Commentary

The taste of UV light: using sensomics to improve horticultural quality

Victor Castro-Alves[1], ORCID: 0000-0002-9535-6821
Irina Kalbina[1], ORCID: 0000-0003-0018-8333
Åsa Öström[2], ORCID: 0000-0001-8848-5812
Tuulia Hyötyläinen[1], ORCID: 0000-0002-1389-8302
Åke Strid[1], ORCID: 0000-0003-3315-8835
[1]Örebro University, School of Science and Technology, SE-70182 Örebro, Sweden
[2]Örebro University, School of Hospitality, Culinary Arts and Meal Science, SE-71202 Grythyttan, Sweden
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UV and greenhouses: friends or foes?

Greenhouse horticulture is in its broad definition the production of plant products within, under or sheltered by structures that provide protection against biotic and/or abiotic stress. In greenhouses, horticultural crops can grow protected from infectious agents and adverse weather conditions, allowing off-season, year-round production. However, greenhouse production often comes with a trade-off, which is a skewed light environment with a lack of UV light.

In some instances, the blockage of UV by greenhouse glass and plastic covers is beneficial from a commercial perspective, especially on tropical latitudes where plants can often encounter higher UV levels, which may impair plant growth and nutrient absorption (Krause et al. 1999; Verdaguer et al. 2017). On the other hand, reduced UV inside greenhouses may reduce the synthesis of metabolites associated with crop protection against biotic and abiotic stress, such as flavonoids, terpenoids and alkaloids (Yang et al. 2018). This reduction in the amount of protective compounds may not be seen as an important limitation in a protected environment, but these metabolic changes caused by reduced UV exposure may in fact negatively impact on product quality. For example, it is possible to improve of the aroma and taste of greenhouse tomato by exposing plants to low levels of supplementary UV light (Dzakovich et al. 2016).

Bridging the gap

When it comes to defining what sensorial quality is, the most relevant and straightforward description is based on the way humans perceive a given food through their senses; eye sight, smell, taste, touch and hearing. These senses act as gatekeepers for food choices. Nowadays no new food production process is worth developing unless the final product will have a sensory quality accepted by consumers (Tuorila and Monteleone 2009). The need to consider sensory product quality resulted in increased interest in studies that integrate sensory analysis into the context of how environmental factors, such as UV light, influences horticultural product quality (Carvalho et al. 2018; Charles et al. 2017; Dzakovich et al. 2016; Lipan et al. 2019). A new and highly challenging consequence of this is the integration of the scientific knowledge on metabolites acquired by plant scientists with the product quality as defined by consumers.

Research in the field of plant photobiology has expanded our understanding of how UV shapes plant metabolism, especially when it comes to specific metabolite classes such as flavonoids, anthocyanins and terpenoids (reviewed by Thoma et al. 2020). Some of these compounds are known to influence colour, aroma and taste of horticultural products, thereby impacting on product quality (Abbas et al. 2017; Kayesh et al. 2013). However, the overall quality of a horticultural product depends on its metabolic signature as a whole rather than on an increment or a reduction of few metabolite classes (Tieman et al. 2017).

Whilst improvements in horticultural quality have been inferred mainly on changes in the concentration of selected metabolites (i.e., target approaches), there are virtually no data linking metabolic effects of UV to product quality as defined by consumers. Supplementary daily doses of UV during greenhouse tomato production improves fruit aroma and taste as evaluated by a sensory panel (Dzakovich et al. 2016); however, it is still not clear which are the metabolic signature of horticultural products that makes consumers consider them as products with high sensorial quality.

One promising strategy to fill this knowledge gap would be to apply top-down systems biology approaches, which combines system-wide data originating from "omics" technologies with mathematical modelling to uncover relationships among genes, proteins, and molecules. Among these top-down systems biology approaches, metabolomics, the comprehensive analysis of all metabolites in a studied biological system, is opening new roads to further our understanding of how metabolites orchestrate various processes in plants. For example, application of metabolomics combined with genomics on plant breeding programs can identify specific markers associated to performance of distinct traits (Fernandez et al. 2016). In the context of sensorial quality defined by the consumers, sensomics, a cutting-edge science concept that integrates metabolomics and network analysis with novel sensory analysis methods, such as the 'repertory grid method' and the 'rate-all-that-apply

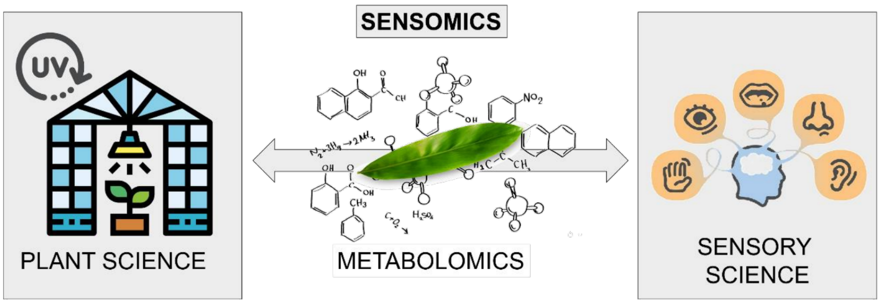

Figure 9.1: Sensomics concept to improve horticultural quality. Sensomics combines plant science with advanced analytical tools and sensory analysis to generate uniquely new insights in horticultural quality.

method' (Aguiar et al. 2018), can provide the necessary link to translate what is happening inside the plant into a person's experience of food quality (Figure 9.1).

Sensomics and UV light: the case of dill

The horticultural industry in northern Europe usually competes with imported produce from more southern (equatorial) latitudes where light conditions are favourable for field growth. From a sustainability and resilience perspective it is important that growers in northern Europe produce food with improved quality. Such improvement in quality is also a key to the competitiveness of the local horticultural industry that operates in an international market.

As a way of addressing the challenges faced by the Scandinavian horticultural industry, we are applying sensomics to improve the quality of horticultural products traditionally grown in the region. For example, we have explored the quality of dill (*Anethum graveolens* L.) produced at commercial standard conditions in greenhouses in the presence or absence of supplementary UV. Plants were exposed continuously during 4-hour daily to either UV-A- or UV-B-enriched light using fluorescent lamps (3.6 $W\,m^{-2}$ plant-weighed UV-A or 0.083 $W\,m^{-2}$ plant weighed UV-B) in the presence of a background of photosynthetically active radiation (150–200 $\mu mol\,m^{-2}\,s^{-1}$, 16 $h\,d^{-1}$) (Qian et al. 2020). Untargeted metabolomics analysis using gas chromatography coupled to ultra-high resolution mass spectrometry revealed that, compared to the control, plants exposed to supplementary UV in greenhouses had a metabolic signature similar to 'gold standard' samples. These 'gold standard' dill samples are imported from southern latitudes and were assessed by a sensory panel of trained volunteers (at Örebro University's School of Hospitality, Culinary Arts and Meal Sciences) as a high-quality product. The shift in dill metabolite profile induced by UV light appears to have a positive impact on product quality as defined by consumers. Sensory analysis showed a move in the sensory quality of UV-exposed dill from the outset towards the desired situation (i.e., from control to 'gold standard') by about 30%, enabling us to find associations between metabolic signatures and product quality.

Further sensomic analysis of other horticultural products including basil, cabbage, lettuce and coriander will help us to define metabolic signatures associated with other high-quality products and establish, most likely species-specific, UV light regimes in greenhouses to grow horticultural products with improved quality. We also envision that discovery of associations between overall plant metabolism and sensory quality will support horticultural breeding.

The project is still ongoing and our promising results will benefit not only the plant science community for scientific reasons, but also primary producers, food industry, and first and foremost, consumers.

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