

KRAK

OP ZOEK NAAR DE PERFECTE
CRUNCH

JAN 2025–
DEC 2026

TETRA PROJECT

BEPALING VAN DE PRODUCTKWALITEIT VAN VOEDING
AAN DE HAND VAN GEAVANCEERDE GELUIDSANALYSE



MET DE STEUN VAN

AGENTSCHAP
INNOVEREN &
ONDERNEMEN



Vlaanderen
is ondernemen



FLANDERS'
FOOD

EEN SAMENWERKING TUSSEN

KU LEUVEN

hogeschool
vives

Michaël Verlinden

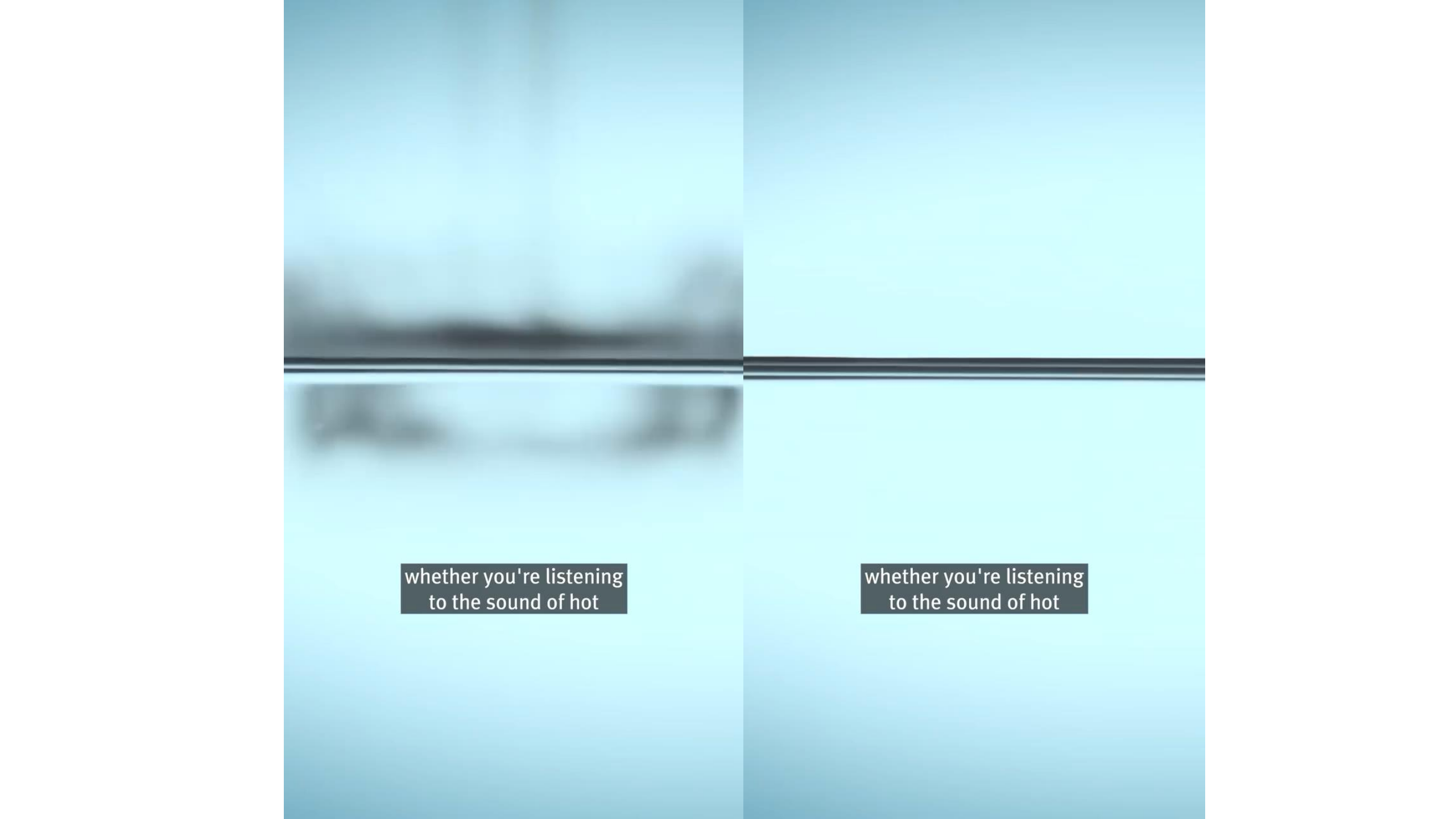
michael.verlinden@vives.be

www.project-krak.be

Woensdag 30 september 2026
Intrafood Kortrijk







whether you're listening
to the sound of hot

whether you're listening
to the sound of hot

EATING WITH OUR EARS

The science behind food crunchiness

Inhoud

1. Voorstelling Project KRAK
2. Hoe kunnen we krokantheid meetbaar maken?
 - Inzicht in metingen
 - Case studies

www.project-krak.be

KRAK

OP ZOEK NAAR DE PERFECTE
CRUNCH

MET DE STEUN VAN

AGENTSCHAP
INNOVEREN &
ONDERNEMEN

Vlaanderen
in innovatie

FF
FLANDERS
FOOD

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Huidige uitdagingen in voedingsbedrijven

- ☐ Sterke afhankelijkheid van sensorische analyses
- ☐ Textuur moeilijk te kwantificeren/objectiveren
- ☐ AI en datagedreven modellen nog weinig geïntegreerd in QC en R&D



Analyse van **geluid** tijdens gecontroleerd breken van voedingsproducten

=

De enige objectieve manier om **krokantheids**gerelateerde parameters te bepalen



The logo features the word "KRAK" in a large, bold, black sans-serif font. It is positioned over a light orange, irregular, jagged shape that resembles a splash or a stylized sound wave. Below "KRAK", the words "OP ZOEK NAAR DE PERFECTE CRUNCH" are written in a smaller, black, all-caps sans-serif font, centered horizontally.

KRAK

OP ZOEK NAAR DE PERFECTE
CRUNCH

KRAK heeft als doel **geavanceerde akoestische methoden** te ontwikkelen en te valideren voor de **objectieve** meting van **krokantheid, knapperigheid of snap** in voedingsproducten. Door textuurmetingen te combineren met akoestiek, signaalverwerking en AI ondersteunt het project de voedingsindustrie bij het verbeteren van **productkwaliteit, procescontrole en sensorische voorspelling**.



Food
Innovation
Park

A

CONSORTIUM OVERVIEW

KRAK
OP ZOEK NAAR DE PERFECTE
CRUNCH
JAN 2025–
DEC 2026

STEERING COMMITTEE



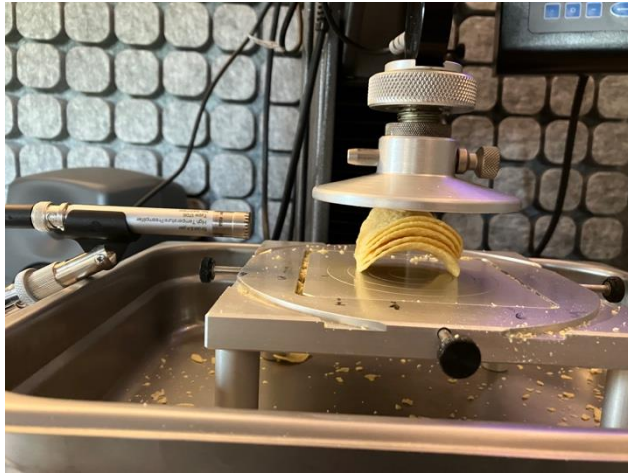
PARTNERS



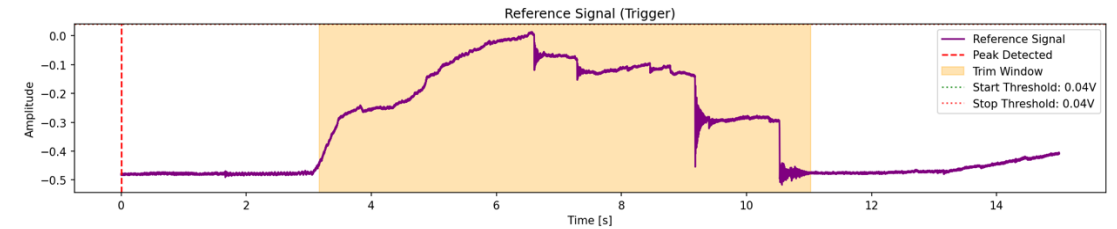
FEDERATIONS & RESEARCH



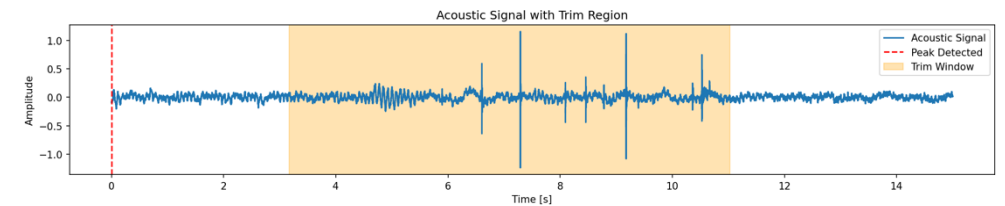
How do we measure?



Loadcell



Microphones

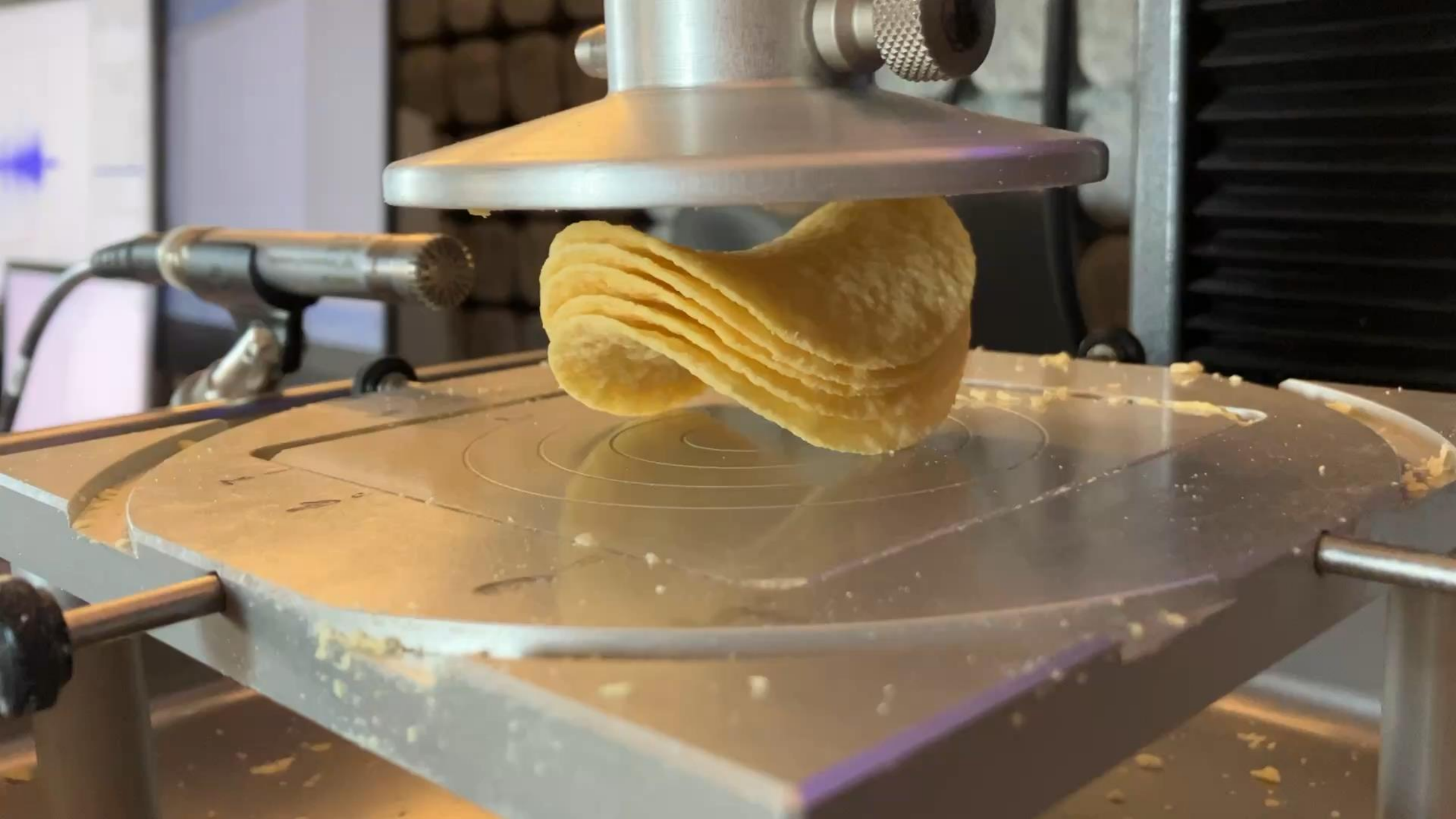


1

Controlled Breaking

2

Collect Data



Measurement Pipeline

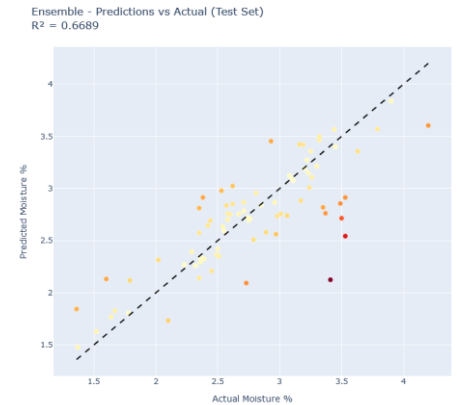
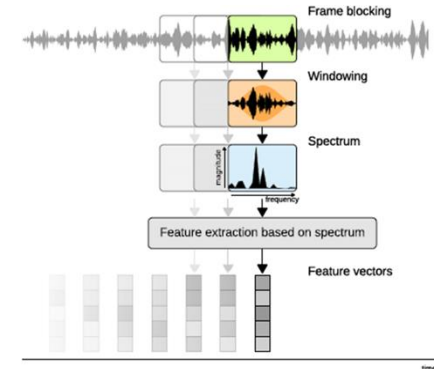
KRAK
DIP ZUERICH, UNIVERSITÄT
CRUNCH

JAN 2025-
DEC 2026



Method
Optimization

Probe
Speed
Distance
Orientation
Microphone
Sensor



Audio Selection
-
Region of
Interest (ROI)

Audio Analysis
&
Feature
selection

Model Selection
Model Training
&
Validation

correlation & validation

Sensory Data Collection



-1-
Chips



-3-
Cookies



-5-
Chocolate



-2-
French
Fries



-4-
Bread
(Baguette)



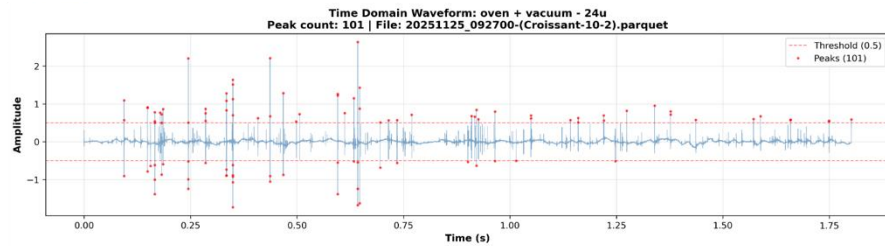
-6-
Breaded &
Battered
products



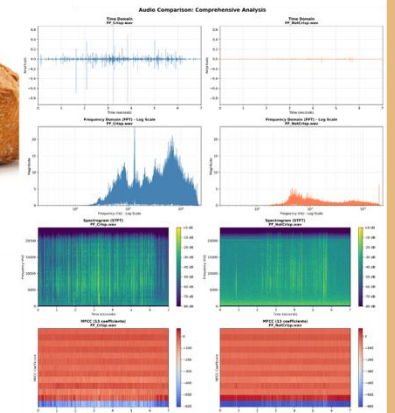
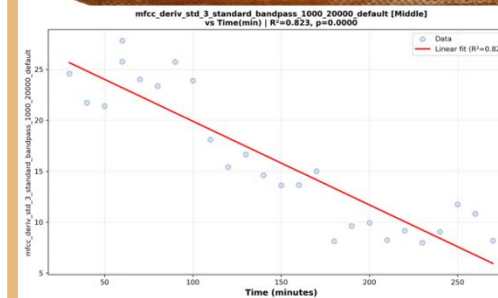
Different approaches



Preprocess audio
One Feature: number of peaks
(time domain)



Preprocess Audio
Feature extraction & selection
Model Training

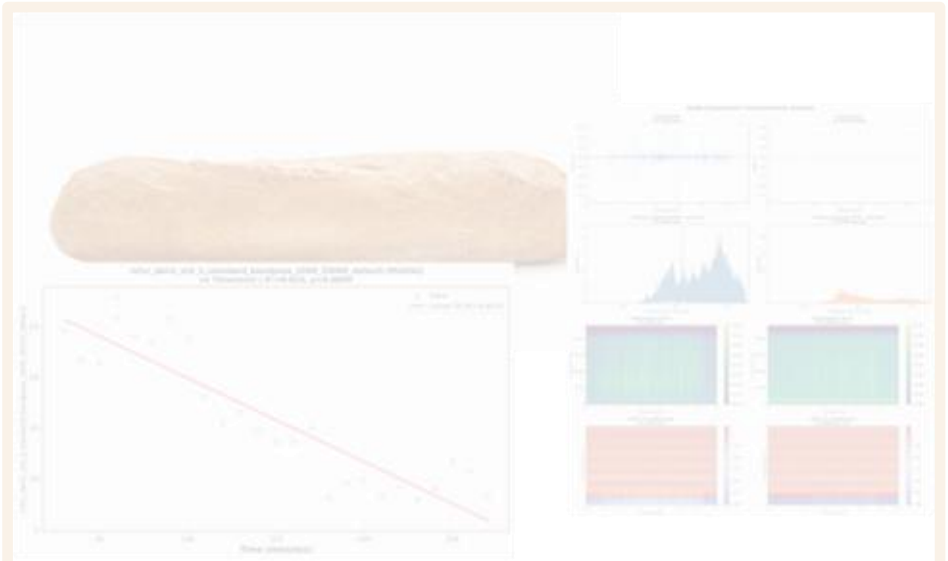
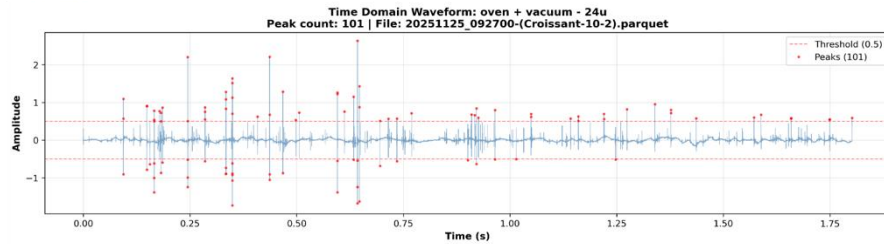


Preprocess audio
Selection best feature for linear correlation
for time, frequency and more complex features

Different approaches



Preprocess audio
One Feature: number of peaks
(time domain)



Preprocess audio
Selection best feature for linear correlation
for time, frequency and more complex features



Preprocess Audio
Feature extraction & selection
Model Training





Bake Samples Overview (sorted by a*: green → red)

061125 croissants1 middenstand oven-184.tif
a*=17.25



061125 croissants2 middenstand oven +vac-190.tif
a*=17.30



061125 croissants2 middenstand oven +vac191.tif
a*=17.45



061125 croissants2 lichtste stand oven.tif
a*=17.55



061125 croissants2 middenstand oven-187.tif
a*=17.73



061125 croissants1 lichtste stand oven.tif
a*=17.98



061125 croissants2 tweede lichtste stand oven174.tif
a*=18.30



061125 croissants1 middenstan oven + vac188.tif
a*=18.37



061125 croissants3 tweede lichtste stand oven180.tif
a*=18.42



061125 croissants1 tweede lichtste stand oven172.tif
a*=18.68

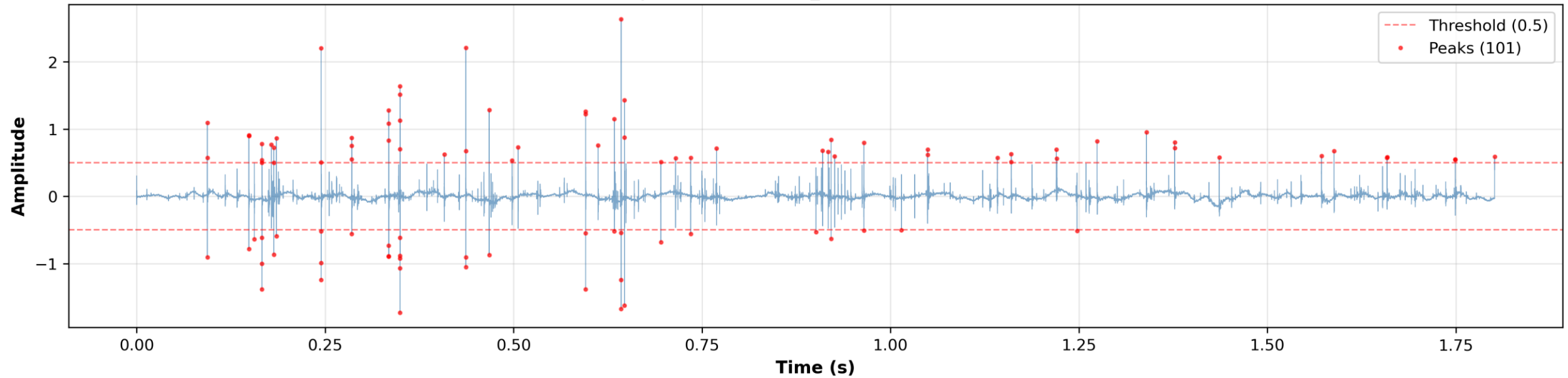


061125 croissants3 lichtste stand oven_.tif
a*=18.88



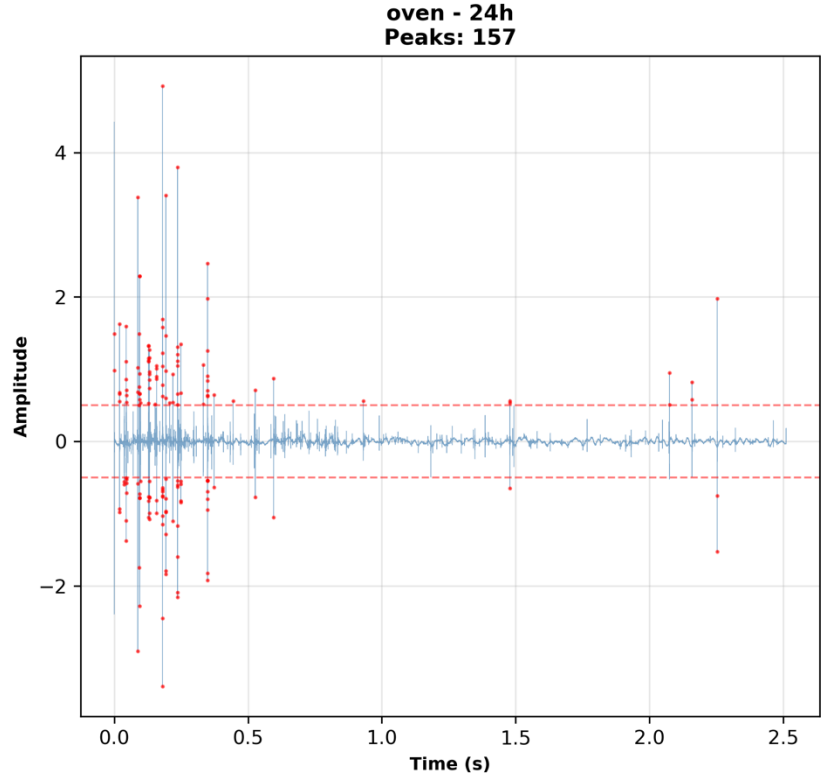
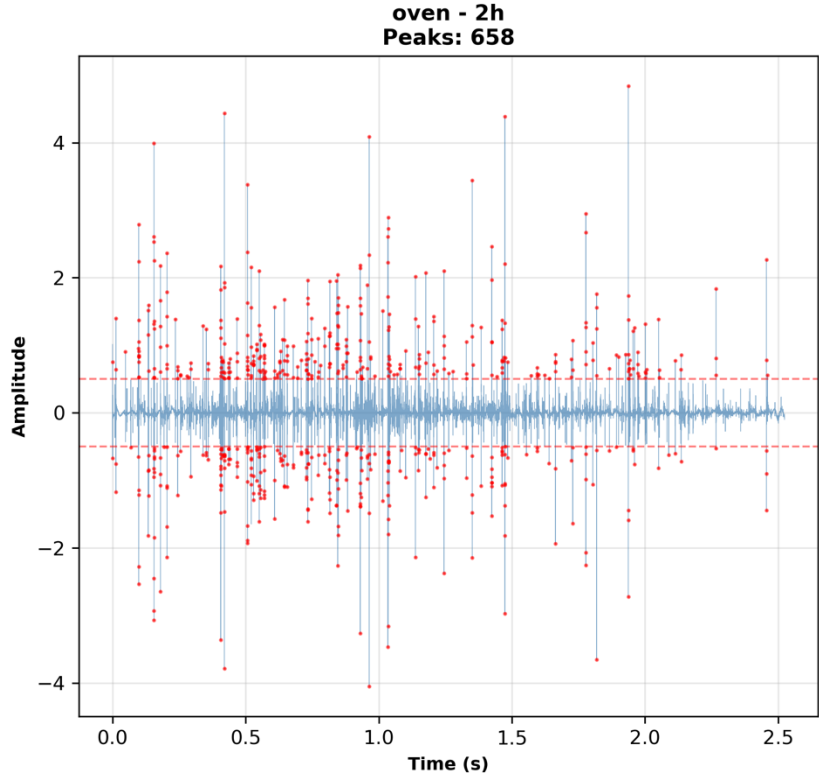
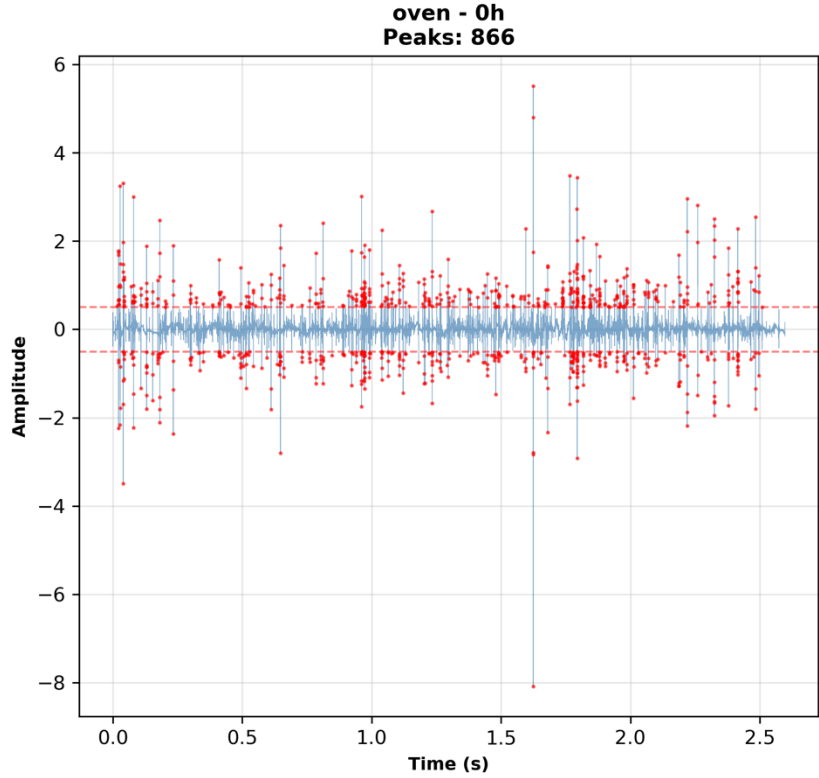


Time Domain Waveform: oven + vacuum - 24u
Peak count: 101 | File: 20251125_092700-(Croissant-10-2).parquet



Preprocessing: Highpass @ 1000kHz

Croissant Waveform Comparison Grid
Time Domain Analysis Across Processes and Storage Times





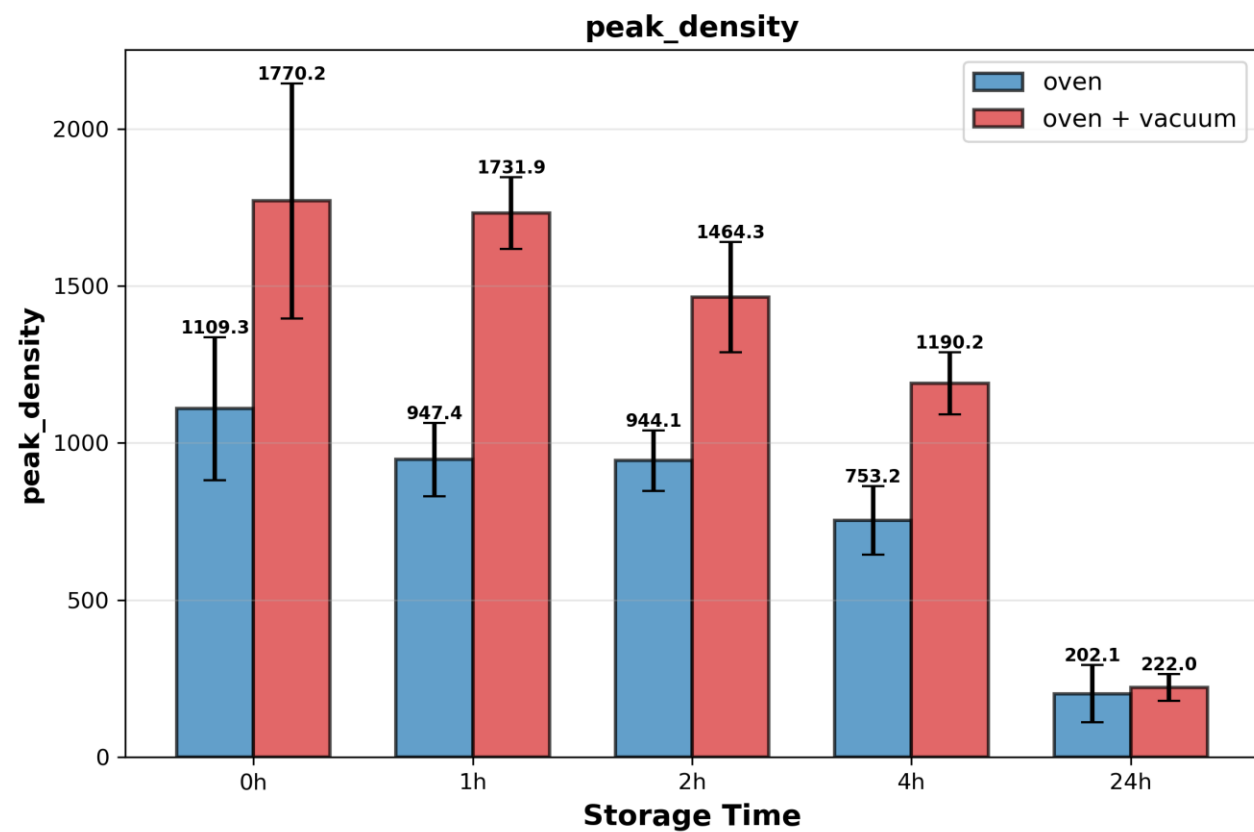
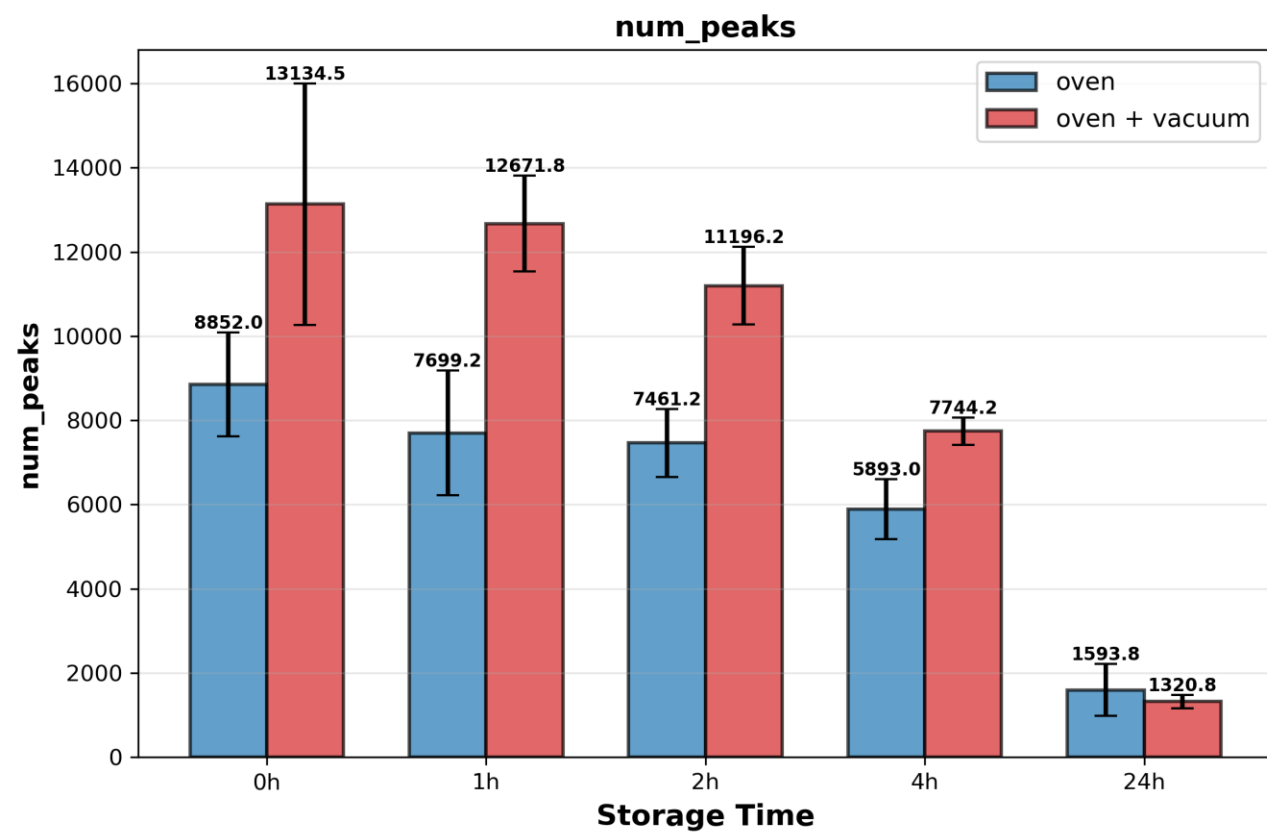
Oven - 30 min after baking



Oven – 24h after baking

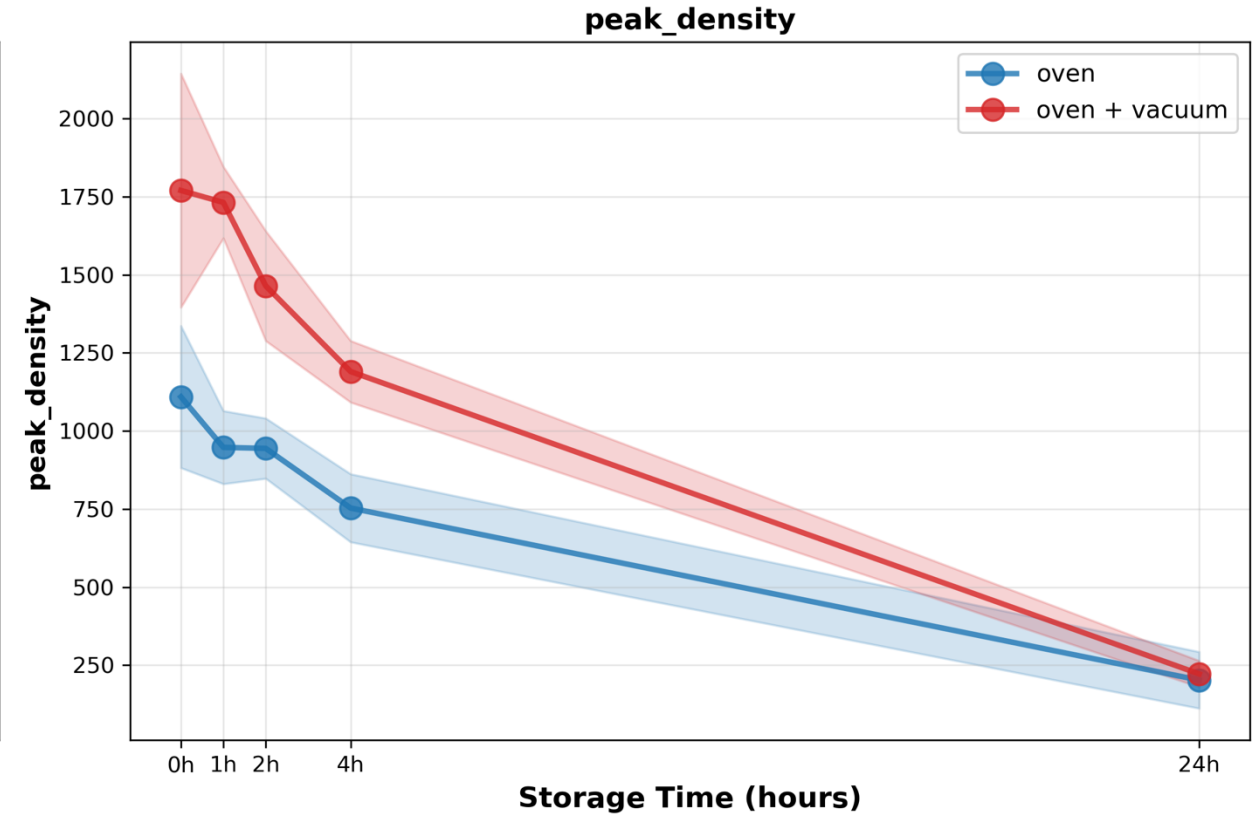
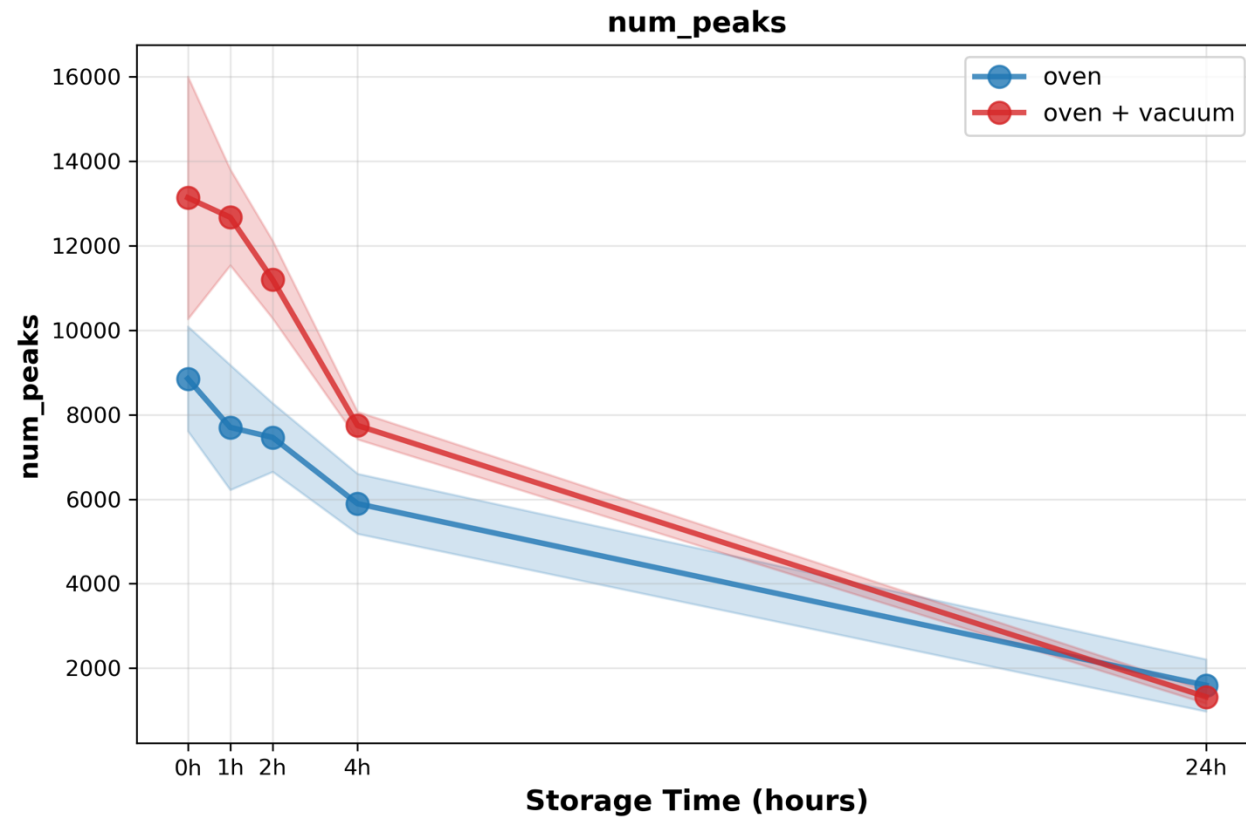


COMBINED COMPARISON OVEN vs OVEN + VACUUM





CRISPINESS DEGRADATION TIMELINE OVEN vs OVEN + VACUUM

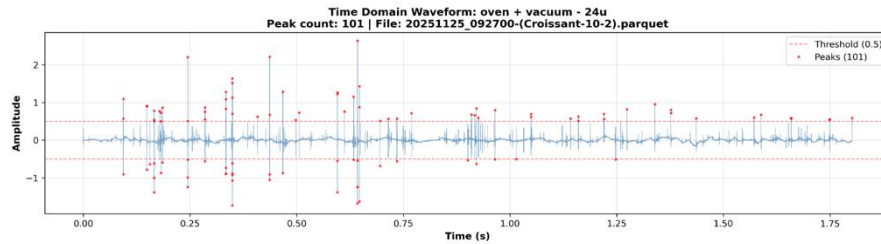


t

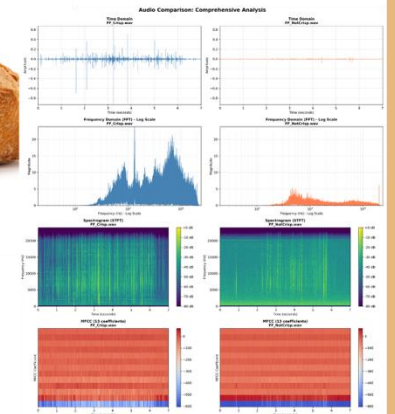
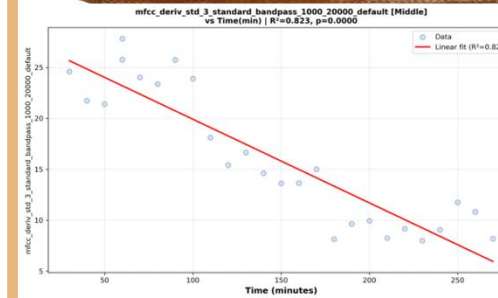
Different approaches



Preprocess audio
One Feature: number of peaks
(time domain)

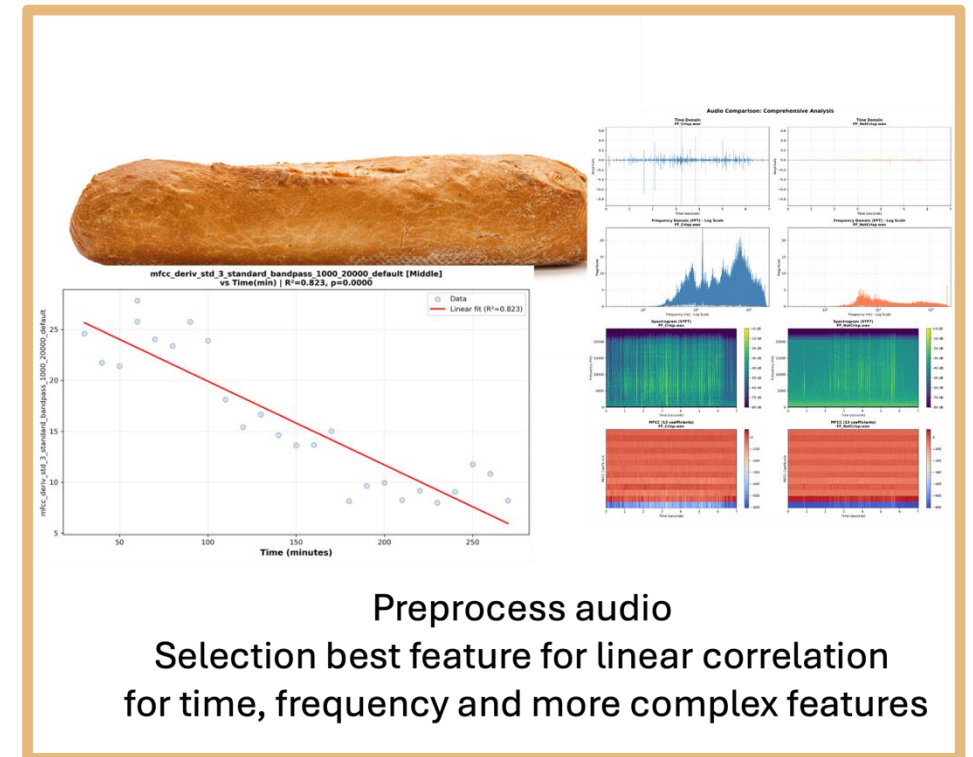
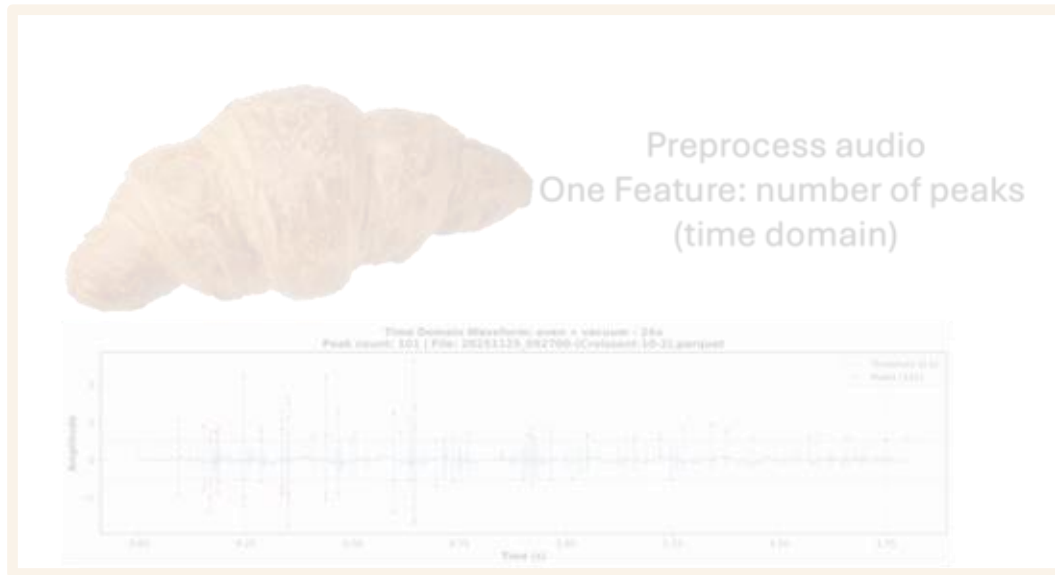


Preprocess Audio
Feature extraction & selection
Model Training



Preprocess audio
Selection best feature for linear correlation
for time, frequency and more complex features

Different approaches







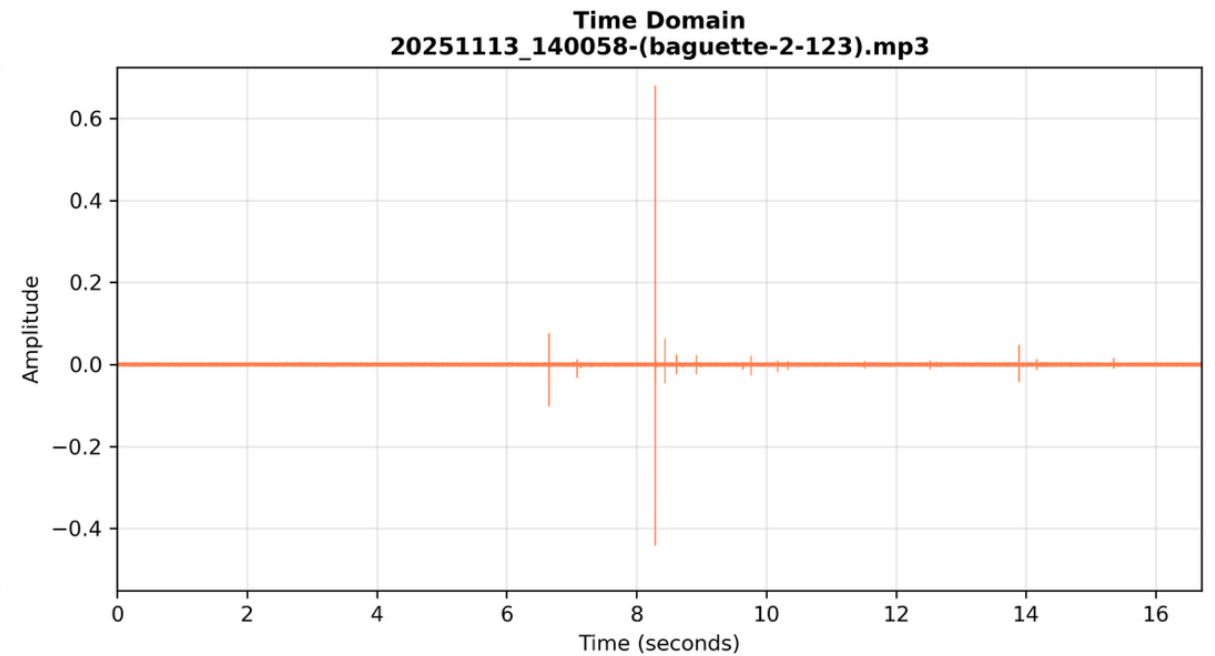
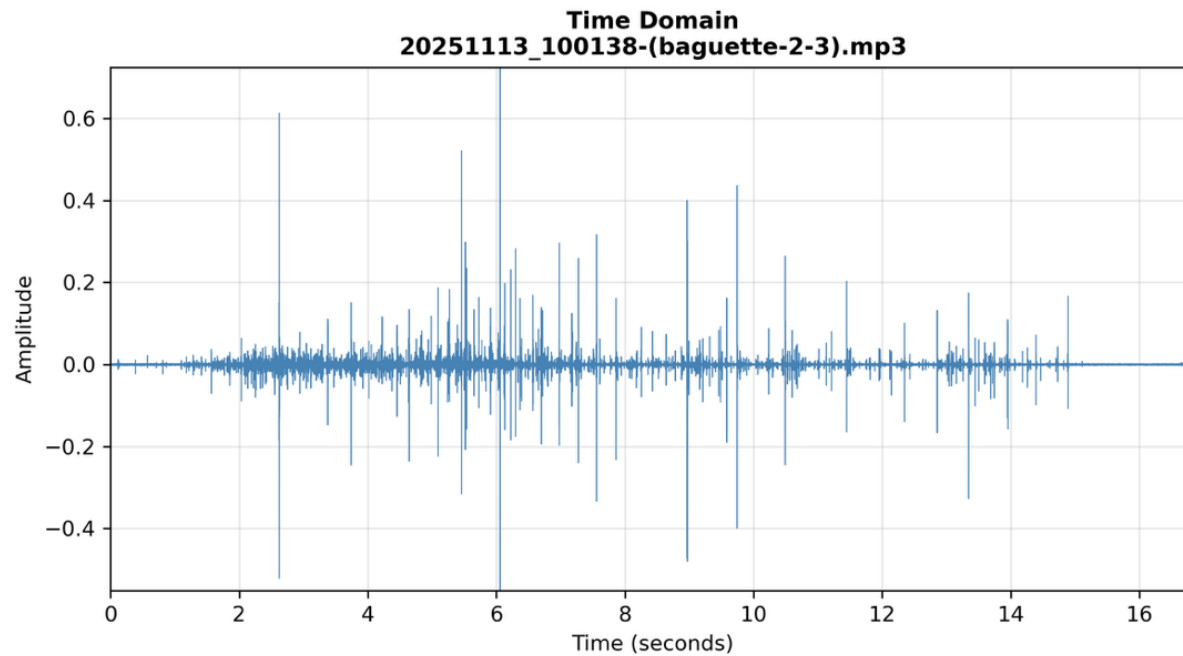


Fresh baked



After 5 hours

Audio Comparison: Comprehensive Analysis





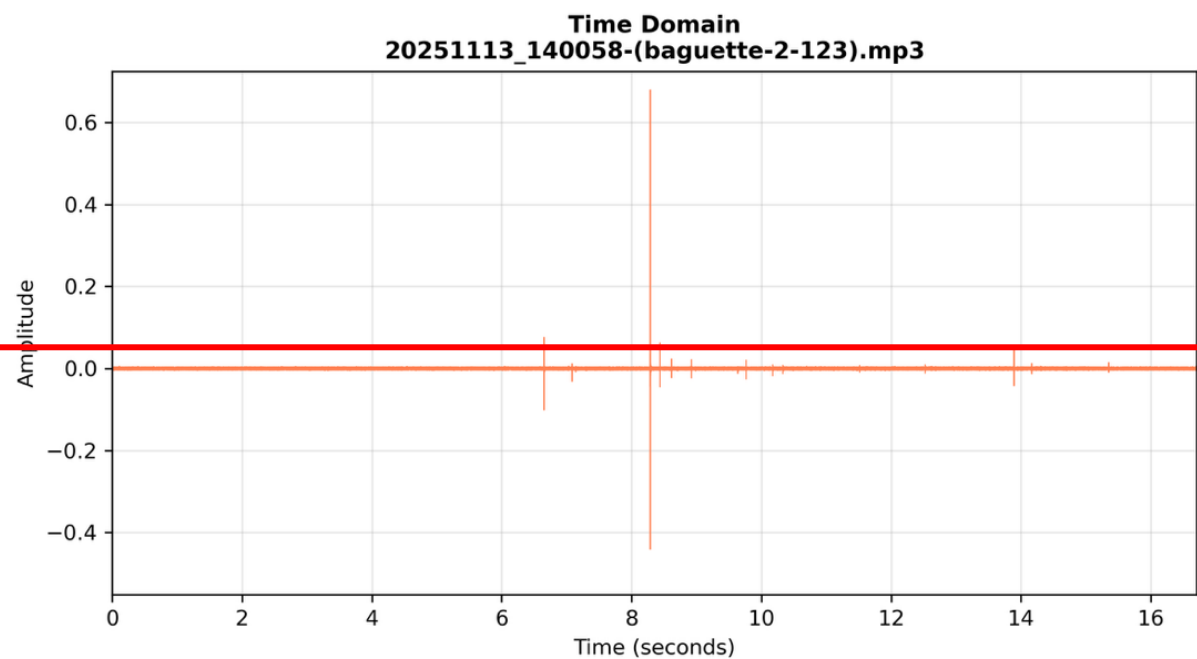
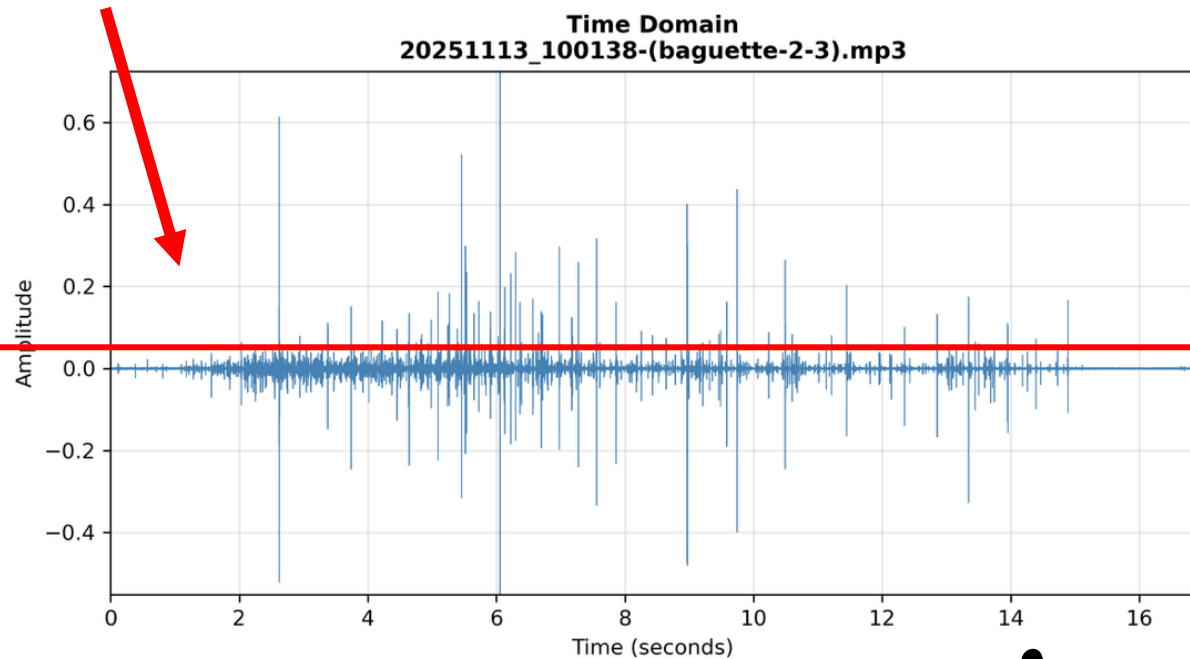
Fresh baked



After 5 hours

Threshold

Audio Comparison: Comprehensive Analysis



Peak counts ~ crispiness



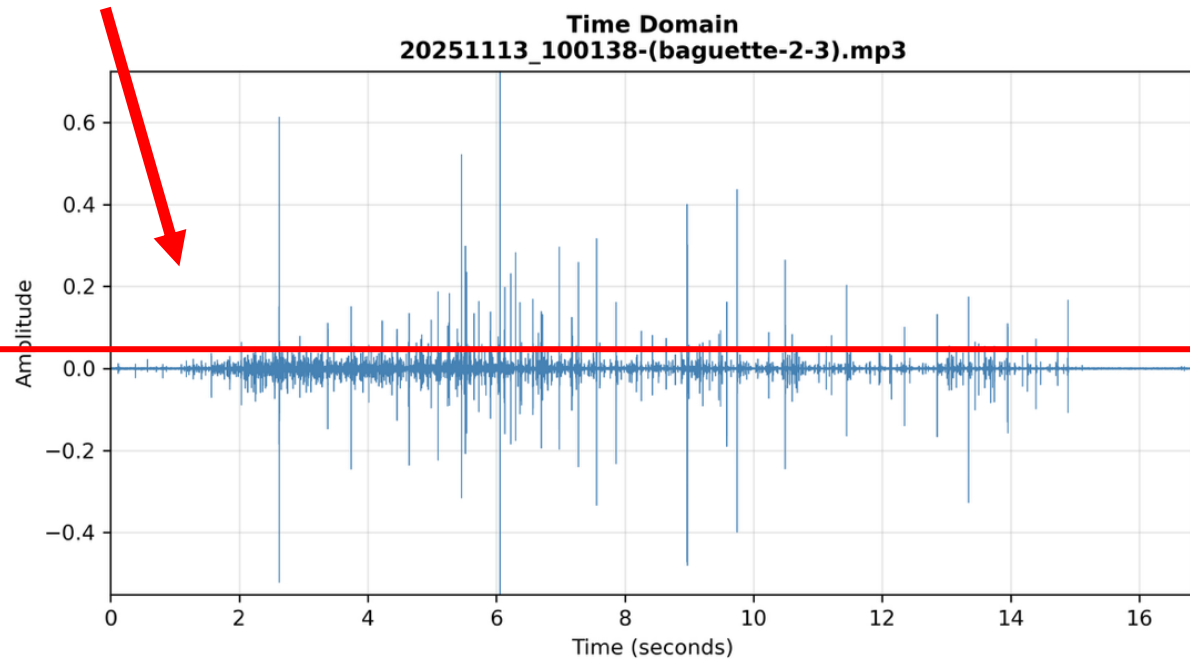
Fresh baked



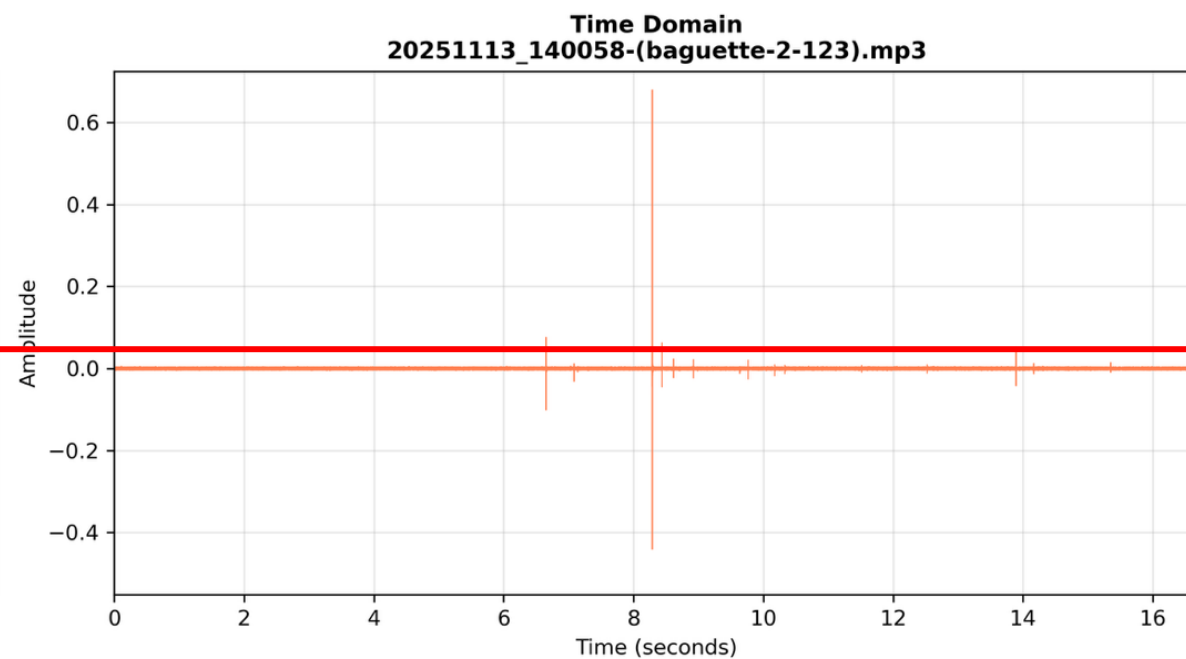
After 5 hours

Threshold

Audio Comparison: Comprehensive Analysis

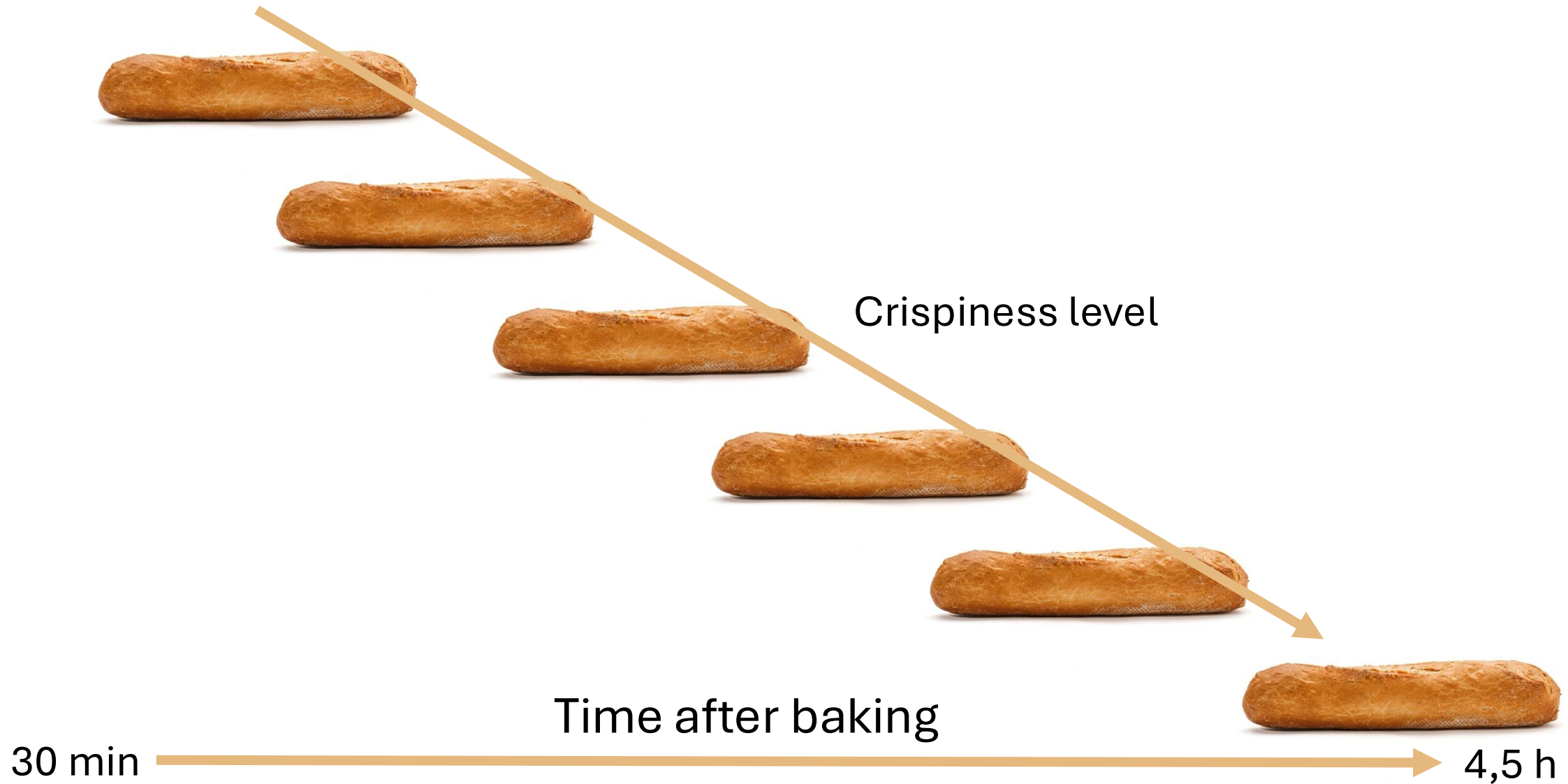


Crisp Bread

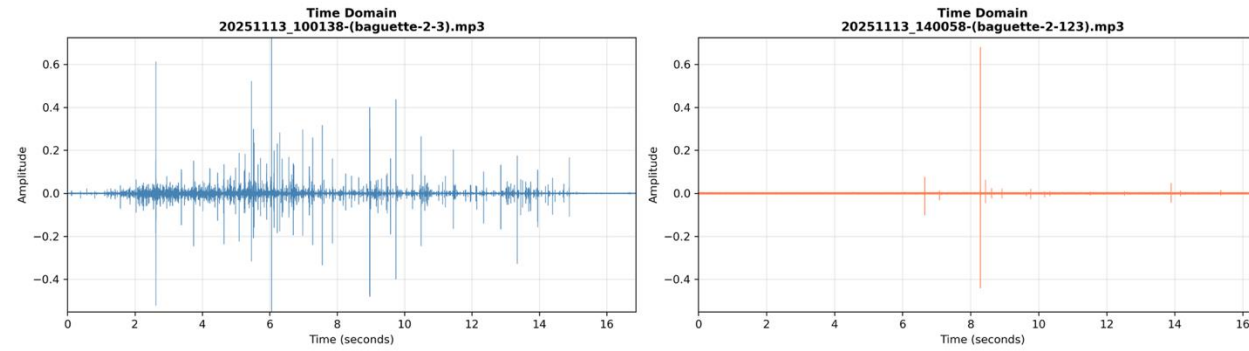


Not at all crisp

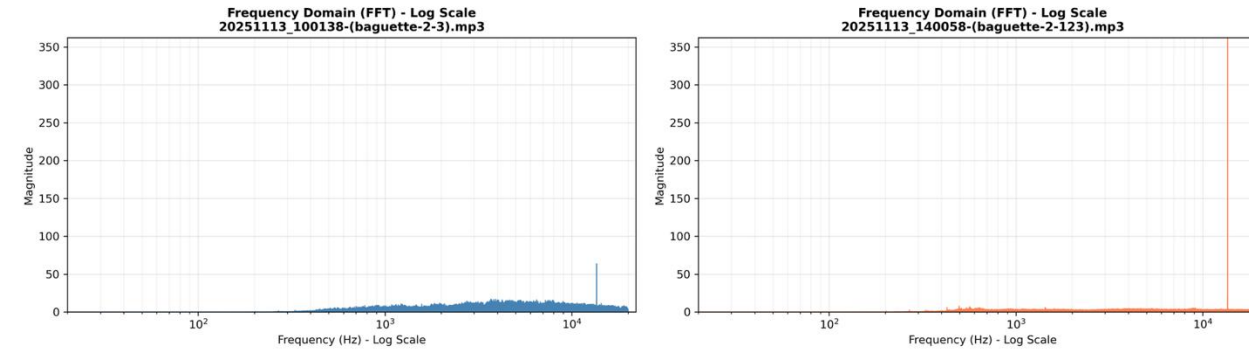
Crispiness measurement over time



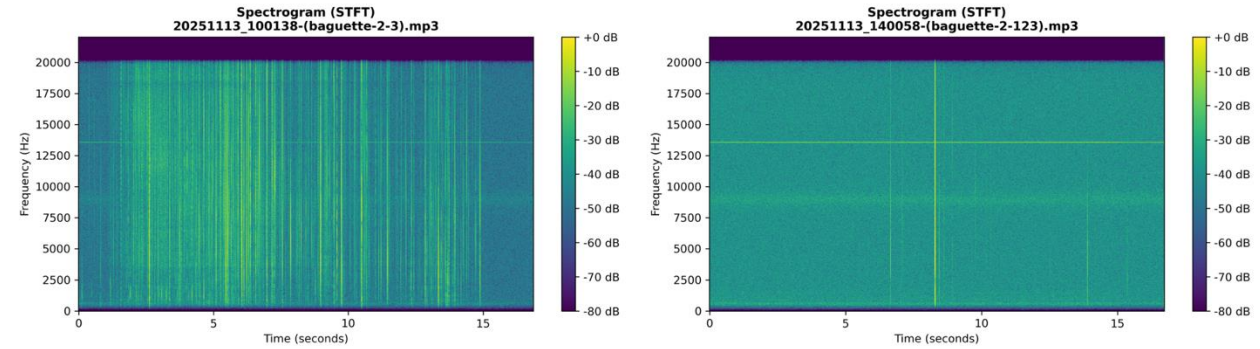
Time Domain



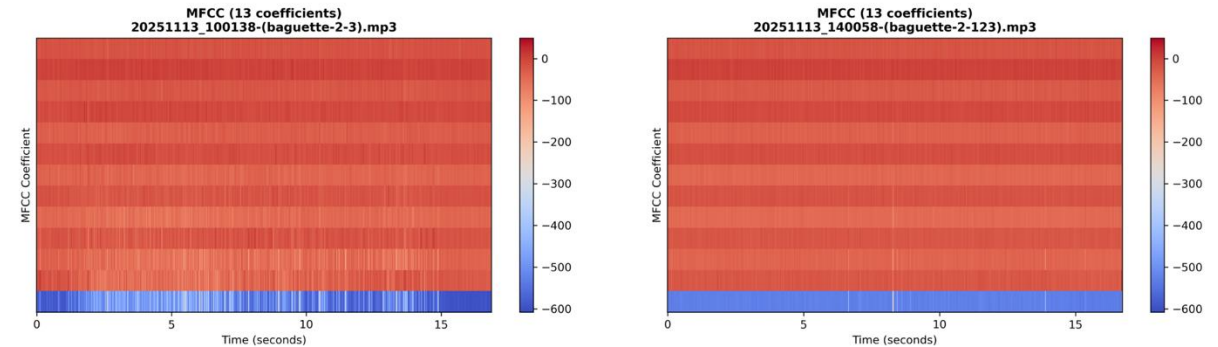
Frequency domain



Spectrogram



Mel Spectrogram



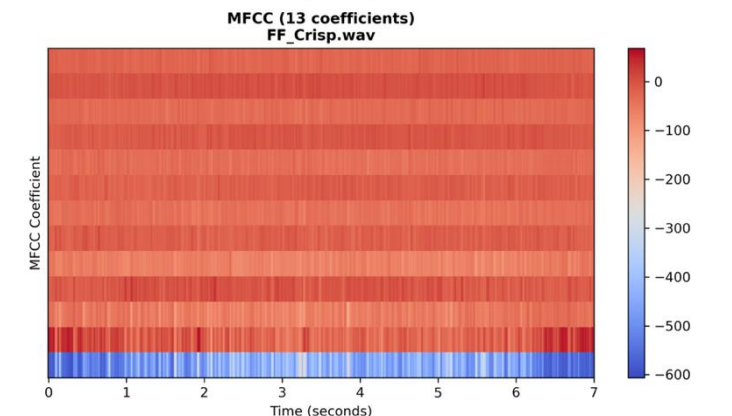
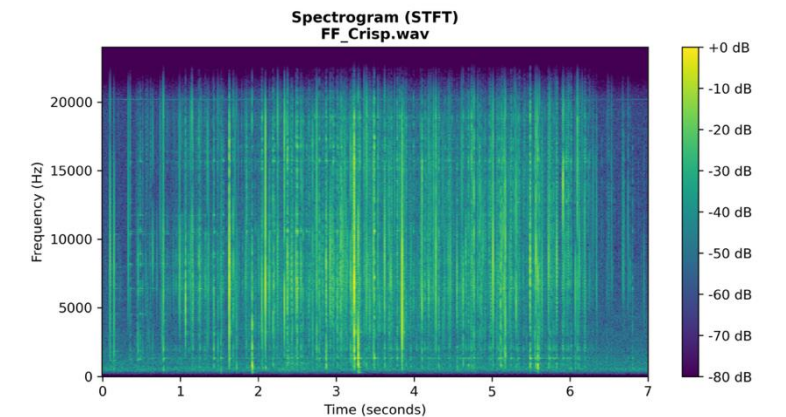
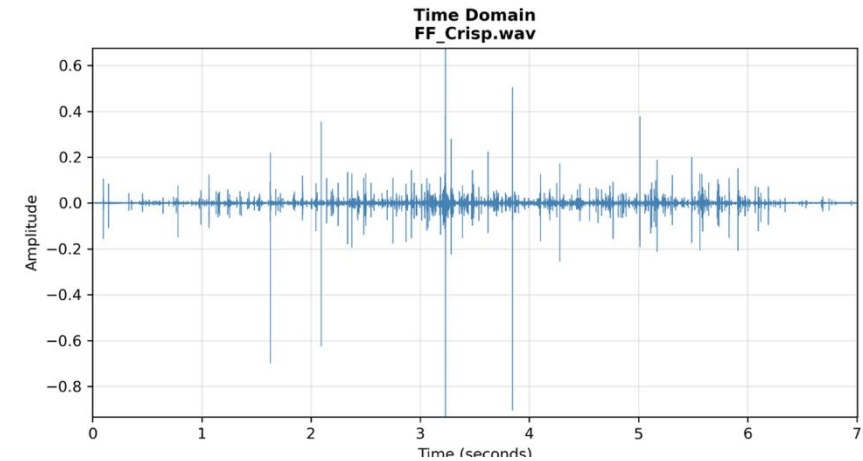
Welke audio-eigenschappen (features) ~ krokantheid?

Features voorbeelden

- **Tijdsdomein**
 - Energie
 - Pieken: /s , piekhoogte, scherpte van pieken
- **Frequentiedomein**
 - Energieverdeling over frequentiespectrum
 - Harmonischen aanwezig?
- **Mel frequentiedomein (MFCC)**
 - Karakteriseren de klank → getallen
- **Chroma features**
- **Impact & crack geralateerde features**
- **Spraak features**



Audio Comparison: Coi





Time domain Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
RMS	0.0040	0.0017
Zero-crossing rate	0.4521	0.5103
Peak count	1346	32
Max amplitude	0.5686	0.5375
Std amplitude	0.0040	0.0017



Time domain Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
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Time domain Features

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Frequency domain Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
Spectral centroid (Hz)	9842.3936	10014.4301
Bandwidth (Hz)	5389.2187	5586.1908
Rolloff (Hz)	16298.7230	16654.6017
Flatness	0.1865	0.1101
Dominant freq (Hz)	13569.3493	13569.3735



Frequency domain Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
Spectral centroid (Hz)	9842.3936	10014.4301
Bandwidth (Hz)	5389.2187	5586.1908
Rolloff (Hz)	16298.7230	16654.6017
Flatness	0.1865	0.1101
Dominant freq (Hz)	13569.3493	13569.3735



Chroma features Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
Chroma 1	0.7730	0.4692
Chroma 2	0.8150	0.5590
Chroma 3	0.8002	0.5562
Chroma 4	0.7555	0.4844
Chroma 5	0.6939	0.4353



Chroma features Features

Feature	20251113_100138-(baguette-2-12)	20251113_140058-(baguette-2-12)
Chroma 1	0.7730	0.4692
Chroma 2	0.8150	0.5590
Chroma 3	0.8002	0.5562
Chroma 4	0.7555	0.4844
Chroma 5	0.6939	0.4353

From 5 to features



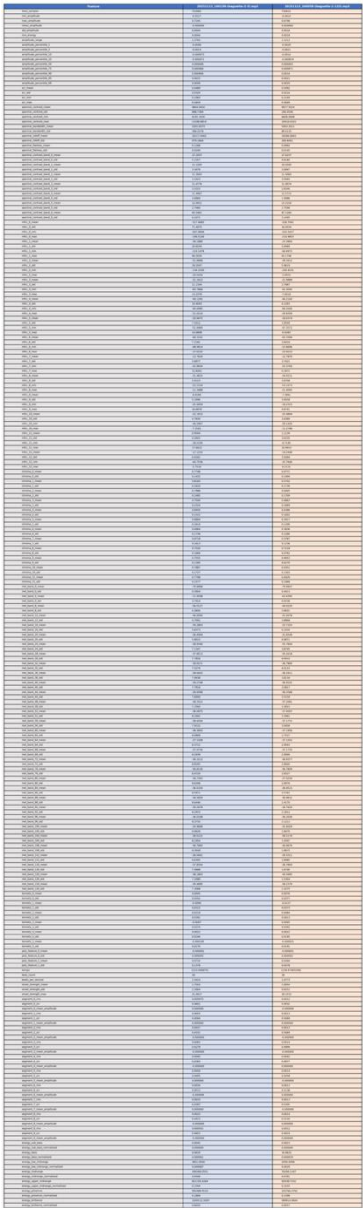
Basis Audio Statistieken (5 Features)

Statistiek	20251113_100138-(baguette-2-3).mp3	20251113_140058-(baguette-2-123).mp3
Min amplitude	-0.5517	-0.4414
Max amplitude	0.7245	0.6798
Mean abs amplitude	0.0009	0.0010
RMS energie	0.0044	0.0018
Aantal peaks	1375	36



Uitgebreide Audio Statistieken (50 Features)

Statistiek	20251113_100138-(baguette-2-3).mp3	20251113_140058-(baguette-2-123).mp3
Min amplitude	-0.5517	-0.4414
Max amplitude	0.7245	0.6798
Mean abs amplitude	0.0009	0.0010
RMS energie	0.0044	0.0018
Aantal peaks	1375	36
Zero-crossing rate	0.4489	0.5092
Spectral centroid (mean)	9804.94	9977.50
Spectral rolloff (mean)	16217.94	16586.07
Spectral bandwidth (mean)	5355.84	5563.20
Amplitude std	0.0044	0.0018
Spectral centroid (std)	898.74	246.45
Spectral centroid (min)	6243.16	6608.09
Spectral centroid (max)	13186.88	10416.43
Spectral rolloff (std)	979.17	269.60
Spectral bandwidth (std)	346.33	89.01
Spectral contrast band 0	27.20	27.62
Spectral contrast band 1	11.12	10.50
Spectral contrast band 2	11.30	11.51
Spectral contrast band 3	11.48	11.91
Spectral contrast band 4	11.50	12.27
Spectral contrast band 5	12.09	13.22
Spectral contrast band 6	65.55	67.13
Spectral flatness (mean)	0.1368	0.0902
Spectral flatness (std)	0.0240	0.0145
MFCC 0 (mean)	-517.4685	-526.7041
MFCC 0 (std)	71.4075	16.0034
MFCC 1 (mean)	-39.1880	-23.3864
MFCC 1 (std)	20.8244	5.6889
MFCC 2 (mean)	-51.8998	-39.3412
MFCC 2 (std)	19.3507	5.9619
MFCC 3 (mean)	-21.1612	-21.9989
MFCC 3 (std)	11.1364	3.7887
MFCC 4 (mean)	-49.1292	-46.2160
MFCC 4 (std)	10.4043	4.1293
Chroma (mean)	0.7471	0.5235
Chroma (std)	0.1644	0.2193
Tempo (mean)	0.0008	0.0015
Tempo (std)	0.0316	0.0344
Amplitude percentile 10	-0.0010	-0.0016
Amplitude percentile 25	0.0005	0.0009
Amplitude percentile 50	0.0000	0.0000
Amplitude percentile 75	0.0005	0.0009
Amplitude percentile 90	0.0010	0.0016

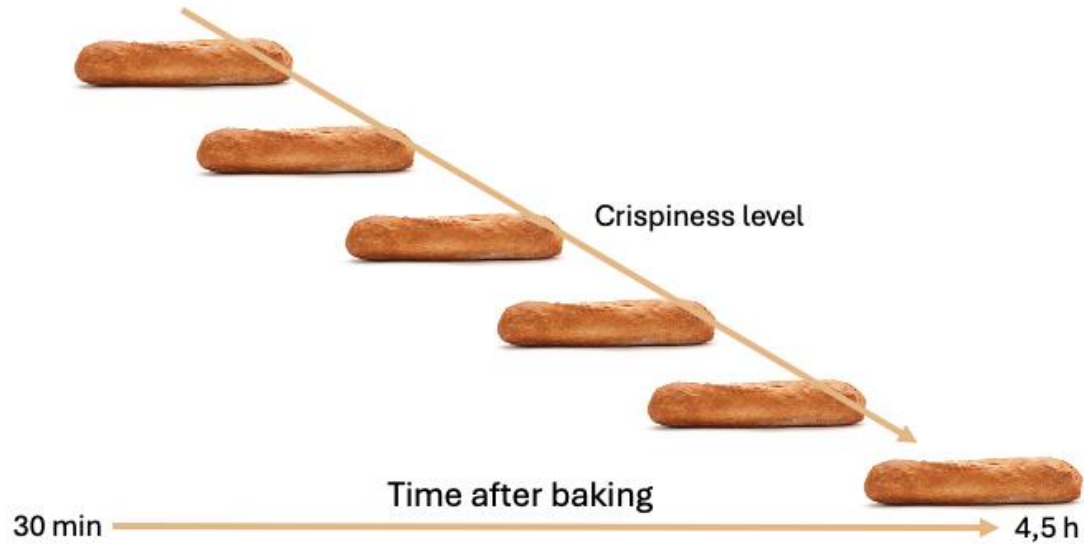


Selection of best correlated feature

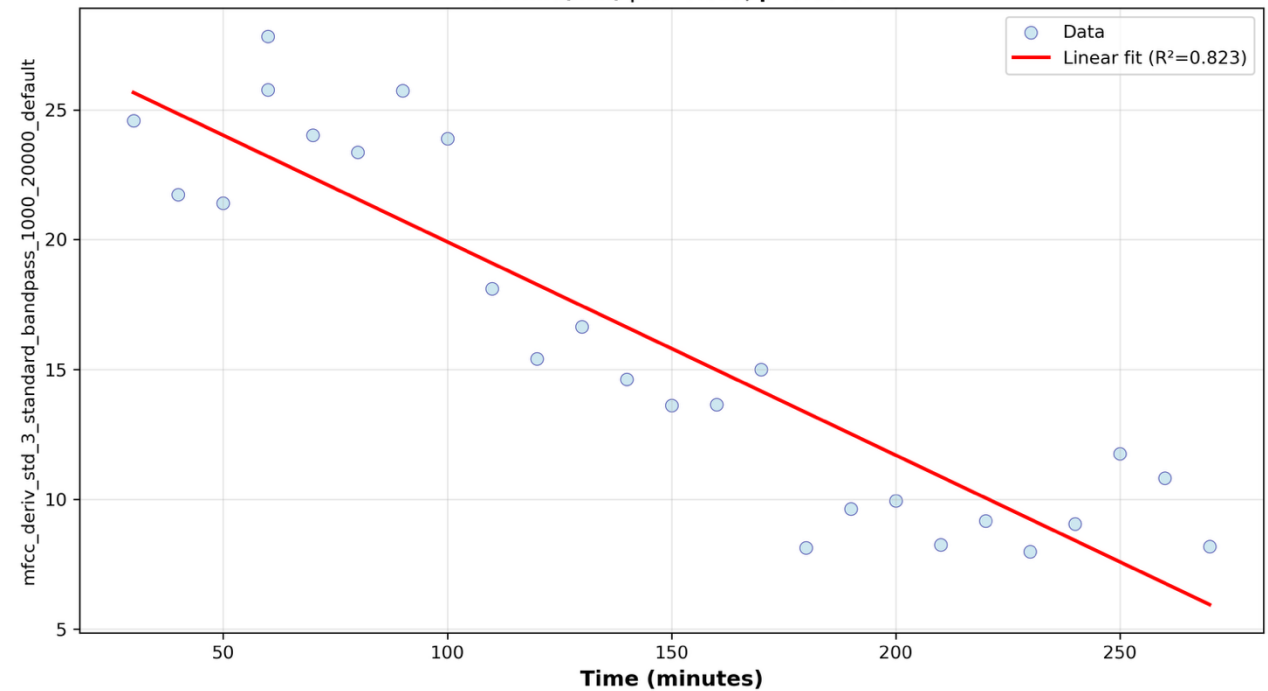
Crispiness over time



Crispiness measurement over time



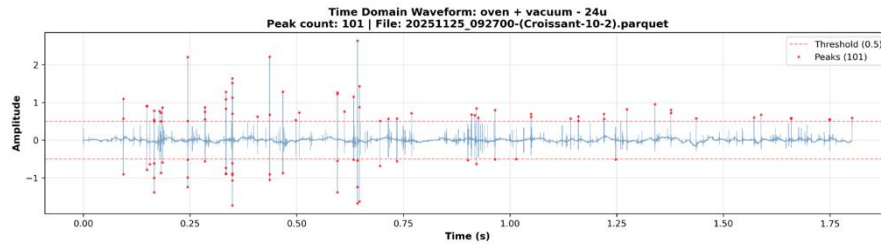
mfcc_deriv_std_3_standard_bandpass_1000_20000_default [Middle]
vs Time(min) | $R^2=0.823$, $p=0.0000$



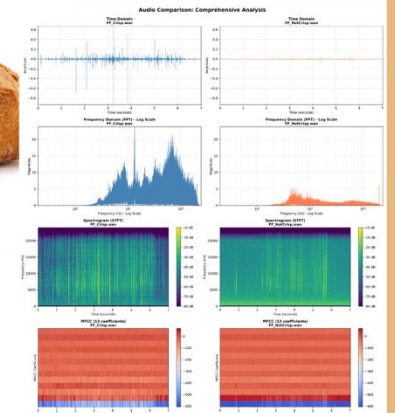
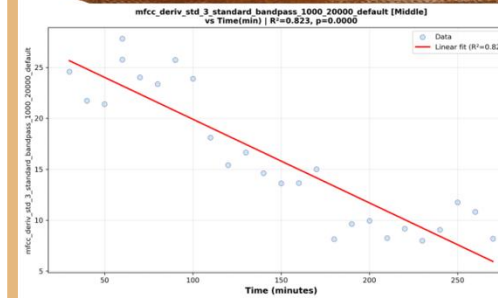
Different approaches



Preprocess audio
One Feature: number of peaks
(time domain)

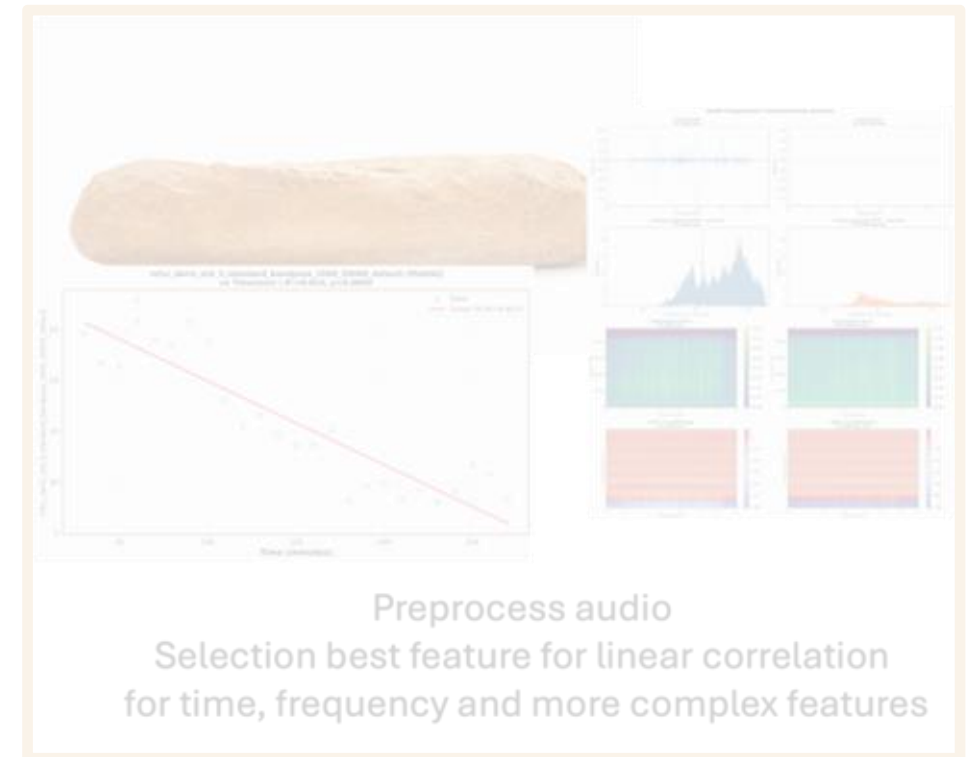
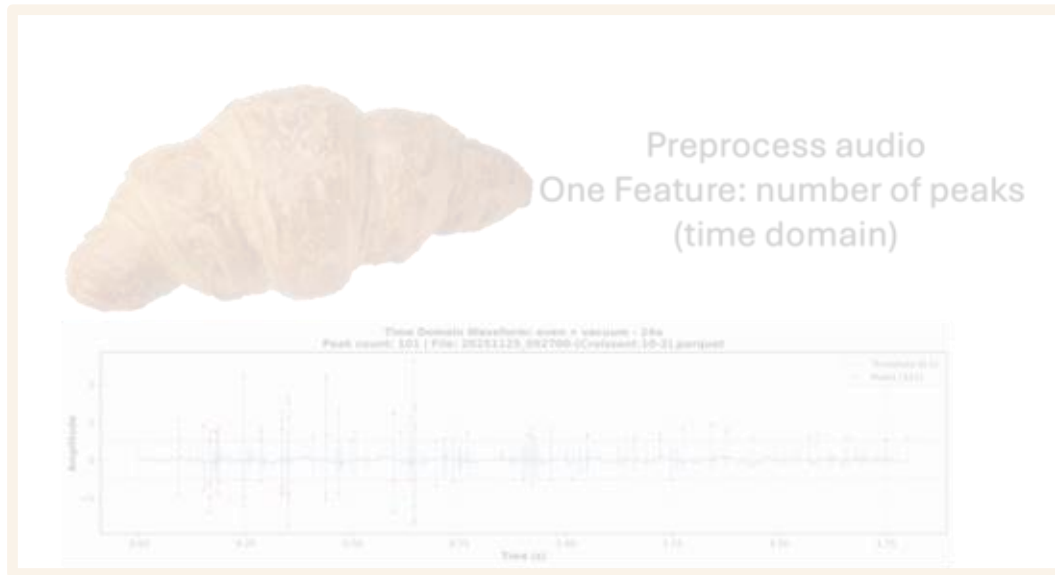


Preprocess Audio
Feature extraction & selection
Model Training



Preprocess audio
Selection best feature for linear correlation
for time, frequency and more complex features

Different approaches

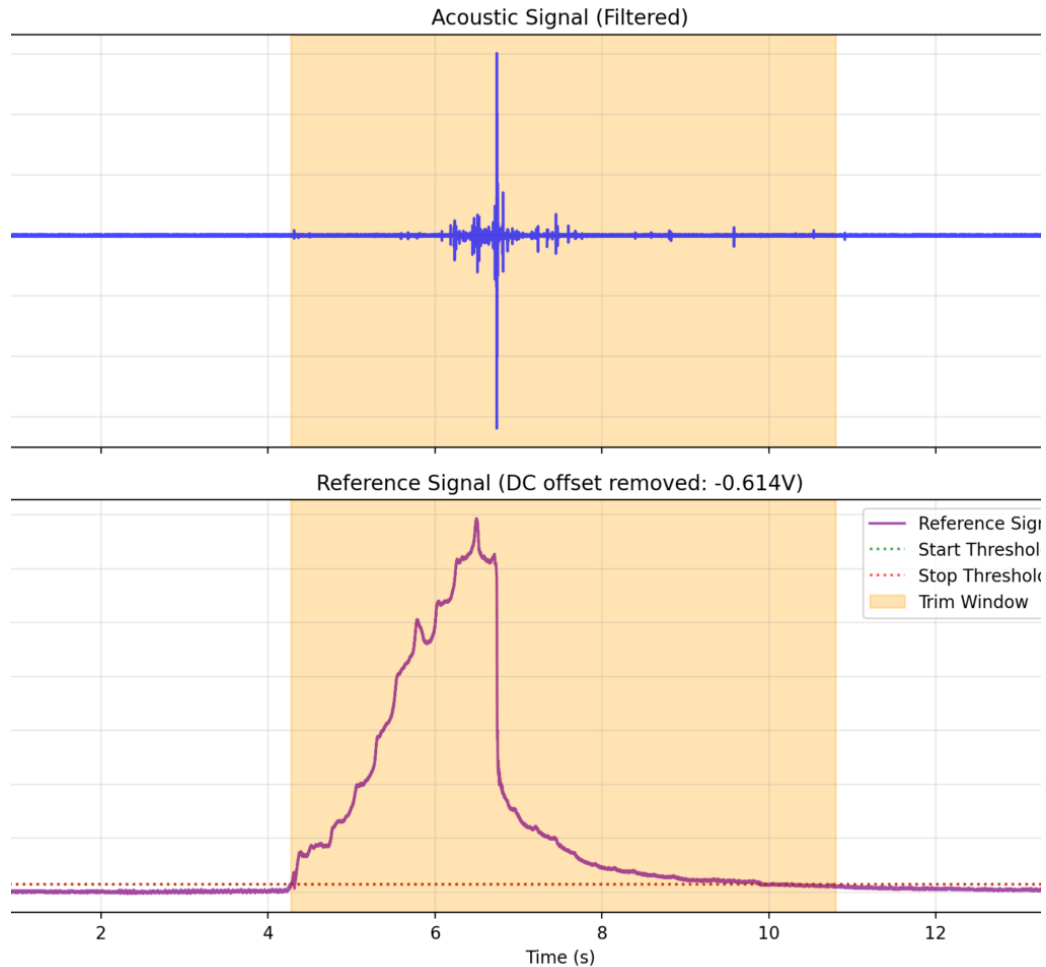


Preprocess Audio
Feature extraction & selection
Model Training

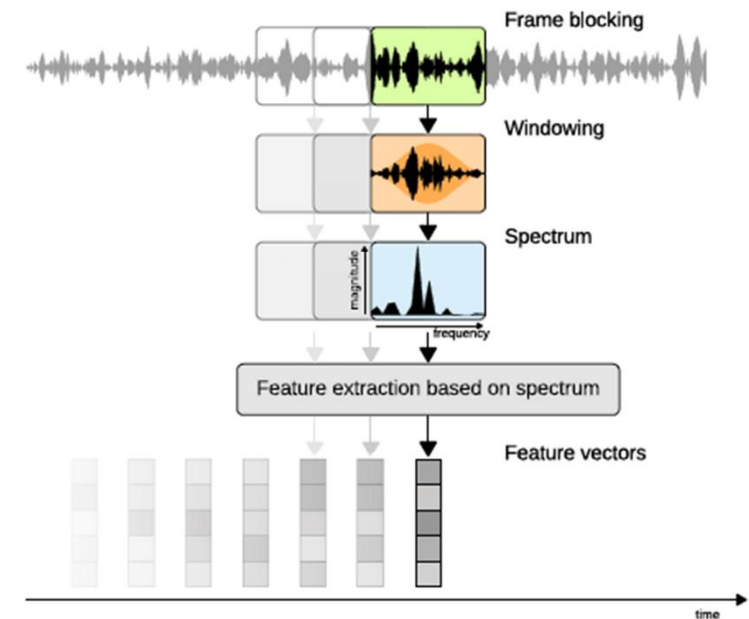
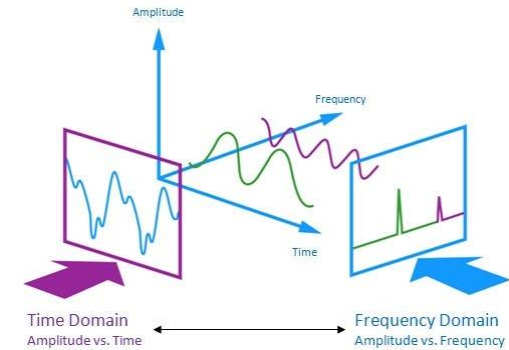
The figure shows a stack of potato chips and a stack of cookies on the left. On the right is a circular logo featuring a brain silhouette filled with circuitry and the Python logo in the center. The text "Preprocess Audio", "Feature extraction & selection", and "Model Training" is written below the images.

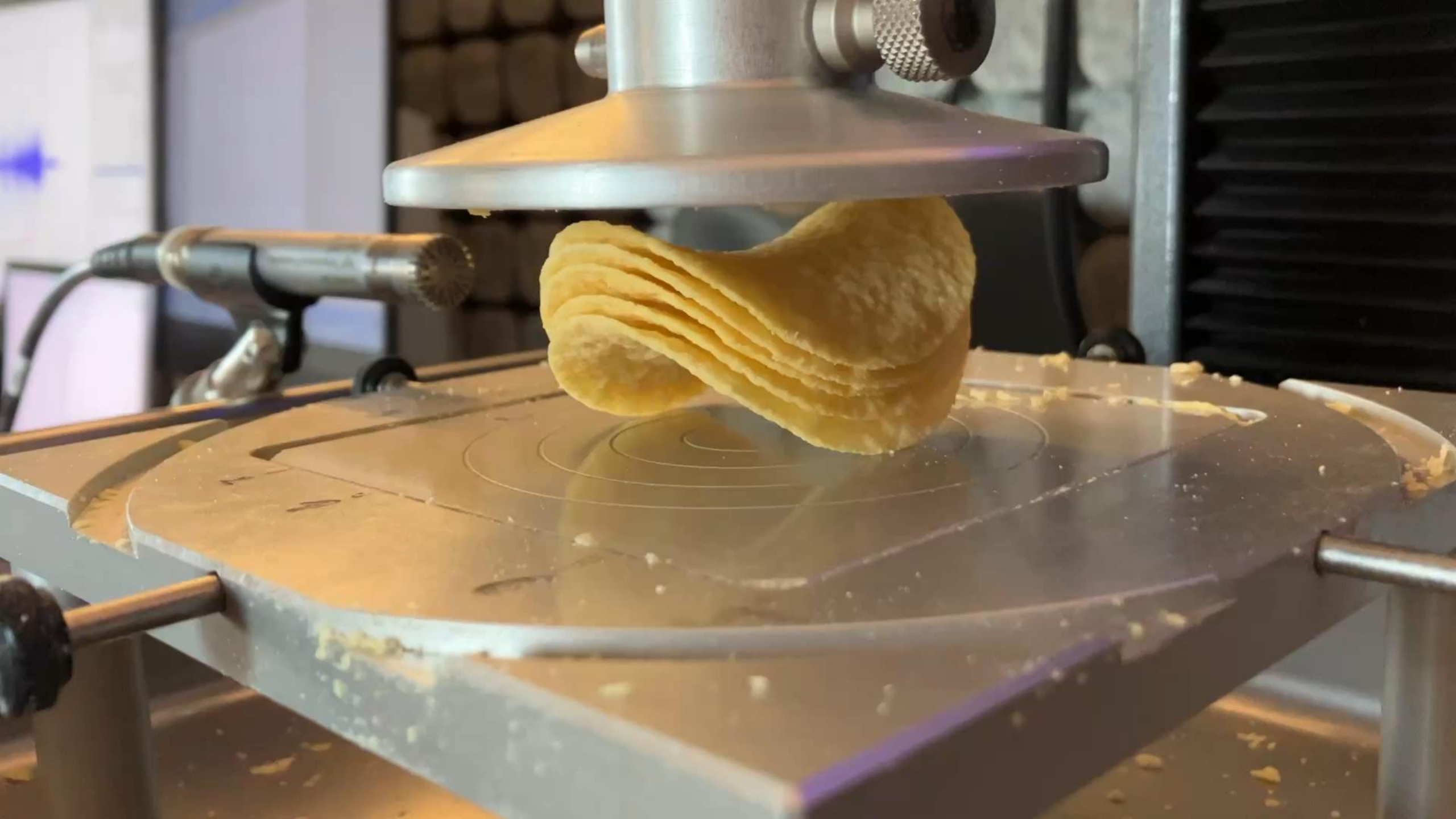
Signal processing

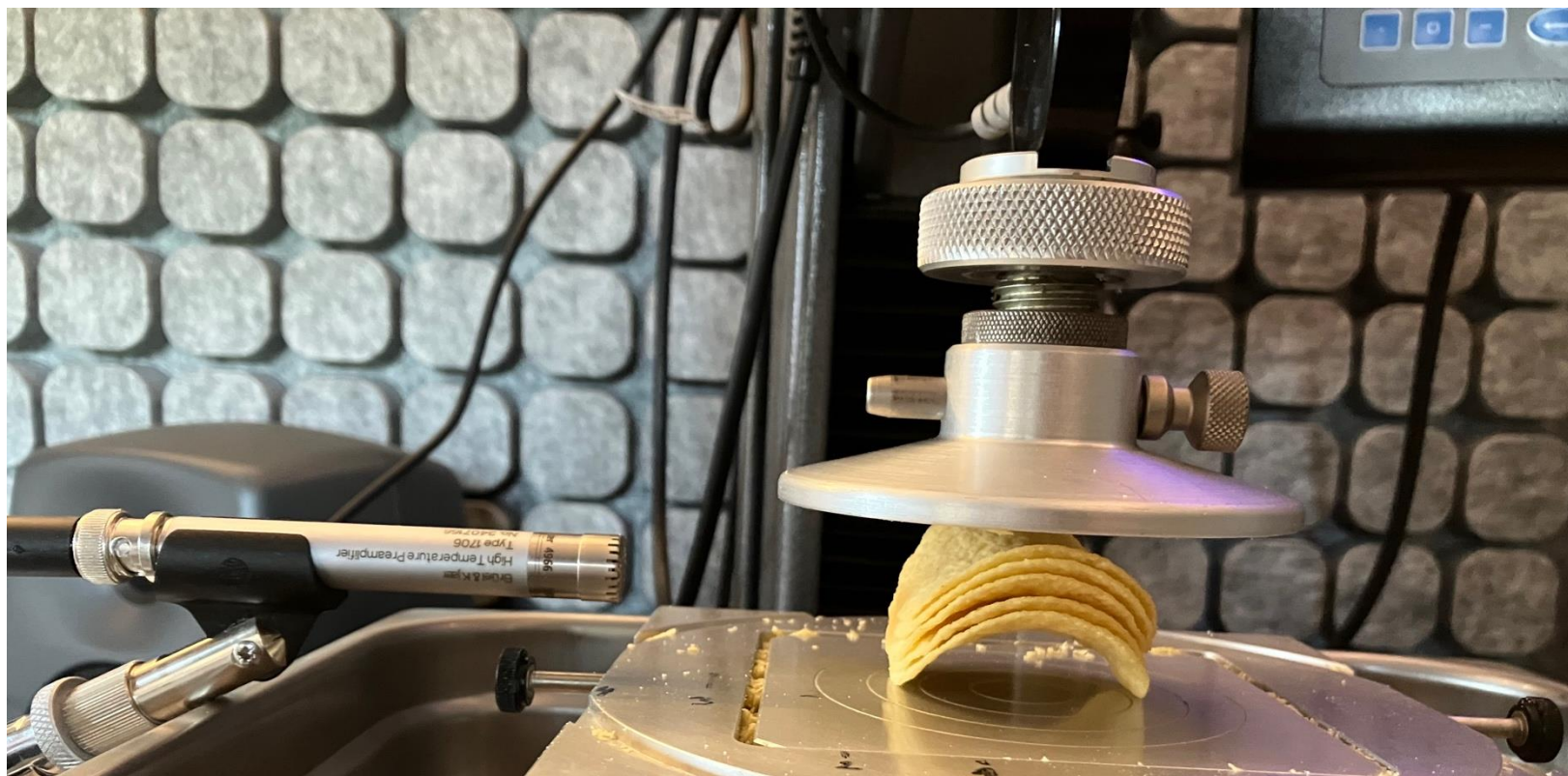
1. Analysis window



2. Feature extraction





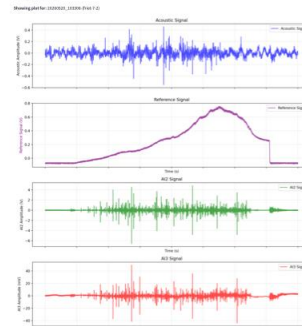


Raw	Soft	Reference	Hard	Burnt
-----	------	-----------	------	-------

5 categories with different 'levels of hardness/crispiness'

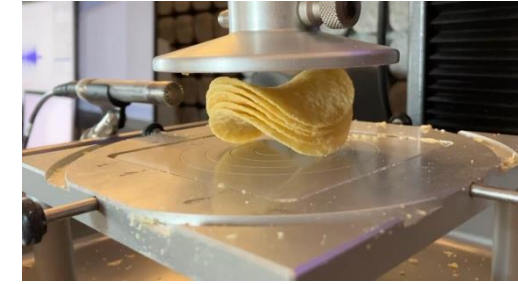
Model training & crispiness prediction

5 fold nested cv



Audio dataset

Feature extraction
(time,frequency,
MFCC...)



Cross validation

Training data

Test data

Logistic regression model
and
feature selection

1. Remove low-variance features/
remove correlated features

2. Remove features
with no correlation
to moisture

3. Keep
features
which
increase
the
predictive
power of
the ML
model

Best model on
best features

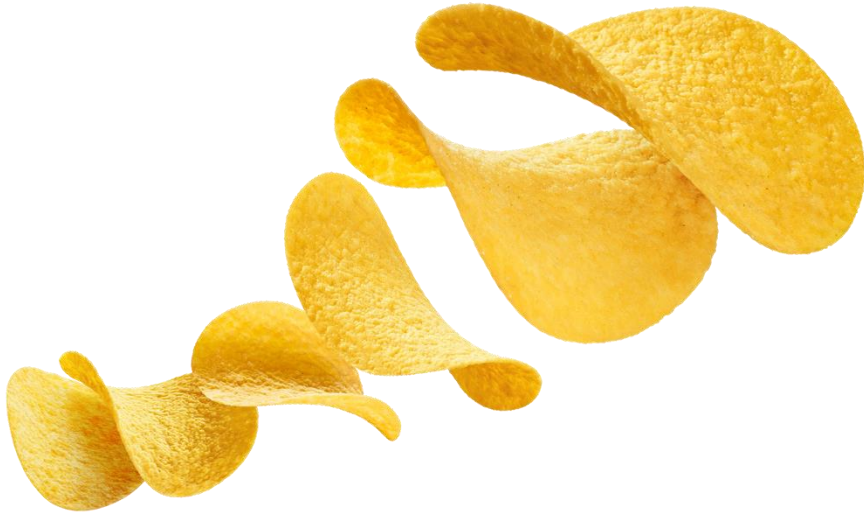
Final evaluation



Confusion Matrix (Test Set)

	crisp	soft	hard	burst	Percentage
crisp	100 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	100
soft	0 (0.0%)	100 (100.0%)	0 (0.0%)	0 (0.0%)	100
hard	0 (0.0%)	0 (0.0%)	100 (100.0%)	0 (0.0%)	100
burst	0 (0.0%)	0 (0.0%)	0 (0.0%)	100 (100.0%)	100

Machine learning: Chips crispiness prediction

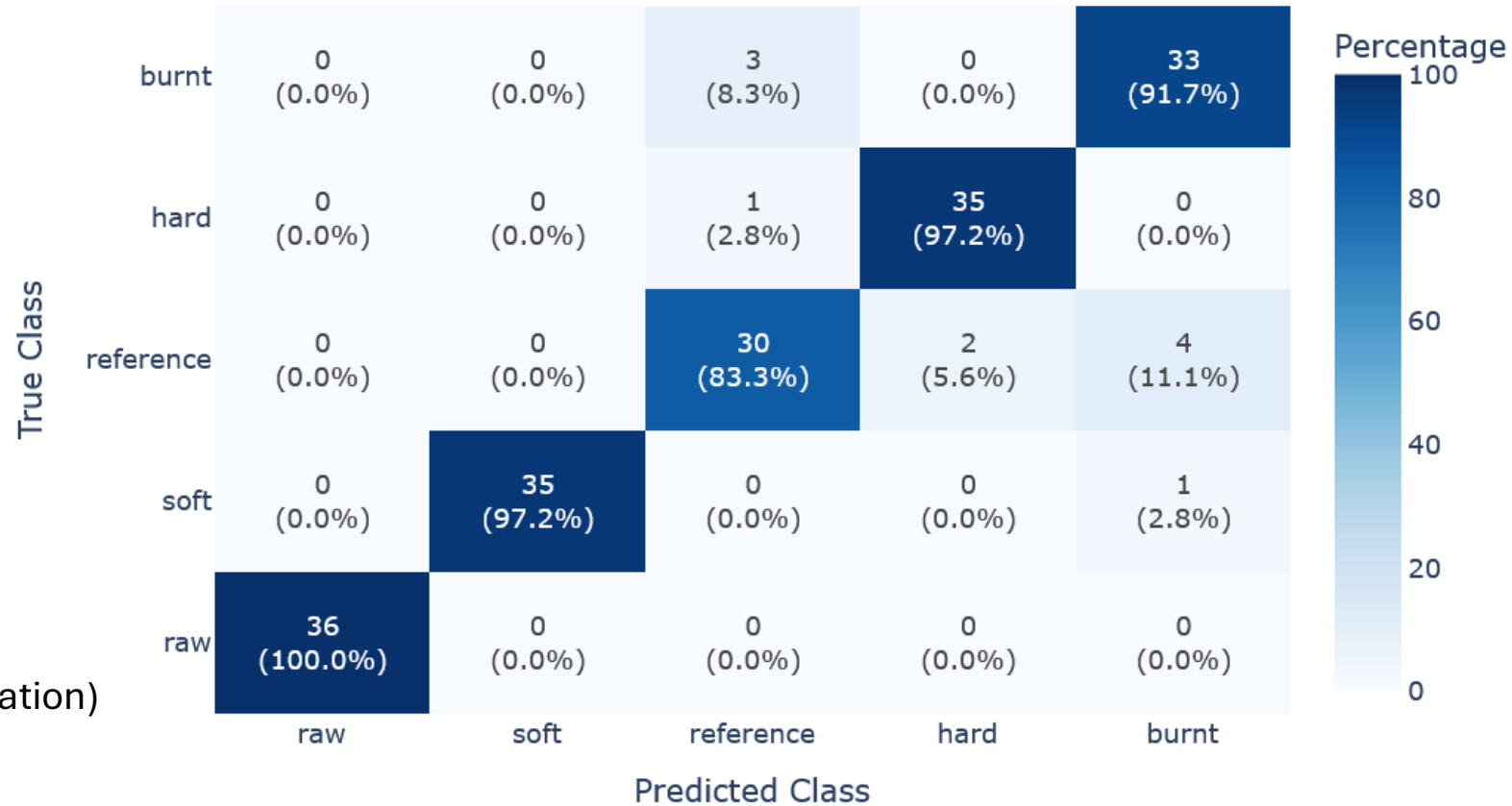


Logistic regression

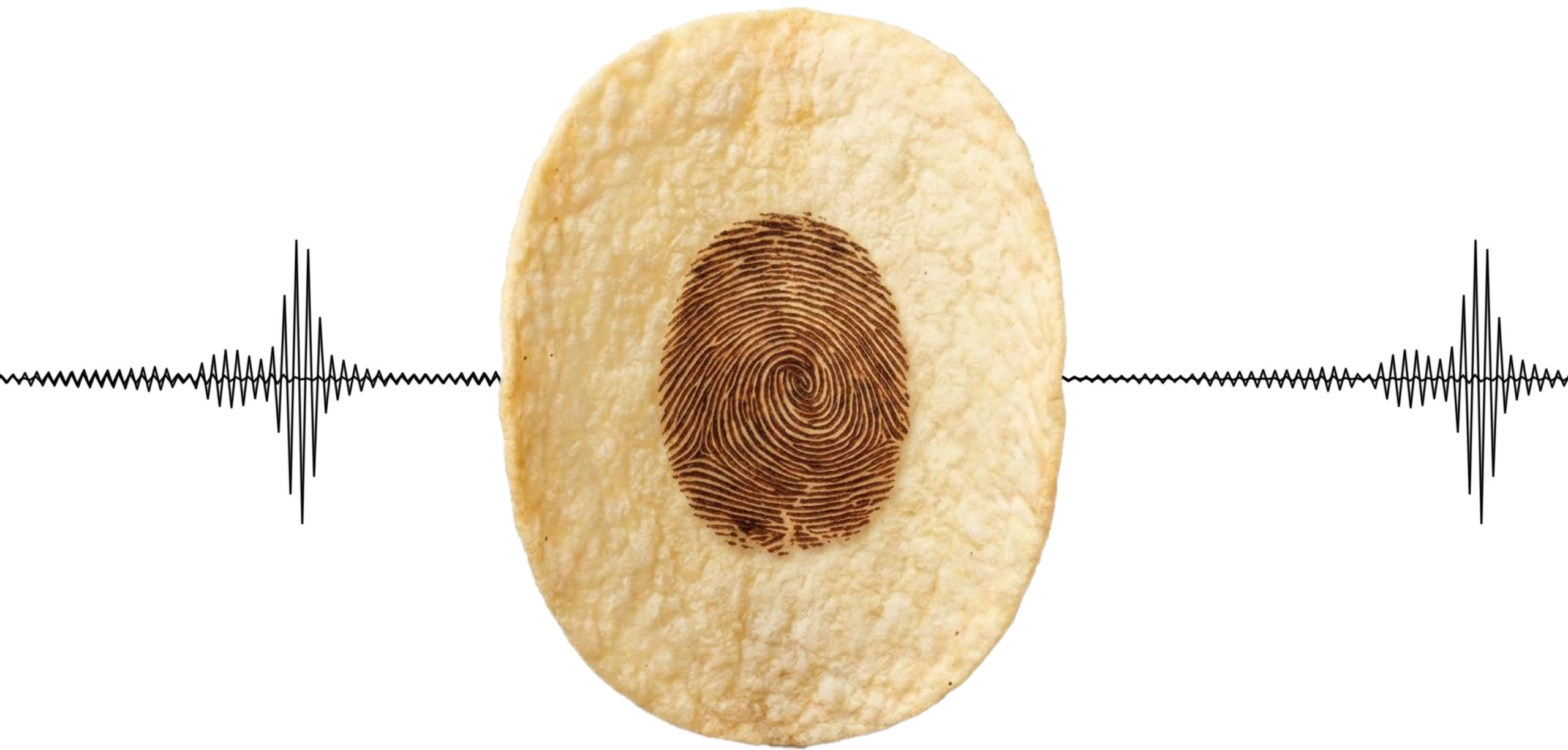
- Chips predicted quality vs real quality (classification)
- Overall accuracy: 94 %

Overall Confusion Matrix (5-Fold CV)

Accuracy = 0.9389, F1 = 0.9388







The audiolab



Food Innovation Park

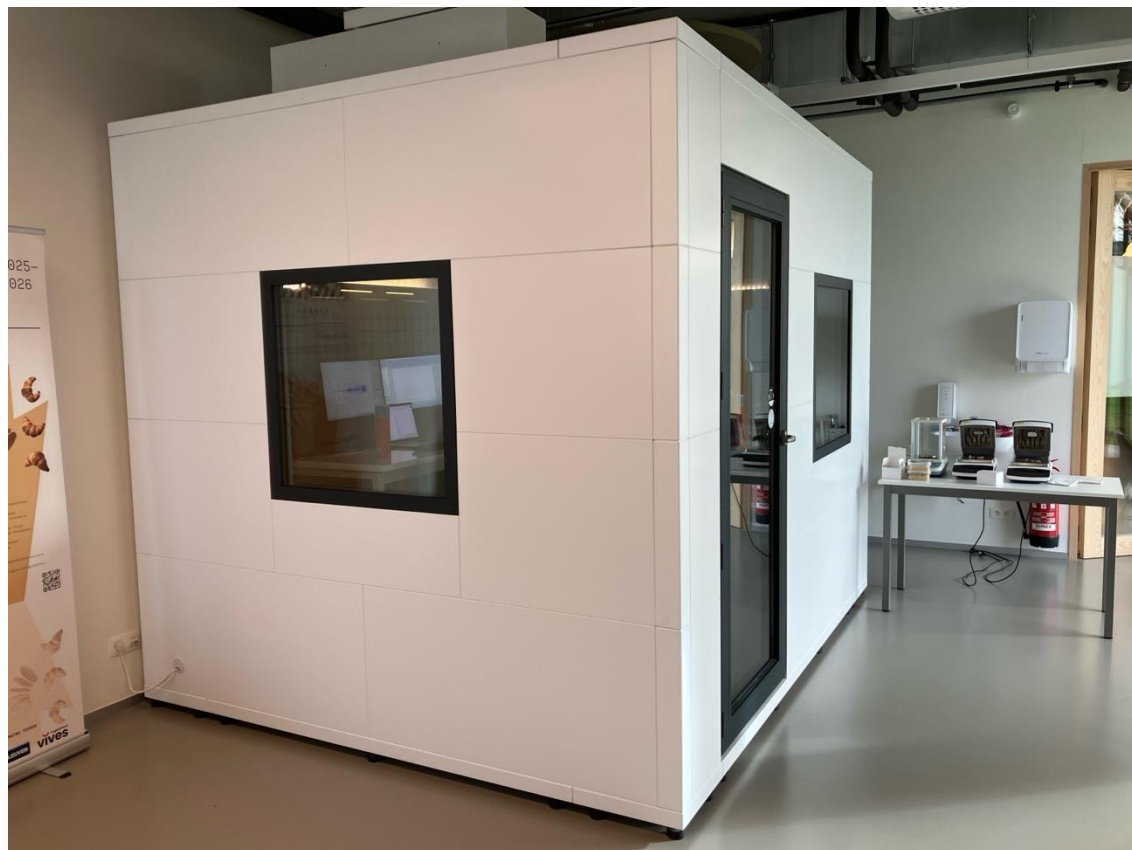




Food Innovation Park

AUDIOLAB

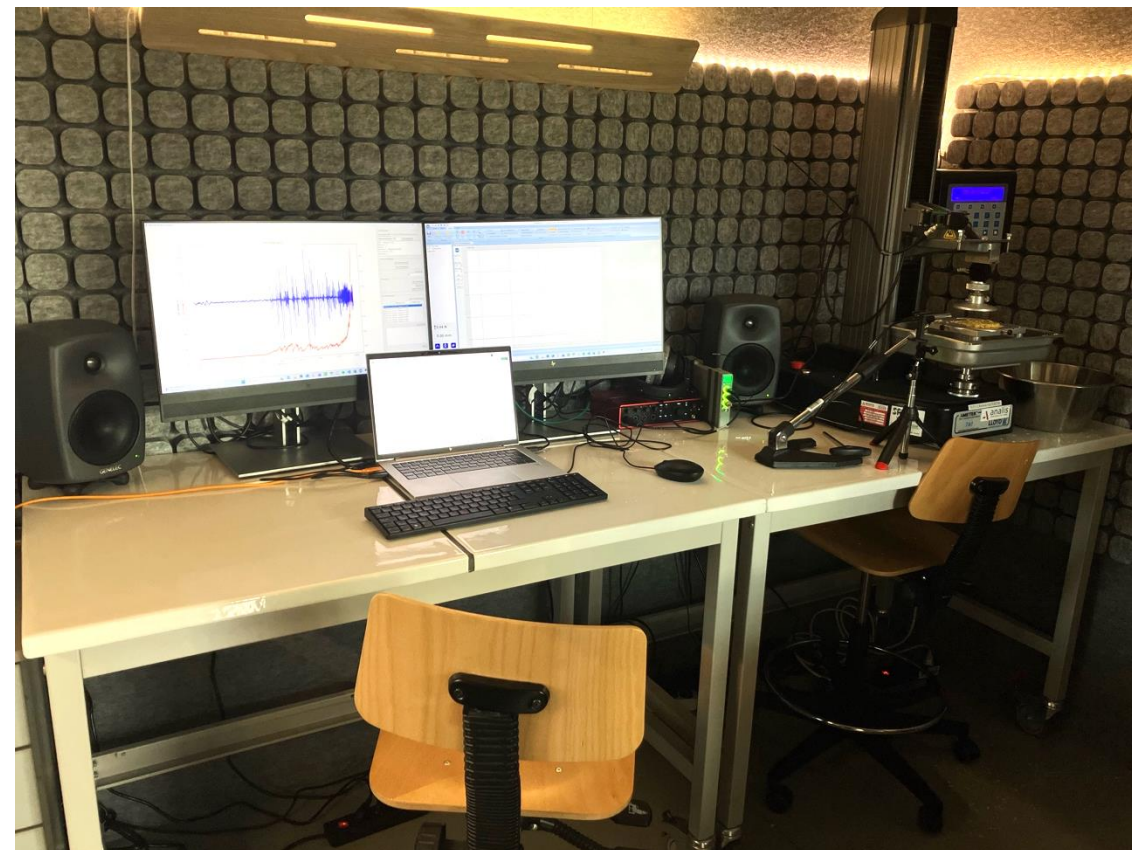




Audiobooth

Isolation index: 45dB – ISO 717-01

Double Wall



More info & specs?

<https://www.project-krak.be/audiolab/>

CRISP

ACOUSTIC INTELLIGENCE
FOR FOR FOOD TEXTURE

- Generalization across recording conditions
- Generalization to different foods
- Multi-sensory prediction
- development of cost-effective, at-line or laboratory system

Triggered ?

KRAK
OP ZOEK NAAR DE PERFECTE
CRUNCH

JAN 2025–
DEC 2026

TETRA PROJECT

BEPALING VAN DE PRODUCTKWALITEIT VAN VOEDING
AAN DE HAND VAN GEAVANCEERDE GELUIDSANALYSE



MET DE STEUN VAN

AGENTSCHAP
INNOVEREN &
ONDERNEMEN



Vlaanderen
is ondernemen

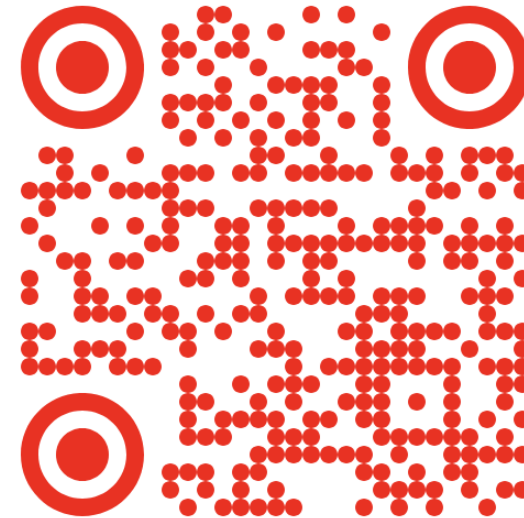


EEN SAMENWERKING TUSSEN



HBC.2024.0136

Michaël Verlinden
Michael.Verlinden@vives.be



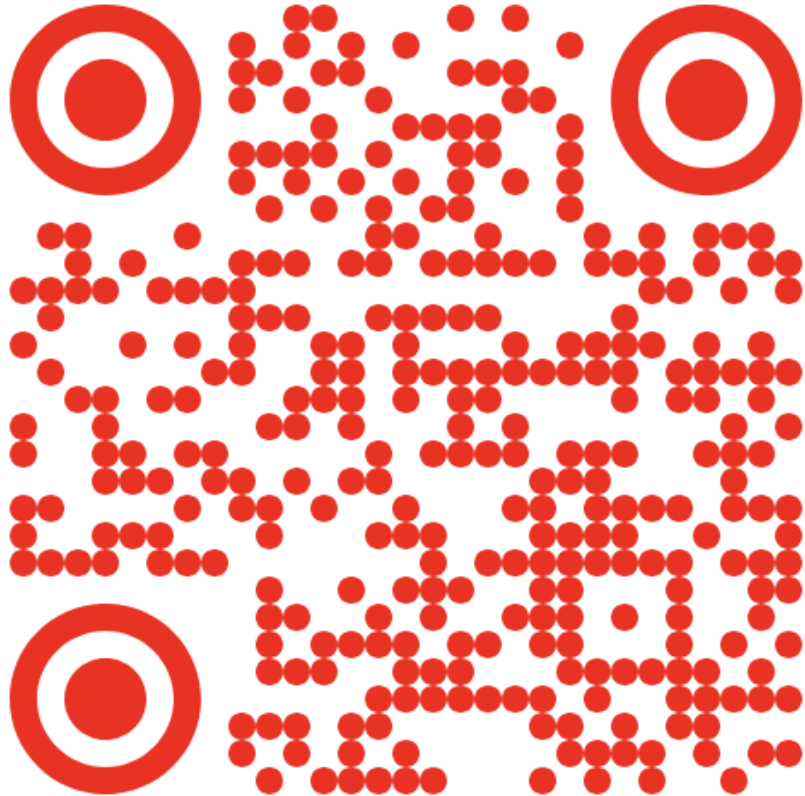
hogeschool
VIVES

RESEARCH GROUPS
FOOD PROCESSING
&
MECHATRONICS

Questions?

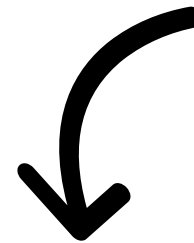
<https://vivaa.mechatronics.be/>

Triggered ?



RESEARCH GROUPS
FOOD PROCESSING
&
MECHATRONICS

Discover more projects!



<https://vivaa.mechatronics.be/>