

# Automatic Classification of Crispiness: Integration of Mechanical and Acoustical Sensor Data

Solange Sanahuja<sup>a</sup>, Manuel Fédou, Heiko Briesen<sup>a</sup>

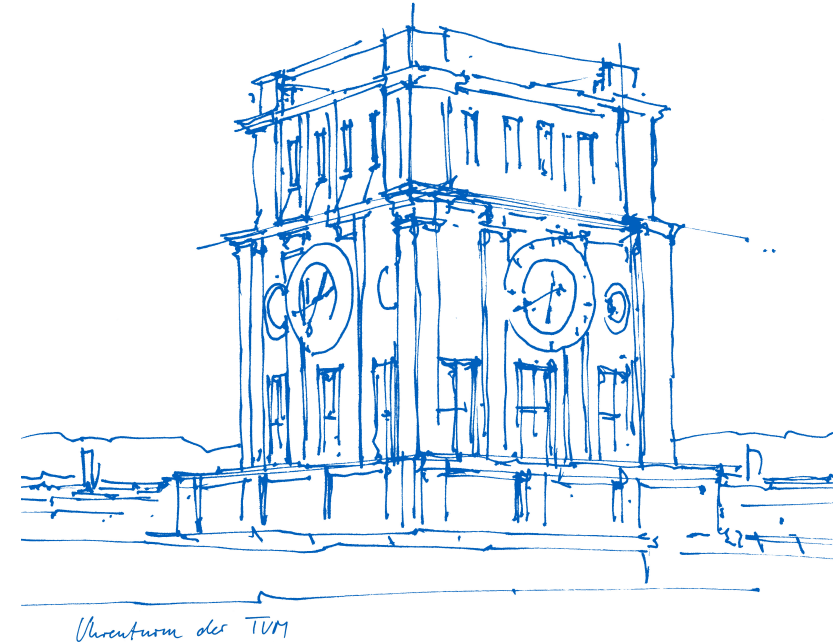
<sup>a</sup> Technical University Munich

Center for Life and Food Sciences Weihenstephan

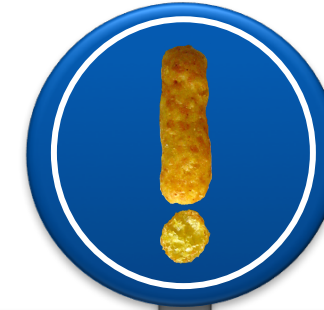
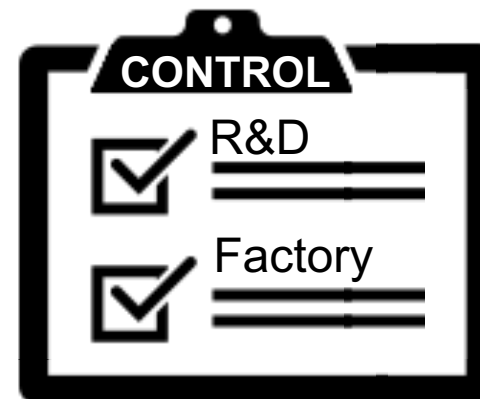
Chair of Process Systems Engineering

MATLAB Expo

Munich, 27. June 2017



# The challenge for crispy snacks



## REQUIREMENTS



Brittle: porous, not tough neither soft



Dry: sensitive to humidity

## MEASUREMENTS



Sensory panels: time-/cost-intensive

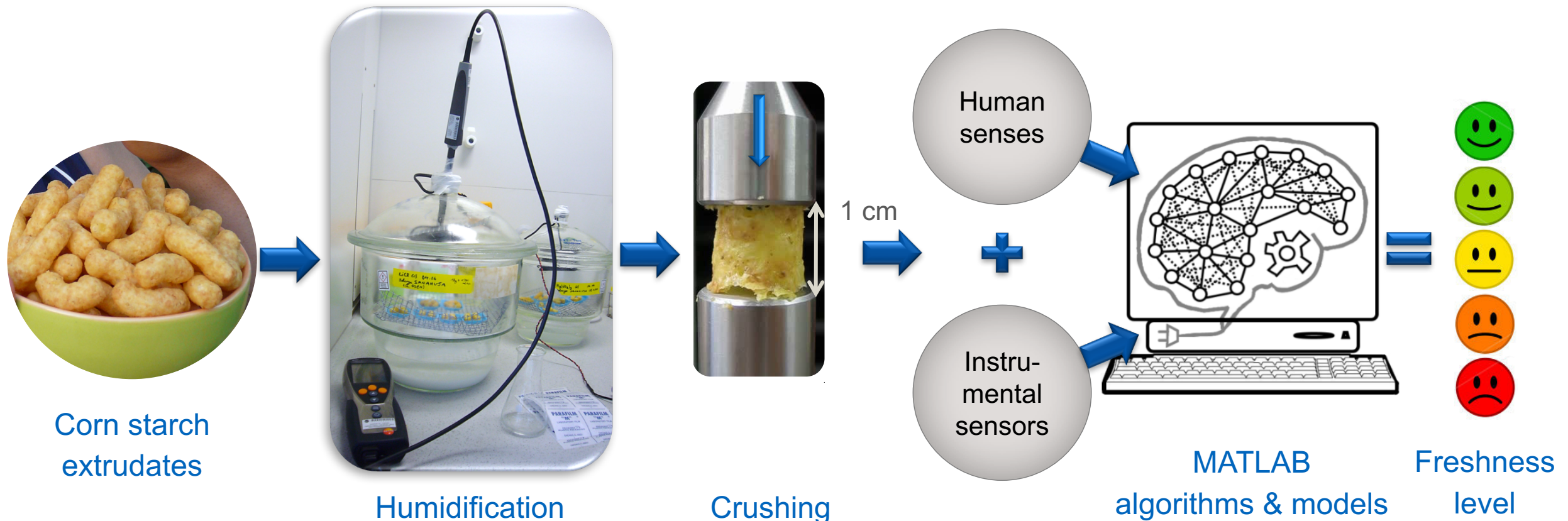


Instrumental analysis: lack of reliable & accurate methodology

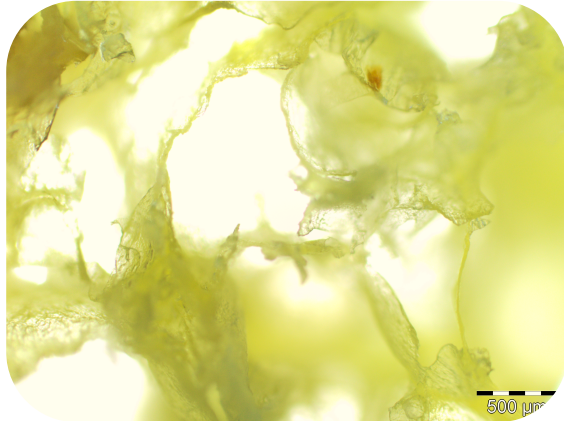


# Overview

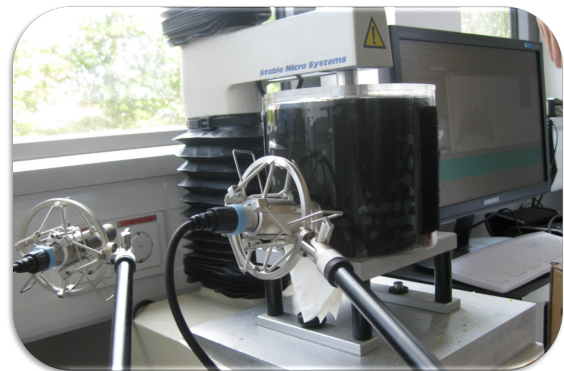
- 1) Instrumental sounds → crisps freshness distinction by humans?
- 2) Multimodal texture characterization → improved accuracy of crisps freshness classification?
- 3) Spectral features vs. traditional temporal features → impact on classification?



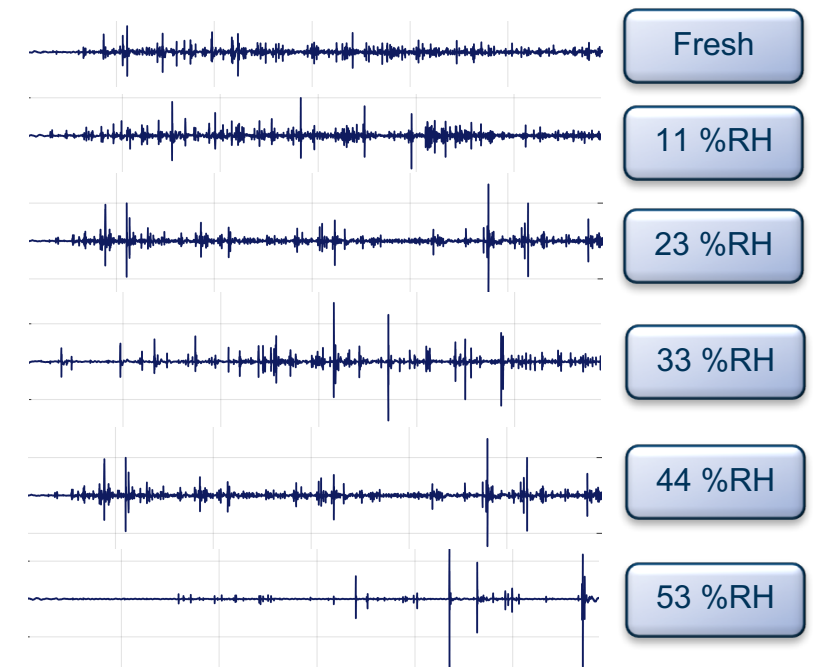
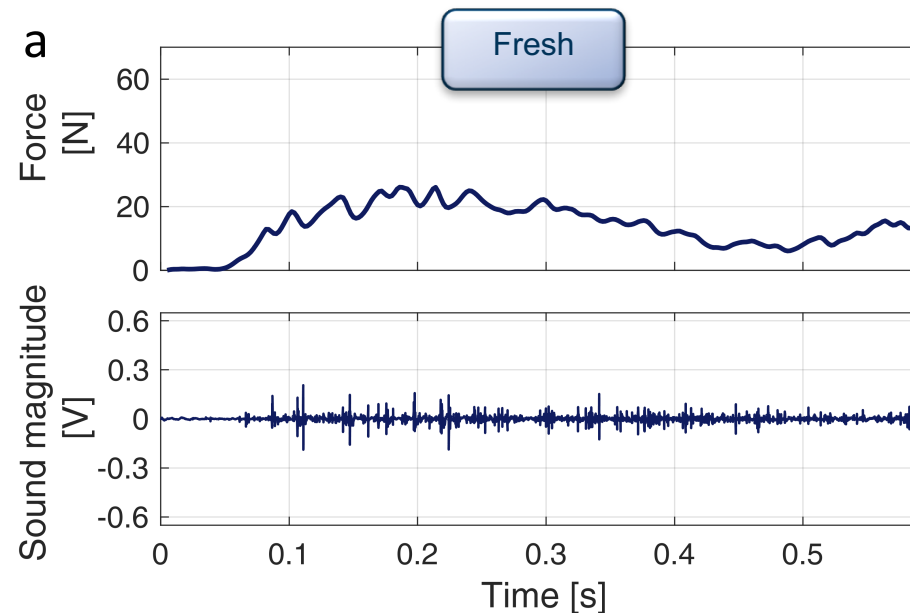
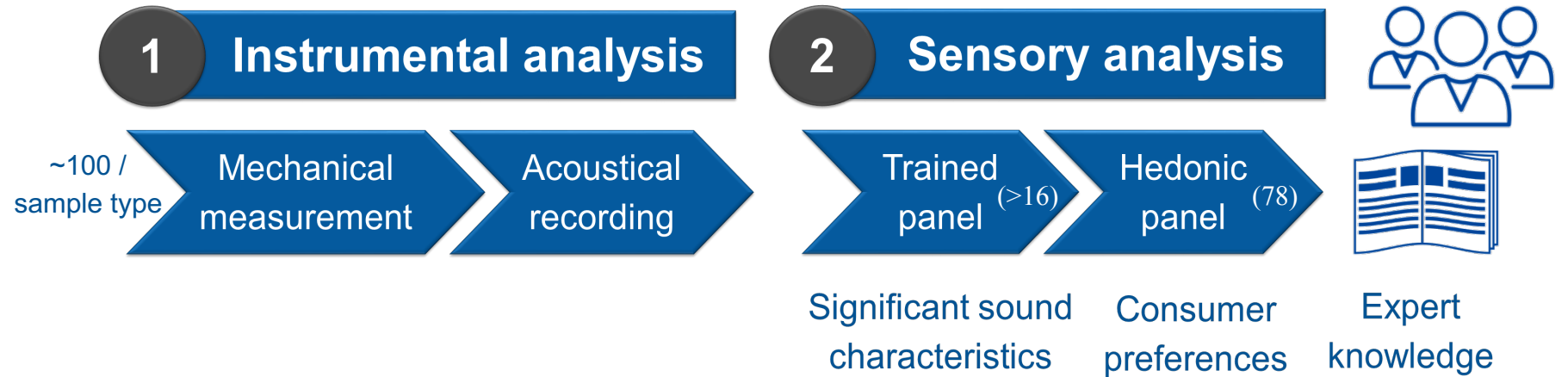
# Multimodal data acquisition



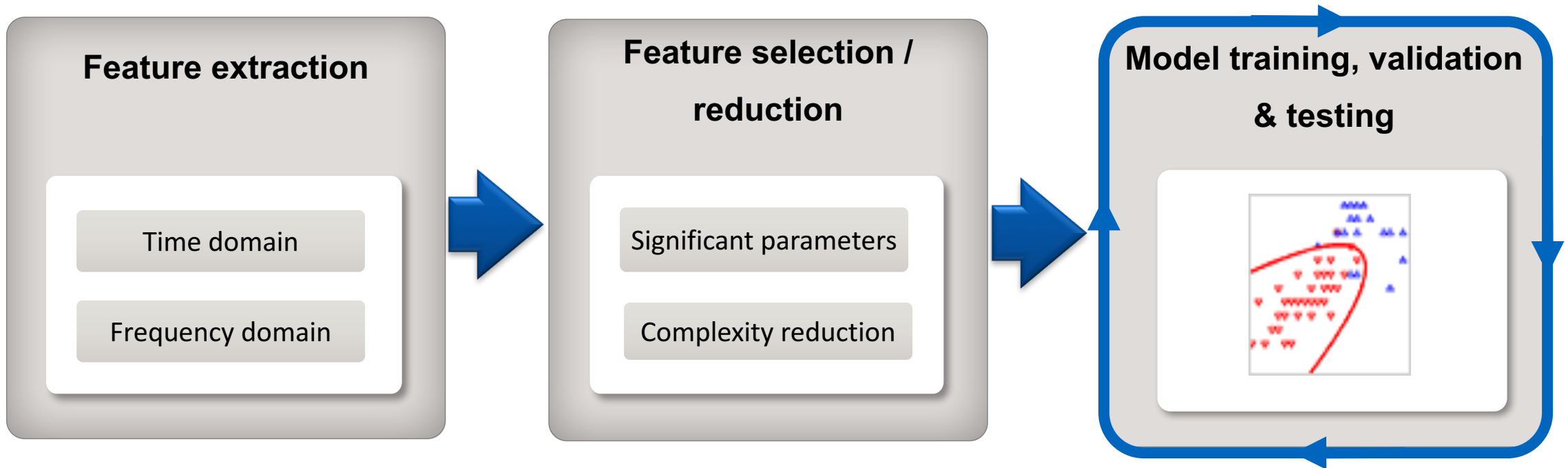
Light microscopy [500μm bar]



Compression test + sound recording



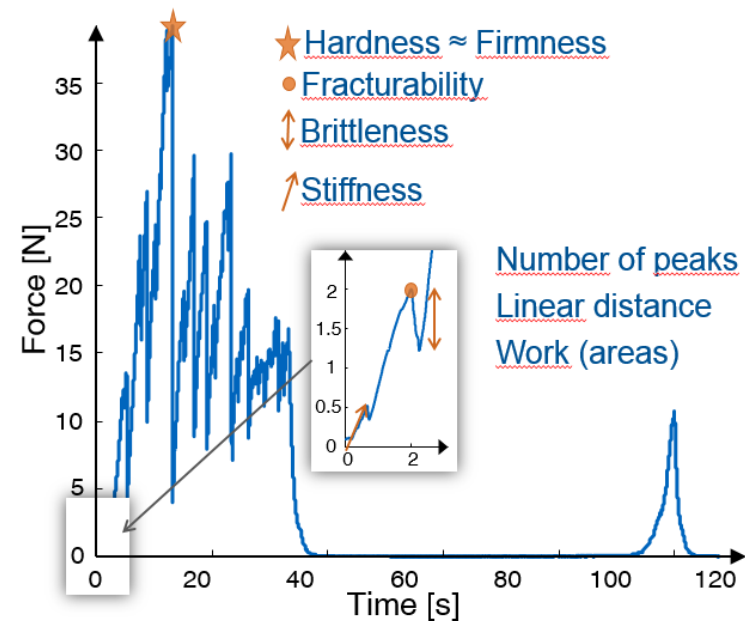
# Automatic classification strategy



# Temporal vs. Spectral analysis

70 features:

Time domain



→ No reproducible & reliable prediction of crispiness using single texture parameters

Frequency domain

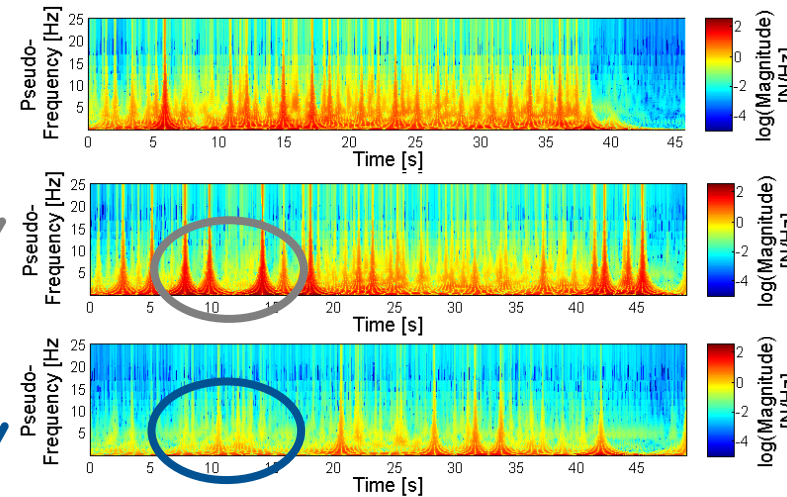
11%RH

Toughening

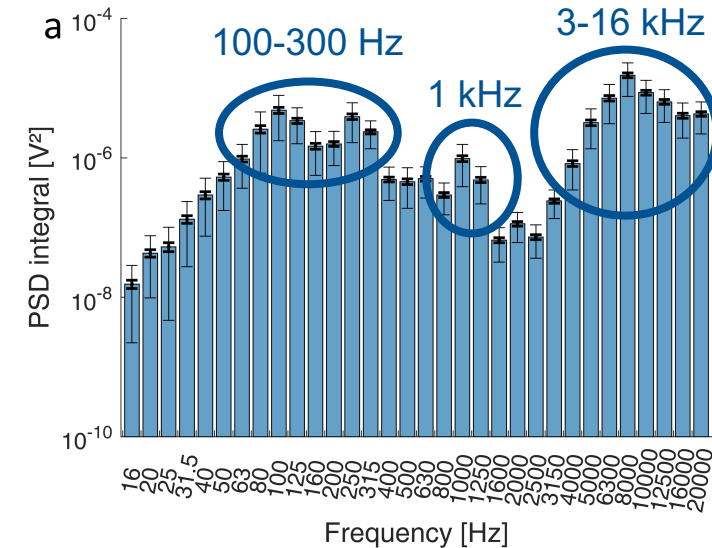
33%RH

Softening

53%RH



→ STFT, CWT & HHT suitable for irregular multi-fracture phenomena



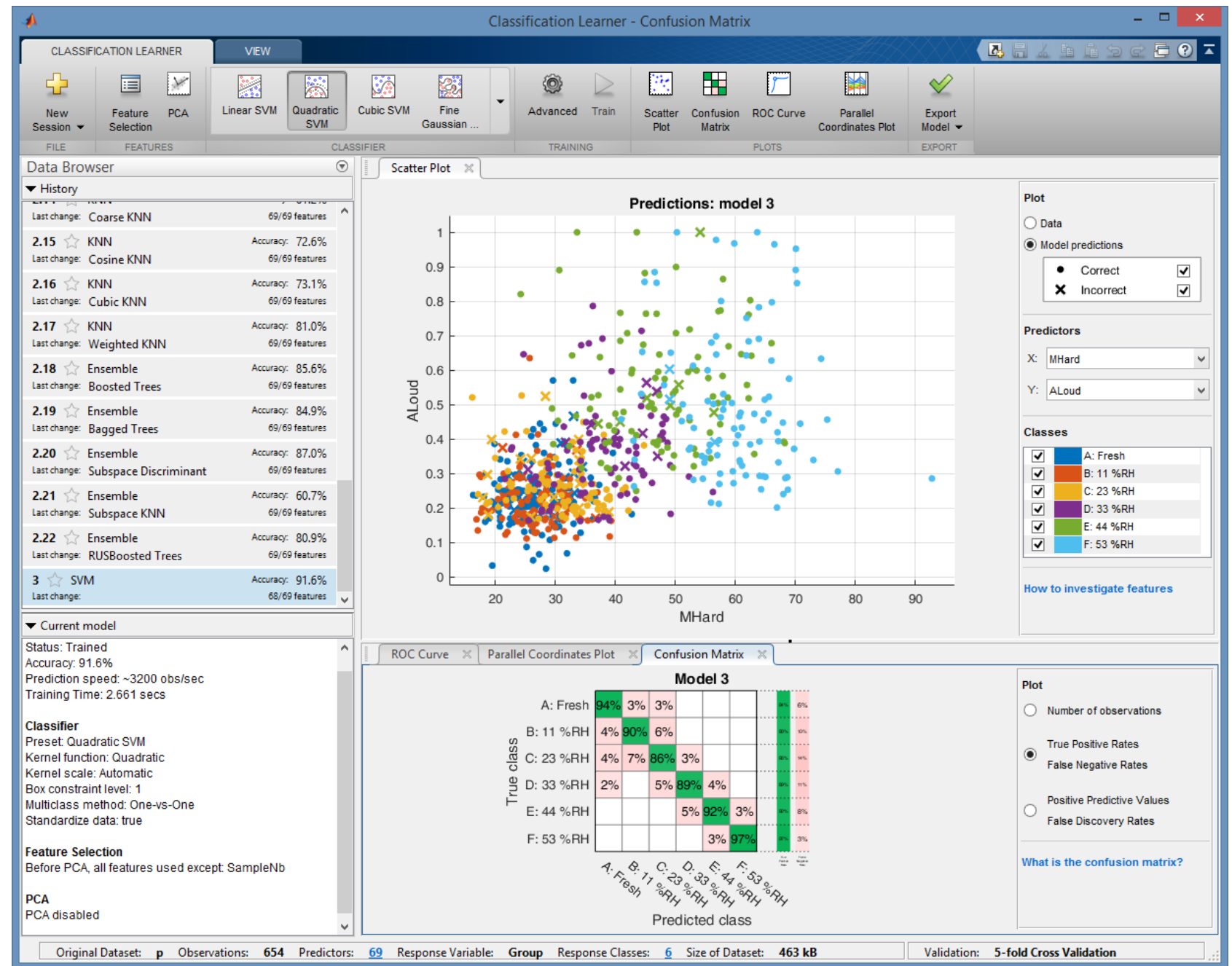
→ Fourier spectrum in octaves suitable for classification



# Classification Learner App

## Algorithms screening:

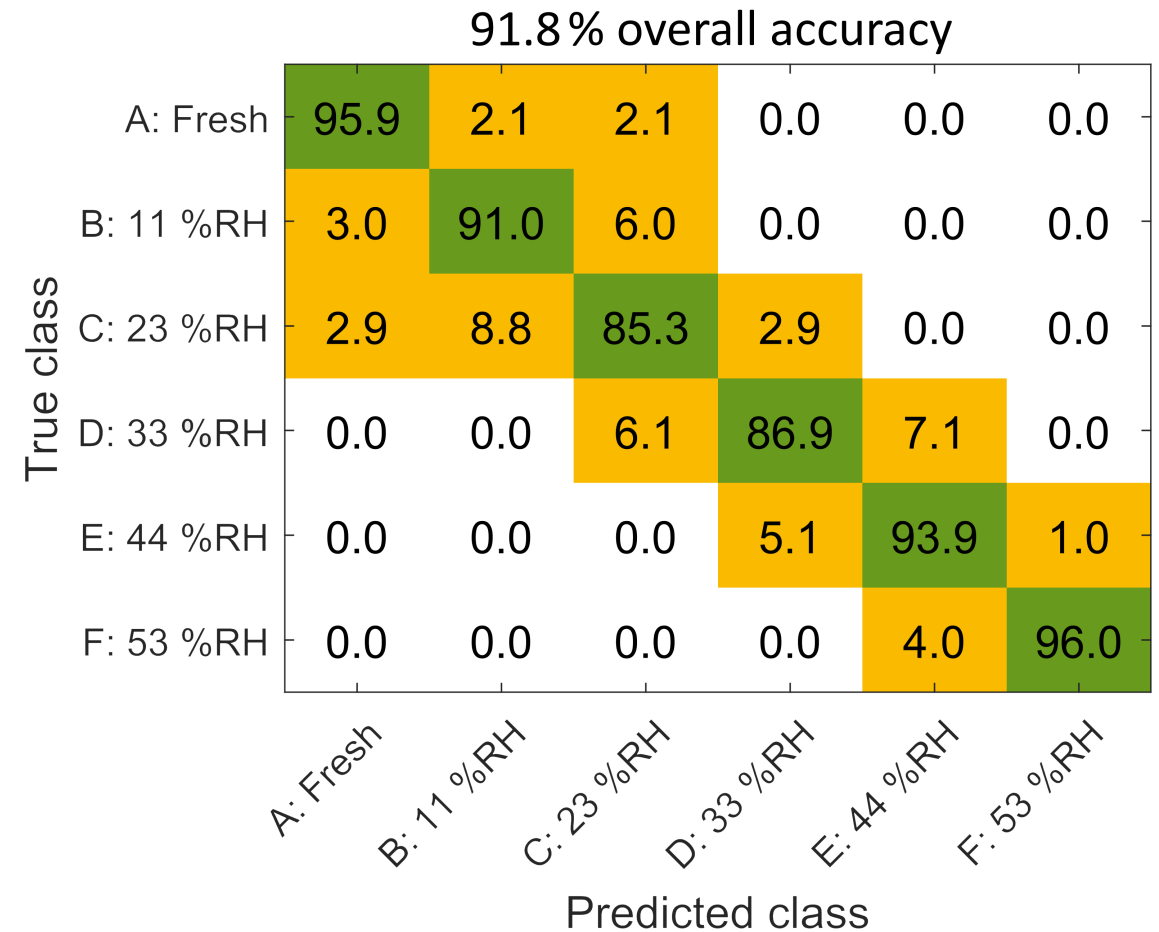
- Decision trees
- Discriminant analysis
- Nearest neighbor
- Ensemble classifiers
- Support vector machines (SVM)
- Artificial neural networks (ANN)





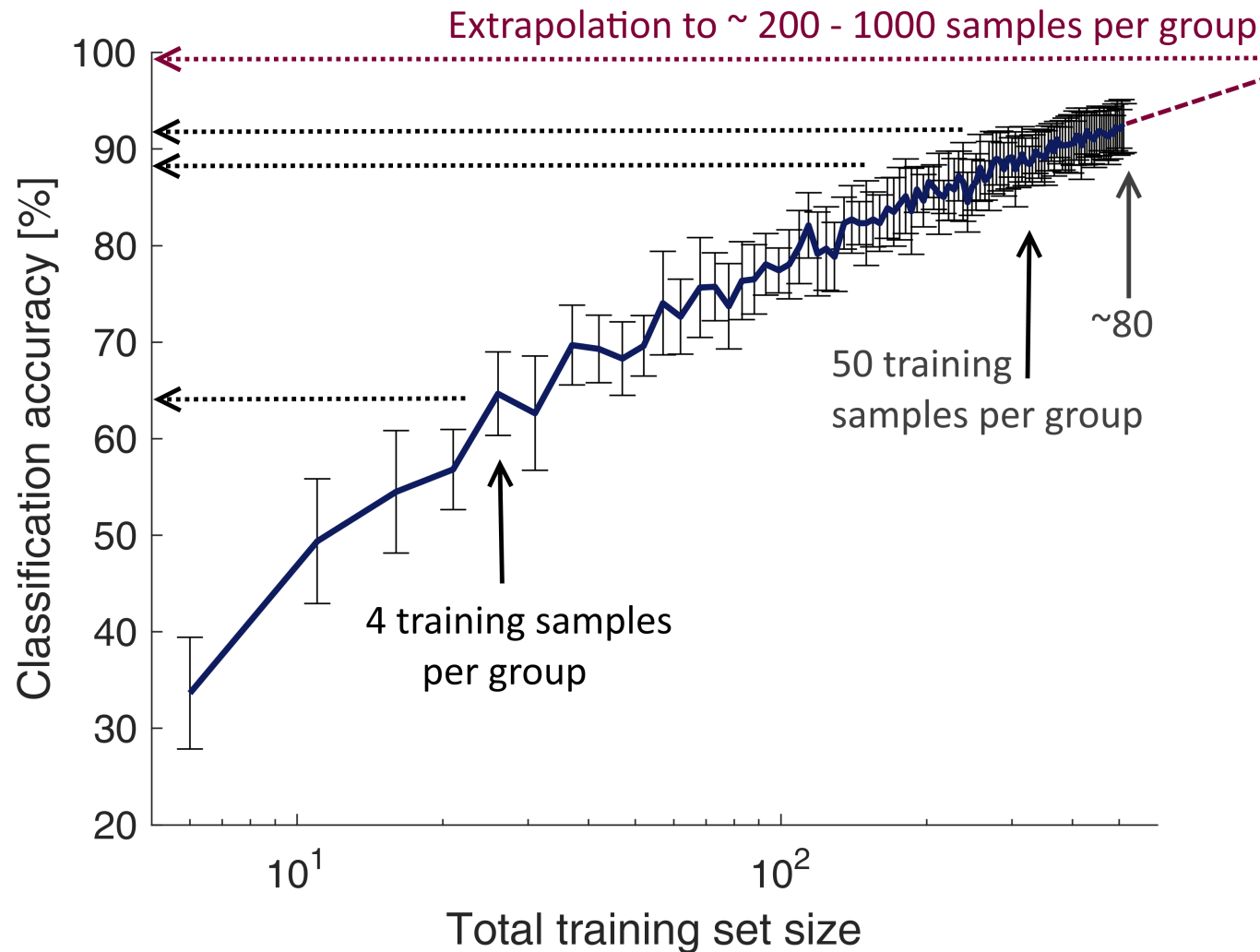
# Classification results

- Non-linear relationships between food physics and freshness  
→ mimics psychophysics of sensory integration
- Best predictions using
  - selected temporal
  - third-octave spectral features
  - from mechanics & acoustics



Quadratic SVM: 5-fold cross-validation, 20% test data, measured at 10 mm/s crushing

# Learning Curve

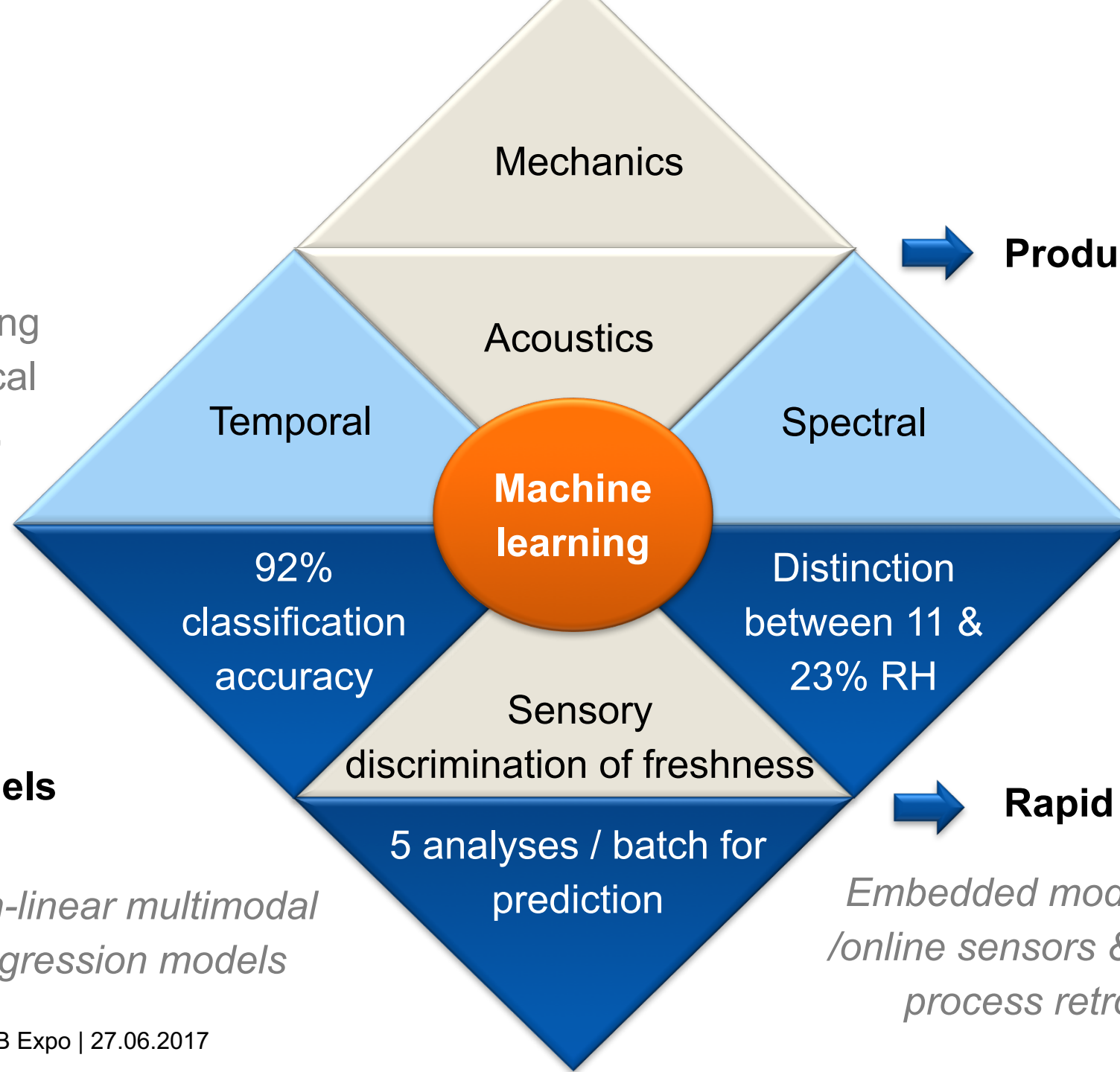


**High potential for improvement using more training data**

# Conclusion

## Impact factors:

loudness, pitch,  
homogeneity of crushing  
acoustical & mechanical  
patterns, toughness,  
brittleness



## Classification models

*Non-linear multimodal regression models*

*Embedded models with in-/online sensors & production process retrocontrol*

# Thanks



- Horst-Christan Langowski (institute access)
- Cornelia Stramm + Sven Sangerlaub + Verena Jost + Astrid Pant + Oliver Miesbauer + Andreas Strehlke (humidity control, packaging materials)
- Raffael Osen (TA access + extruder)

## TUM Diversity Laura Bassi-award



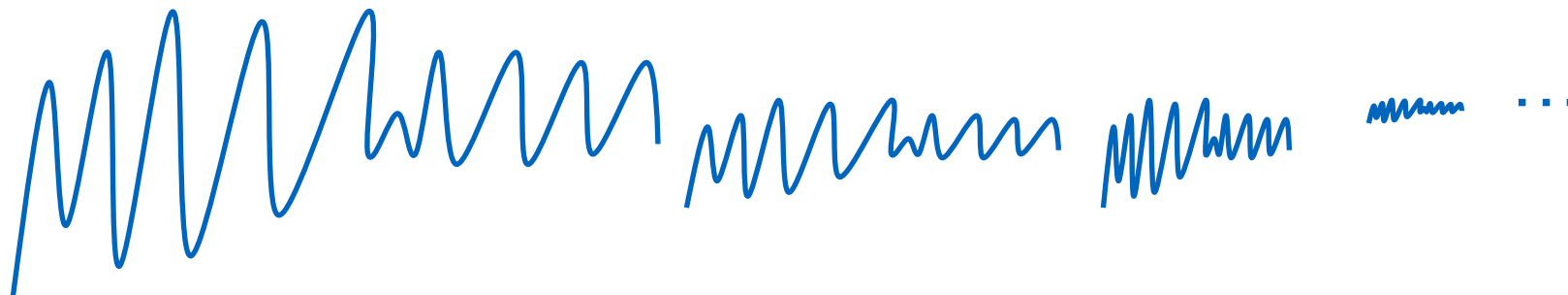
- Hubert Kollmannsberger (sensory)
- Carlotta Ziegltrum, Simone Maurer, Katja Jontes
- Many colleagues (advice, discussion, sensory panel)



Let's ride food science waves!

## Externals

- Henri Braun (EMD)
- Lisa Drobny (Winopal, TA-help)
- Michael Mudra, Uwe Beis (acoustics)



- Bourne, M. C. (2002). Correlation between physical measurements and sensory assessments of texture and viscosity. In M. C. Bourne (Ed.), *Food Texture and Viscosity: Concept and Measurement* (Vol. Food Science and Technology, pp. 294-323).
- Saeleaw, M., & Schleining, G. (2011). A review: Crispness in dry foods and quality measurements based on acoustic–mechanical destructive techniques. *Journal of Food Engineering*, 105(3), 387-399.
- Sanahuja, S., & Briesen, H. (2015). Dynamic Spectral Analysis of Jagged Mechanical Signatures of a Brittle Puffed Snack. *Journal of Texture Studies*, 46(3), 171-186.
- Van Vliet, T., & Primo-Martín, C. (2011). Interplay between product characteristics, oral physiology and texture perception of cellular brittle foods. *Journal of Texture Studies*, 42, 82–94.



# Automatic Classification of Crispiness: Integration of Mechanical and Acoustical Sensor Data

Solange Sanahuja<sup>a</sup>, Manuel Fédou, Heiko Briesen<sup>a</sup>

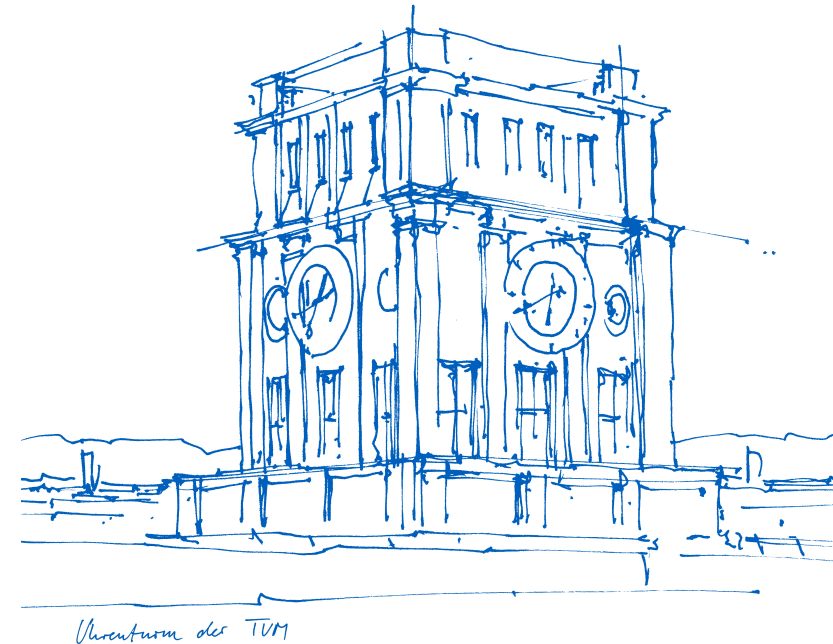
<sup>a</sup> Technical University Munich

Center for Life and Food Sciences Weihenstephan

Chair of Process Systems Engineering

MATLAB Expo

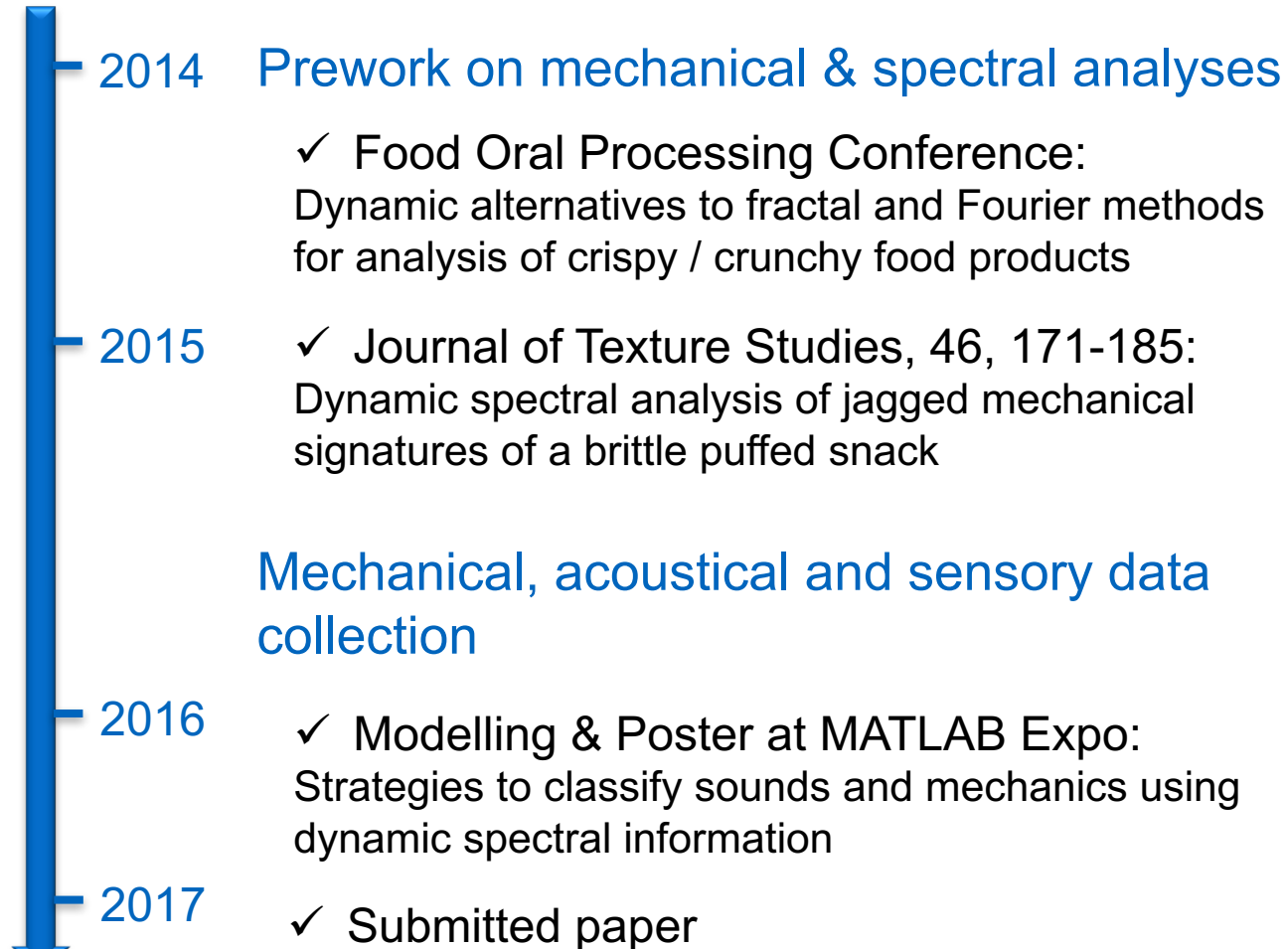
Munich, 27. June 2017



- Crispy project timeline
- Sensory freshness classes
- PCA representation
- Automatic classification strategy
- SVM results
- ANN results

# Crispy project

## Timeline



## Strategies to classify crispy sounds and mechanics using dynamic spectral information

Solange Sanahuja, Heiko Briesen

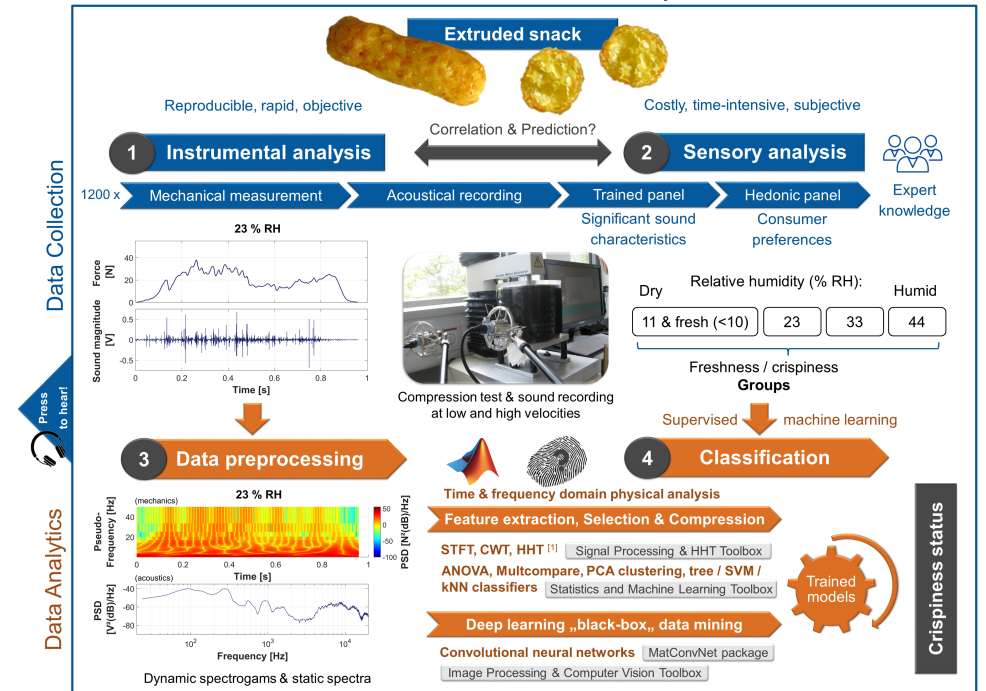
### Motivation

- Crispy food textures = stimulating, fresh, pleasant & have highest impact on consumer preference and quality evaluation [1]
- Food industry and research requirements for quality control and development
- **Crispiness evaluation = essential but causes persistent difficulties in practice, in particular for differentiating low-humidity crispness levels (10 to 20 % RH) [1]**

### Goals

- Optimizing crispy products = appropriately stiff and brittle during chewing & release pleasant rhythmic sounds of particular pitch and loudness avoiding use of sensory panels
- Improvement of available texture measurements and data analysis methods
- **Freshness levels classification from instrumental data corresponding to sensory crispiness grades, mimicking multisensory & temporal integration during oral breakdown**

### Multimodal texture characterization process



### Conclusion

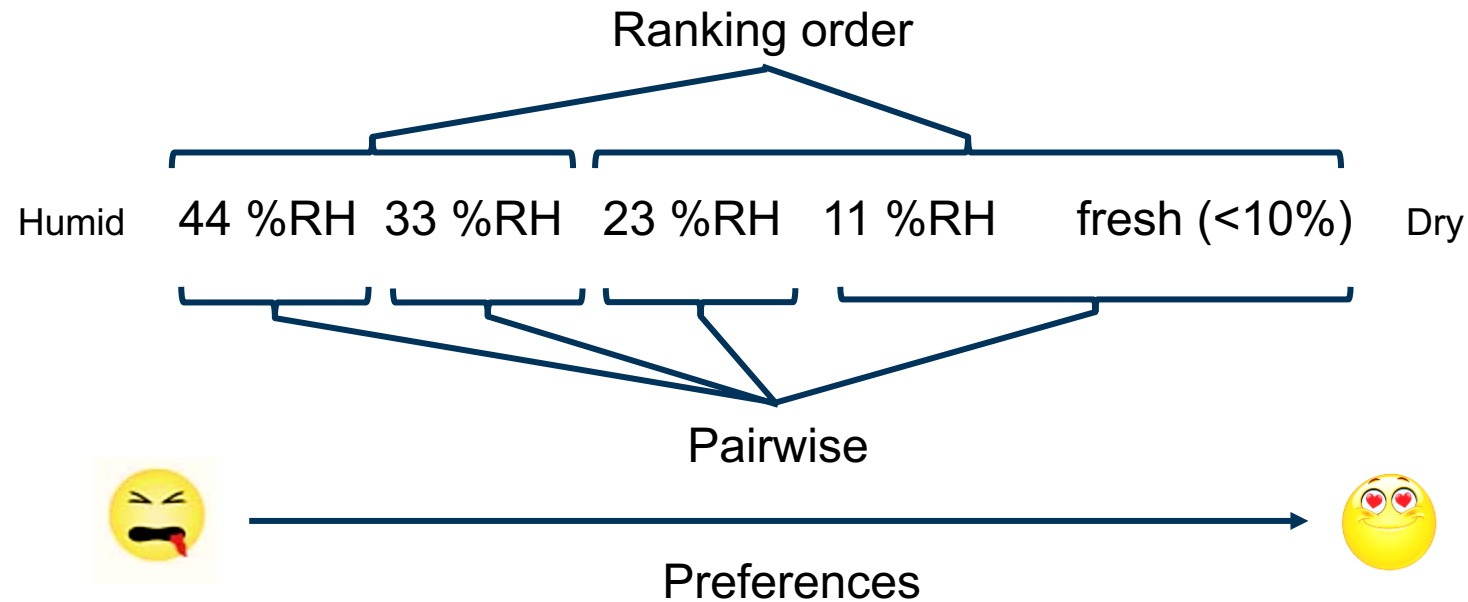
- **Classification needs more than simple mechanical features**
- Instrumental crushing sounds → perception of food freshness
- Dynamic spectral analysis → mathematical analytic description & display of whole complexity of foods' signature
- Multimodal classification → multitude of modern methods & optimum not straightforward, but improved accuracy

### Further Improvements

- Synchronized denoising & bone-conducted sounds using transfer function models of isolation box and human head

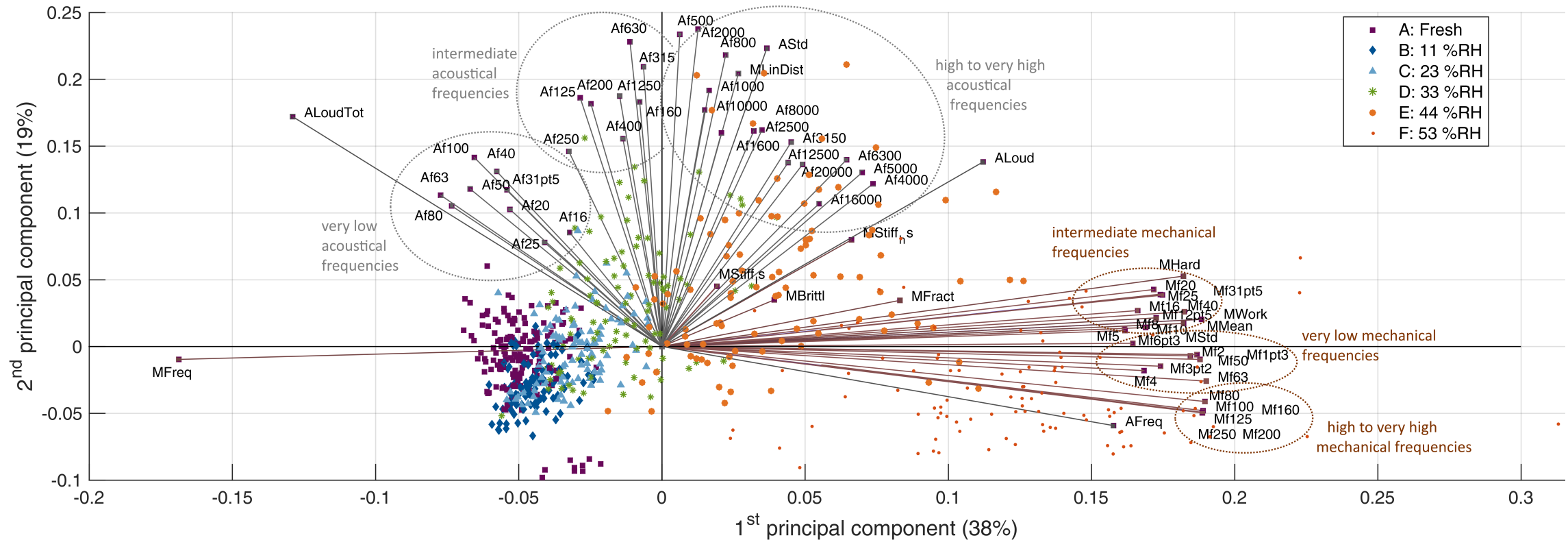
[1] Sanahuja, S. and Briesen, H. 2015. Dynamic spectral analysis of jagged mechanical signatures of a brittle puffed snack. Journal of Texture Studies, 46, 171-186.  
Technische Universität München, Process Systems Engineering, Gregor-Mendel-Strasse 4, 85354 Freising. <http://wzw.tum.de/svt>  
Contact: [solange.sanahuja@gmx.de](mailto:solange.sanahuja@gmx.de)

# Humans perceive & evaluate freshness of chips only based on instrumental texture analysis sound records



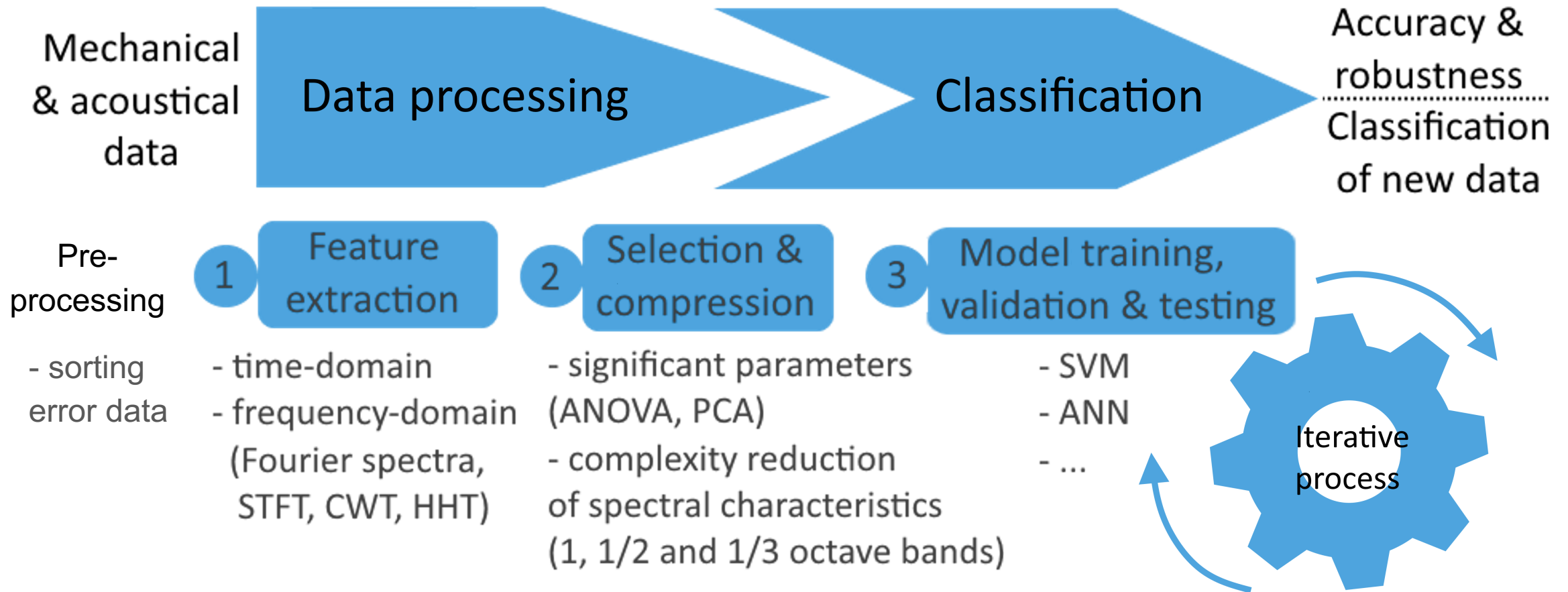
- Significant differences (Friedman-Test,  $\alpha = 0.01$ ) & ranking (Page-Test,  $\alpha < 0.05$ )
- 2 groups (LSD „Least Significant Difference“)

Linear relationships not sufficient for modelling psychophysics phenomenon of crispiness sensation





# Automatic classification strategy



# Classification models & results

## Modeling & evaluation

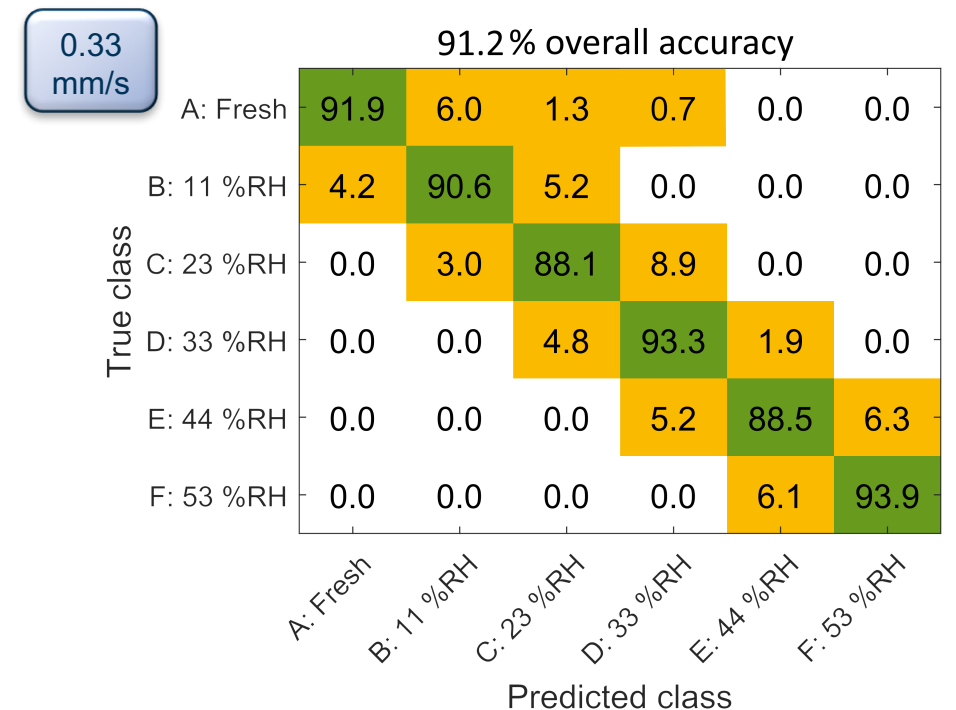
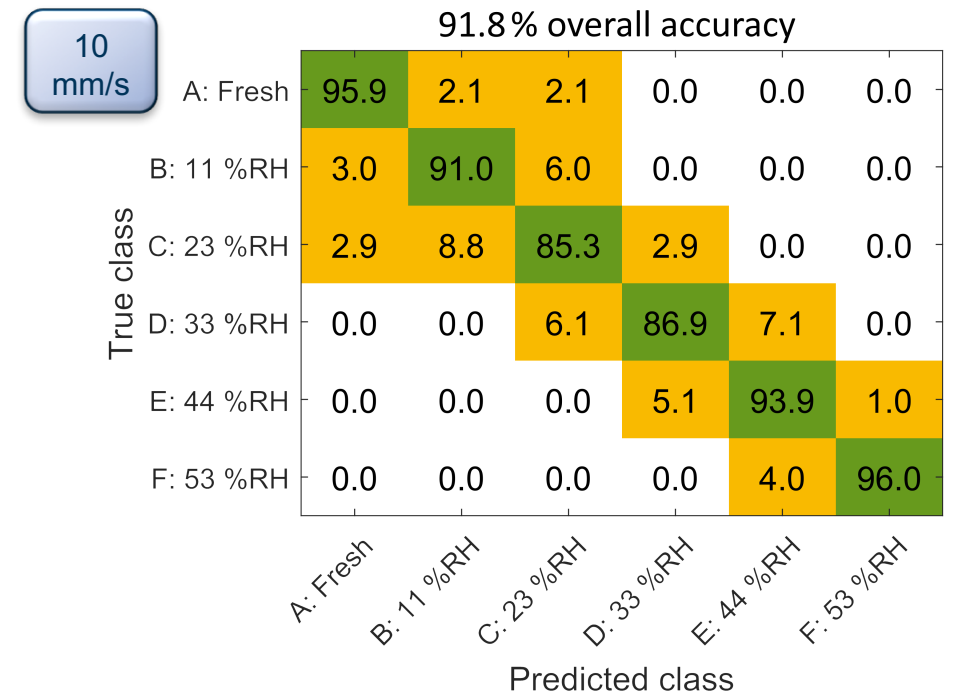
- 10 x 5-fold cross-validation: suited for small datasets  
→ average accuracy & variability estimation
- Training/validation with 80%, test with 20% random samples for each sub-model

## Model selection

- Psychophysics models: non-linear relationships between food physics and sensory sensation  
→ Best models: Quadratic SVM & ANN with disabled PCA preselection (linear)

## Results

- Best predictions using selected temporal + third-octave spectral features from mechanics & acoustics
- Crushing velocity: better overall accuracy at 10 mm/s but better distinction between 11 & 23% RH at 0.33 mm/s



# ANN results



## Confusion matrices

- one of the best ANN models
- 1 layer of 10 hidden neurons
- high-velocity selected temporal combined with third-octave spectral mechanical and acoustical features

Overall accuracies [%] on the test sets:

- (a) 1 layer of 10 hidden neurons;
- (b) 3 layers of 20 hidden neurons;
- (c) 1 layer of 250 hidden neurons.

| Domain           | Features          | Octave bands | Number of features | Test velocity | ANN model |          |          |
|------------------|-------------------|--------------|--------------------|---------------|-----------|----------|----------|
|                  |                   |              |                    |               | (a)       | (b)      | (c)      |
| Time & Frequency | Combined selected | 1/3          | 68                 | 10 mm/s       | 85.8±3.8  | 85.1±4.9 | 80.9±5.8 |

**Training Confusion Matrix**

| True class \ Predicted class | A: Fresh     | B: 11 %RH     | C: 23 %RH     | D: 33 %RH    | E: 44 %RH    | F: 53 %RH    | Accuracy      |
|------------------------------|--------------|---------------|---------------|--------------|--------------|--------------|---------------|
| A: Fresh                     | 96<br>22.9%  | 1<br>0.2%     | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%    | 0<br>0.0%    | 99.0%         |
| B: 11 %RH                    | 0<br>0.0%    | 71<br>16.9%   | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%    | 0<br>0.0%    | 100%          |
| C: 23 %RH                    | 0<br>0.0%    | 0<br>0.0%     | 63<br>15.0%   | 0<br>0.0%    | 0<br>0.0%    | 0<br>0.0%    | 100%          |
| D: 33 %RH                    | 0<br>0.0%    | 0<br>0.0%     | 1<br>0.2%     | 65<br>15.5%  | 0<br>0.0%    | 0<br>0.0%    | 98.5%         |
| E: 44 %RH                    | 0<br>0.0%    | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%    | 61<br>14.6%  | 0<br>0.0%    | 100%          |
| F: 53 %RH                    | 0<br>0.0%    | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%    | 61<br>14.6%  | 100%          |
| Overall                      | 100%<br>0.0% | 98.6%<br>1.4% | 98.4%<br>1.6% | 100%<br>0.0% | 100%<br>0.0% | 100%<br>0.0% | 99.5%<br>0.5% |

**Validation Confusion Matrix**

| True class \ Predicted class | A: Fresh      | B: 11 %RH    | C: 23 %RH      | D: 33 %RH     | E: 44 %RH      | F: 53 %RH     | Accuracy      |
|------------------------------|---------------|--------------|----------------|---------------|----------------|---------------|---------------|
| A: Fresh                     | 19<br>19.6%   | 0<br>0.0%    | 1<br>1.0%      | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 95.0%         |
| B: 11 %RH                    | 1<br>1.0%     | 9<br>9.3%    | 1<br>1.0%      | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 81.8%         |
| C: 23 %RH                    | 0<br>0.0%     | 0<br>0.0%    | 14<br>14.4%    | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 100%          |
| D: 33 %RH                    | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%      | 16<br>16.5%   | 1<br>1.0%      | 0<br>0.0%     | 94.1%         |
| E: 44 %RH                    | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%      | 1<br>1.0%     | 15<br>15.5%    | 1<br>1.0%     | 88.2%         |
| F: 53 %RH                    | 0<br>0.0%     | 0<br>0.0%    | 0<br>0.0%      | 0<br>0.0%     | 1<br>1.0%      | 17<br>17.5%   | 94.4%         |
| Overall                      | 95.0%<br>5.0% | 100%<br>0.0% | 87.5%<br>12.5% | 94.1%<br>5.9% | 88.2%<br>11.8% | 94.4%<br>5.6% | 92.8%<br>7.2% |

**Test Confusion Matrix**

| True class \ Predicted class | A: Fresh      | B: 11 %RH      | C: 23 %RH      | D: 33 %RH     | E: 44 %RH      | F: 53 %RH     | Accuracy       |
|------------------------------|---------------|----------------|----------------|---------------|----------------|---------------|----------------|
| A: Fresh                     | 27<br>20.9%   | 0<br>0.0%      | 2<br>1.6%      | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 93.1%          |
| B: 11 %RH                    | 1<br>0.8%     | 16<br>12.4%    | 0<br>0.0%      | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 94.1%          |
| C: 23 %RH                    | 1<br>0.8%     | 3<br>2.3%      | 17<br>13.2%    | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%     | 81.0%          |
| D: 33 %RH                    | 0<br>0.0%     | 0<br>0.0%      | 3<br>2.3%      | 16<br>12.4%   | 2<br>1.6%      | 0<br>0.0%     | 76.2%          |
| E: 44 %RH                    | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%      | 1<br>0.8%     | 18<br>14.0%    | 1<br>0.8%     | 90.0%          |
| F: 53 %RH                    | 0<br>0.0%     | 0<br>0.0%      | 0<br>0.0%      | 0<br>0.0%     | 0<br>0.0%      | 21<br>16.3%   | 100%           |
| Overall                      | 93.1%<br>6.9% | 84.2%<br>15.8% | 77.3%<br>22.7% | 94.1%<br>5.9% | 90.0%<br>10.0% | 95.5%<br>4.5% | 89.1%<br>10.9% |

**All Confusion Matrix**

| True class \ Predicted class | A: Fresh      | B: 11 %RH     | C: 23 %RH     | D: 33 %RH     | E: 44 %RH     | F: 53 %RH     | Accuracy      |
|------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| A: Fresh                     | 142<br>22.0%  | 1<br>0.2%     | 3<br>0.5%     | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 97.3%         |
| B: 11 %RH                    | 2<br>0.3%     | 96<br>14.9%   | 1<br>0.2%     | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 97.0%         |
| C: 23 %RH                    | 1<br>0.2%     | 3<br>0.5%     | 94<br>14.6%   | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 95.9%         |
| D: 33 %RH                    | 0<br>0.0%     | 0<br>0.0%     | 4<br>0.6%     | 97<br>15.0%   | 3<br>0.5%     | 0<br>0.0%     | 93.3%         |
| E: 44 %RH                    | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 2<br>0.3%     | 94<br>14.6%   | 2<br>0.3%     | 95.9%         |
| F: 53 %RH                    | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 0<br>0.0%     | 1<br>0.2%     | 99<br>15.3%   | 99.0%         |
| Overall                      | 97.9%<br>2.1% | 96.0%<br>4.0% | 92.2%<br>7.8% | 98.0%<br>2.0% | 95.9%<br>4.1% | 98.0%<br>2.0% | 96.4%<br>3.6% |