Leveraging Hyperspectral Image Spatial Information for Assessing Homogeneity in Wheat Flour Mixtures

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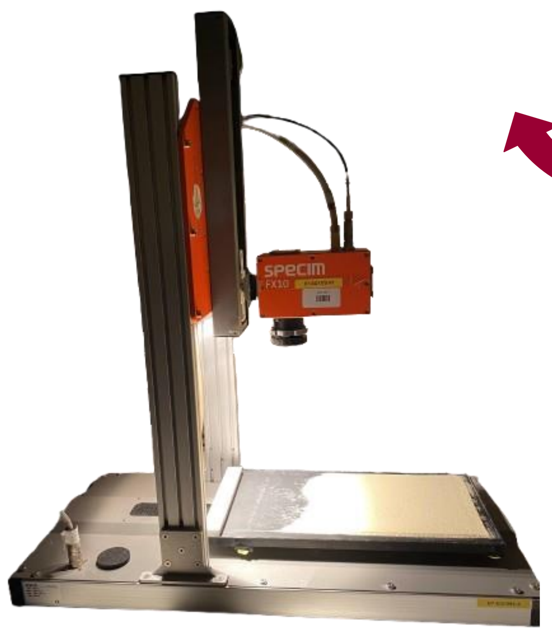
1 INTRODUCTION

Homogeneity is crucial for ensuring consistent quality and stability in food and pharmaceutical products. However, traditional methods are destructive, time-consuming, and prone to sampling bias. Hyperspectral Imaging (HSI) presents a promising alternative, offering non-destructive analysis with both spectral and spatial data to assess distribution patterns. Despite its potential, the spatial dimension is often overlooked. Our study addresses this gap by leveraging the spatial capabilities of HSI to enhance homogeneity evaluation in bread and durum wheat flour mixtures. Distinguishing these two types of flour and their distribution is crucial due to their distinct properties which affect product quality, consistency, and aid in detecting adulteration.

2 MATERIAL AND METHODOLOGY

- 275 samples: 11 mixtures of bread/durum wheat flour. 5 repetitions by mixtures (combinations of 6 different bread wheat and 6 different durum wheat varieties).

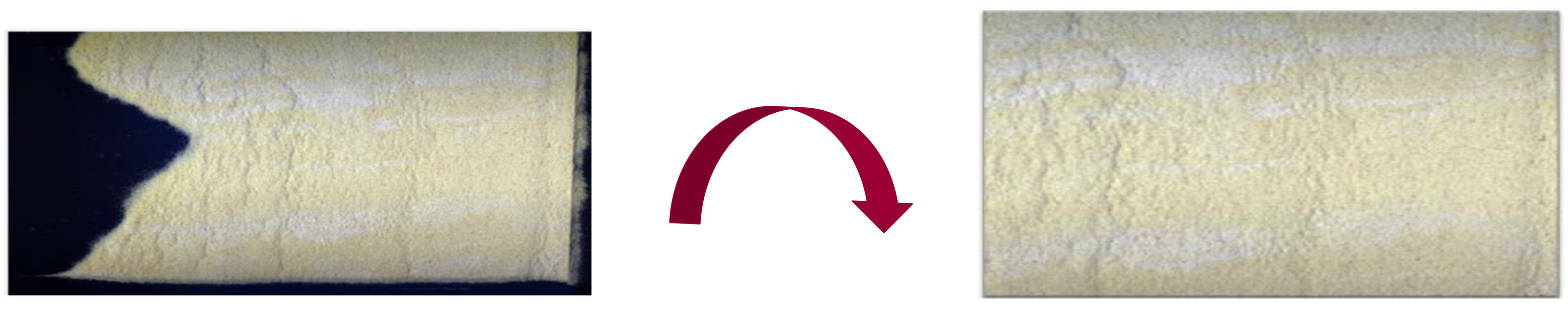
- Homogenization of the samples with the Heidolph Reax 20 blender at 0, 15, 30, 60, and 120 seconds.



- Layer of 3mm of flour (handcrafted pourer).
- Image acquisition using the Specim FX10 camera (400-1000 nm each 2,7 nm).

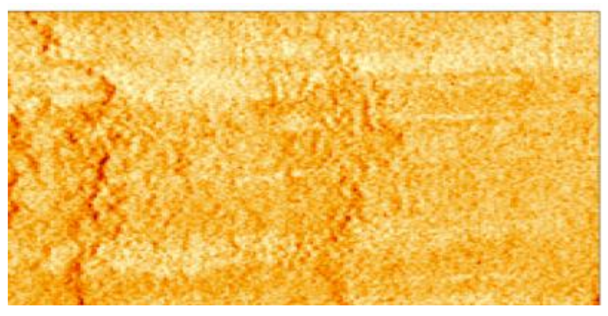
3 CHEMOMETRICS

1. Background removal (PCA)
2. Reshaping
3. SNV + Savitzky-Golay (w = 13, d = 1, p = 2)

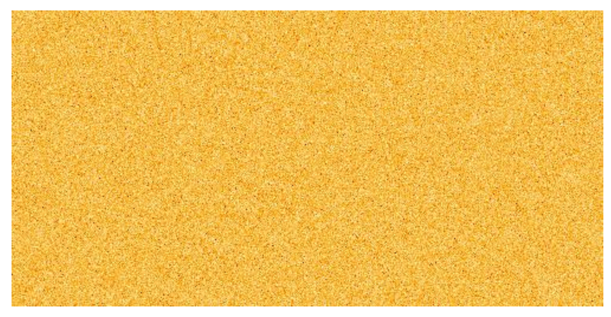


4. Reduce spectral dimensions (e.g. using PCA) – 1 PC selected for this specific case
5. Macropixel algorithm

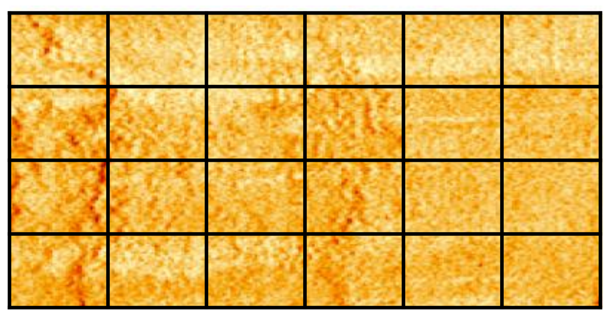
PCA score map (PC1) of the mixture

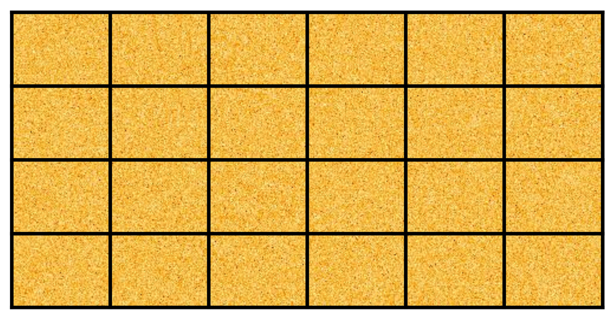


Randomized (1x shuffling pixels) PCA score map (PC1) of the mixture



Creation of macropixels = Sliding windows of fixed pixel size (5x5, 10x10, 25x25)





Mean standard deviation across dimensions for each macropixel

$$SD_i = \sqrt{\frac{\sum_{j=1}^{n}(S_{ij} - \bar{S}_i)}{n-1}} \qquad Mean\ SD = \frac{\sum_{i=1}^{h} SD_i}{h}$$

n = number of pixels per macropixels

h = number of dimensions (PC)

Mean standard deviation for the original image and the randomized image

$$GMSD_{original} = \frac{\sum_{l=1}^{m} Mean\ SD_l}{m} \qquad GMSD_{random} = \frac{\sum_{l=1}^{m} Mean\ SD_l}{m}$$

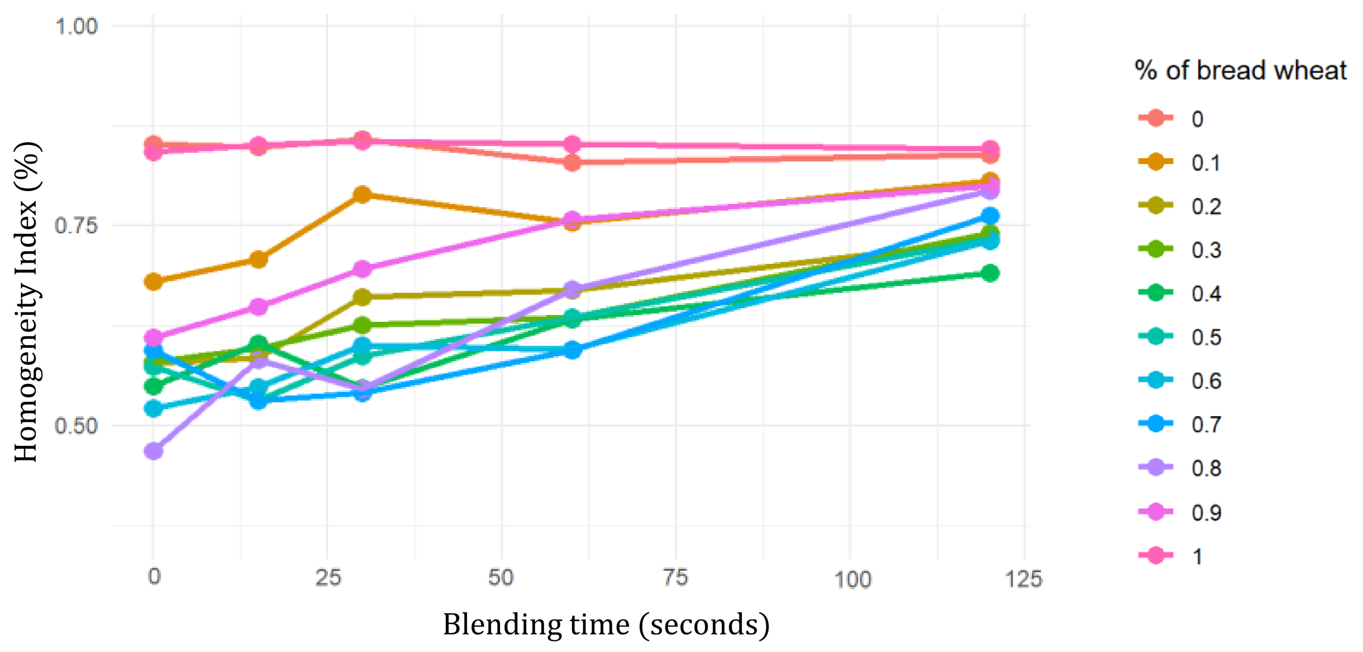
m = number of macropixels

Compute homogeneity index

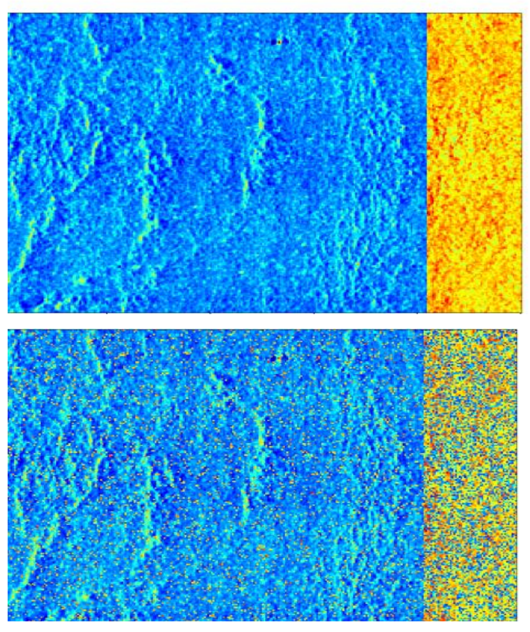
$$H\% = \frac{GMSD_{original}}{GMSD_{random}}$$

4 RESULTS

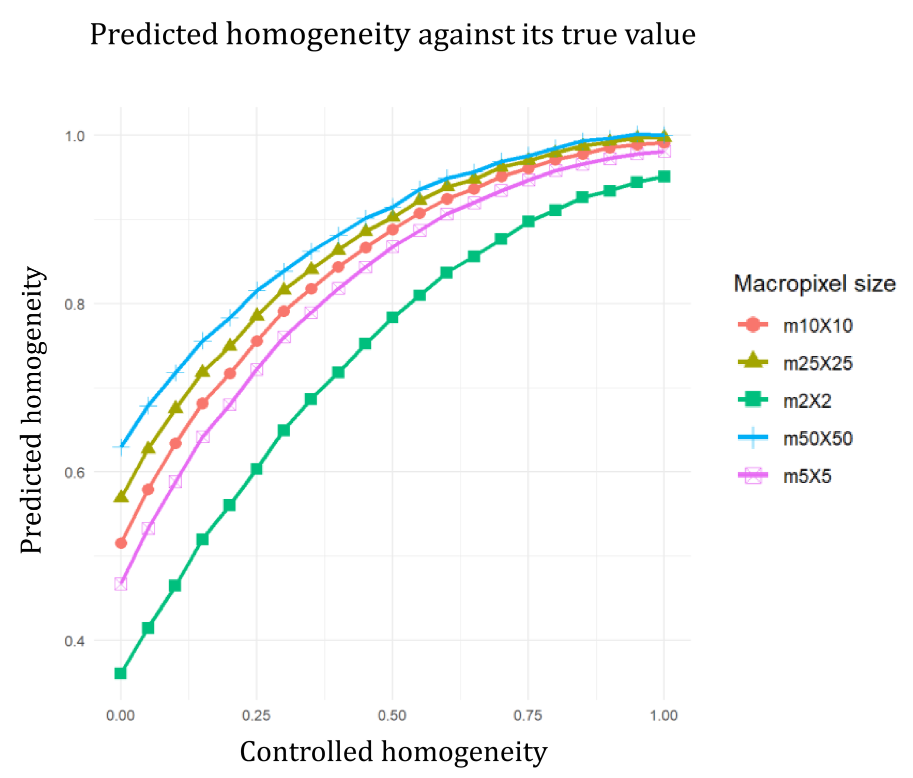
- Homogeneity indices obtained for one mixture at different blending time for a macropixel size of 5x5.



- Algorithm validation with artificial images of desired homogeneities obtained by shuffling pixels of pure components.



Mixture 80% bread wheat and 20% durum wheat homogenized at 50%.



5 CONCLUSIONS

- The developed macropixel algorithm successfully takes into account the spectral and the spatial information of the HSI.
- Algorithm can be combined with other techniques such as PLS or MCR-ALS (concentration maps instead of score maps) to reduce dimensionality.
- Important potential for powder mixtures processability and adulteration.
- Useful tool for diverse hyperspectral imaging applications.

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