

First results from InAFQual: Hyperspectral imaging can detect biofilms on stainless steel surfaces

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The international InAFQual (Innovative Arctic Food Quality Control for SMEs) project, co-funded by the European Union through the Interreg Aurora programme, aims to develop cost-effective methods for quality control and product documentation among food SMEs in the Aurora region, using technologies such as hyperspectral imaging and artificial intelligence (Ojala et al., 2025). Seinäjoki University of Applied Sciences (SEAMK) leads the work packages focusing on data collection and analytics, as well as the validation and demonstration of the developed solutions. One of the research topics at SEAMK is the potential of hyperspectral imaging for assessing surface hygiene in food production. The first promising results have now been reported in a Bachelor's thesis investigating the use of hyperspectral imaging for detecting biofilms (Saavalainen, 2026).

In food production, microorganisms can attach to equipment and work surfaces and form biofilms. Within a biofilm, microorganisms are protected by a surrounding matrix, making them more difficult to remove through cleaning (Wirtanen, 2002). Surface hygiene is traditionally assessed by culturing microorganisms collected from surfaces or using rapid hygiene tests. However, culturing takes time, and rapid tests do not necessarily detect microorganisms directly.

Hyperspectral imaging could provide a faster alternative. When light reaches a surface, some wavelengths are absorbed while others are reflected. The pattern of reflected light depends on the material's composition and structure, producing a characteristic spectrum. Unlike a conventional camera, a hyperspectral camera records information from each image pixel at tens or even hundreds of wavelengths. This makes it possible to

detect differences between materials and surfaces that are invisible to the human eye (Gowen et al., 2007). The method also allows surfaces to be examined without physical contact.

Biofilms cause detectable changes in hyperspectral measurements

The thesis investigated whether hyperspectral imaging could detect changes associated with biofilm formation on stainless steel surfaces (Saavalainen, 2026). Biofilms were grown using *Staphylococcus aureus* on AISI 304 stainless steel plates, a material commonly used in food processing equipment.

The experiments were conducted in two series using different initial bacterial concentrations and incubation times. Abundant biofilms formed on the steel surfaces within 48 hours. Control plates were kept in the same growth medium without added bacteria.

The plates were examined using a Specim IQ hyperspectral camera, and the results were compared with conventional bacterial cultivation and the Clean Card PRO surface hygiene test. Clean Card PRO is a rapid test used in food production and other environments to verify cleaning effectiveness by detecting protein residues on surfaces (Aidian, n.d.). The test produces a colour reaction within approximately 30 seconds, allowing cleaning to be repeated immediately if necessary.

Hyperspectral imaging revealed clear differences between biofilm-containing samples and controls. The spectral signals from biofilm-containing plates were higher than those from the controls in both experimental series and at all measurement points. The differences were particularly evident around 550–600 nm.

The results were generally consistent with those obtained using the other methods. Bacterial cultivation confirmed abundant bacterial growth, while the Clean Card PRO tests indicated the presence of protein-containing material on the surfaces. Although the methods measure different properties, their results supported the potential of hyperspectral imaging for detecting biofilm-associated changes.

Next steps: Detecting thinner biofilms and comparing bacterial species

The first experiments demonstrated the potential of hyperspectral imaging for detecting biofilms and provided valuable information for further method development. However, the spectral signal intensity could not yet be used to reliably estimate the amount of biofilm present.

One important finding was that *S. aureus* formed abundant biofilms even at relatively low initial bacterial concentrations. Bacterial growth on the culture plates was also so extensive that counting individual colonies was difficult. The next experiments will therefore use lower initial bacterial concentrations to investigate the detection of less abundant biofilms.

The research will also be extended to other bacterial species relevant to the food industry. The aim is to determine whether hyperspectral imaging can detect biofilms formed by different species and distinguish between them based on their spectral characteristics.

Machine learning could further improve the analysis of hyperspectral data. Previous research has demonstrated that classification algorithms can be used to identify biofilm-containing areas in fluorescence hyperspectral images (Lee et al., 2021). In the future, hyperspectral imaging could potentially serve as a rapid screening method, identifying areas that require closer examination using conventional surface hygiene tests.

These first results provide a promising starting point for further research at SEAMK and support the potential of hyperspectral imaging as a rapid, non-destructive method for monitoring surface hygiene in the food industry.

InAFQual

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