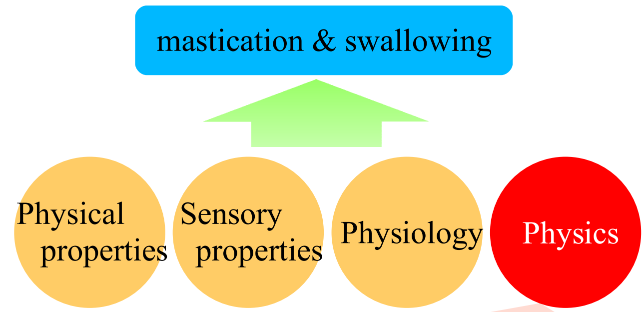
1. The oral processing of foods



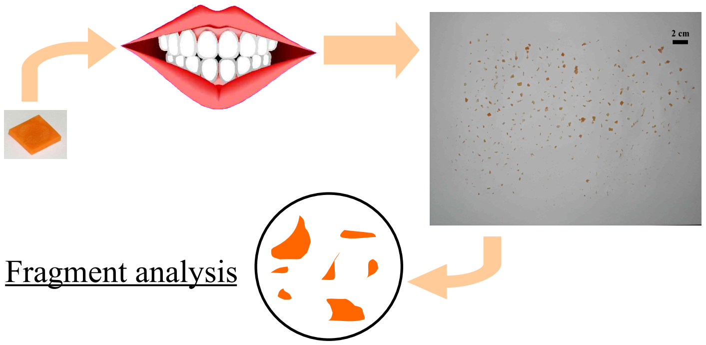
mastication: three-dimensional fragmentation.

A major problem is lack of visualization of what goes on.

→ Simple & physiological model is needed.

2. Experiment

- Samples:
  - raw carrot ... 23×23×4 mm, *ca*. 2 g.
- subject number: 5.



3. Fragment-Size Distribution

The first approximation ...

The mastication by teeth is the sequential fragmentation in the oral cavity.

random multiplicative stochastic process

→ Lognormal distribution (cumulative form)

$$N(s) = \frac{N_T}{2}\left(1 - \mathrm{erf}\left(\frac{\log(s/\bar{s})}{\sqrt{2}\sigma}\right)\right).$$

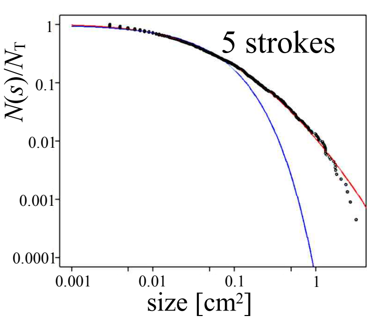


Fig.
Log-log plots for the cum. num. of food fragments of raw carrot versus the size.
red line ... lognormal.
blue line ...Weibull.

A single lognormal distribution well fits the entire region for masticated food fragments.

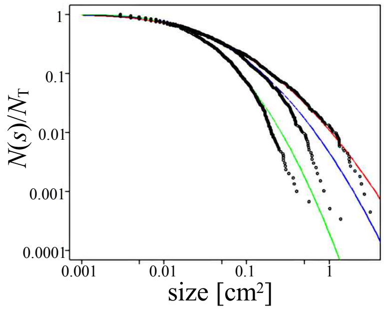
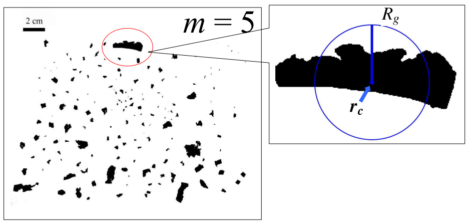


Fig.
Log-log plots for $N(s)/N_T$ versus the size after various numbers of chewing strokes, 5, 10 and threshold number. The solid lines indicate lognormal distributions.

The tail parts deviate from lognormals.

4. Scaling Law for Fragment Shapes



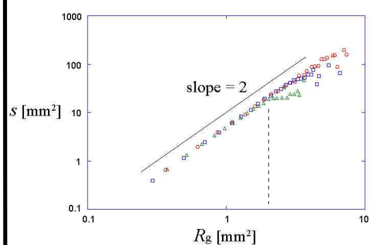
radius of gyration

$$R_g^2 = \frac{1}{N}\sum_{i=1}^{N}(\boldsymbol{r}_i - \boldsymbol{r}_c)^2,$$

$$\boldsymbol{r}_c = \frac{1}{N}\sum_{i=1}^{N}\boldsymbol{r}_i.$$

$$s \sim R_g^{\alpha}$$

α depends on the structure of crack pattern.



△: m = thres. num.,
□: $m = 10$,
○: $m = 5$.

Small pieces have isotropic shape implying $\alpha = 2.0$.

There are two regions separated by a crossover R_g^*.

Dynamic scaling

$$\begin{cases} s \sim m^{-\beta} & (m \ll m^*), \\ s \sim m^{-\delta} & (m \gg m^*), \\ R_g^* \sim m^{-1/z}, \end{cases}$$

β: anti-growth exponent

z: dynamic exponent

$$\rightarrow \quad s \sim m^{-\beta} f\left(\frac{R_g}{R_g^*}\right) \sim m^{-\beta} f\left(\frac{R_g}{m^{-1/z}}\right)$$

$$f(x) = x^{\alpha} \quad (x \ll 1) \rightarrow z = \frac{\alpha}{\beta}.$$ scaling relation

$\beta \simeq 1.0, \quad z \simeq 2.0.$

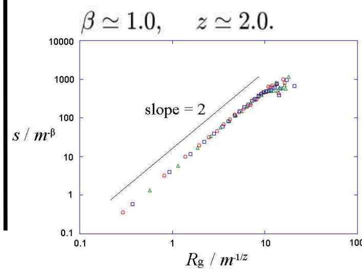


Fig.
Results of data collapse for shapes of food fragments. The different symbols correspond to the number of chewing strokes m = 5, 10 and 25.