6. Conclusions and Future Outlook

This document has shown that by steering the environmental conditions, a substantial manipulation of the chemical composition and bioactive profile of crops can be achieved. Not only the environment but also the choice of crop or cultivar has a profound impact on the biochemical composition (Figure 5.11 and 5.12).

An important aspect that underpins many of the declines in crop nutritional value is the dilution effect (see §5.1.7 and Jarrell and Beverly (1981). The dilution effect is caused by the relative increase in biomass, i.e. carbohydrates and water, compared to the minerals and more complex phytochemicals, i.e. the plants growth and defence machinery. Roughly put, most yield increasing cultivation and breeding practices cause a relative decrease in nutritional value. Figure 5.3 shows the dilution effect for increasing CO_2 levels that lower all mineral nutrients in open field farming studies. Reeve et al (2016) nicely illustrate the dilution effect caused by breeding by reviewing a dozen articles that make a comparisons between old and modern cultivars of grains and vegetables. The review clearly revealed a trend of decreased nutrient contents in modern, higher-yielding cultivars, which can be regarded as a 'genetic dilution effect'.

On the one hand, these declines are currently not yet identified as a concern for high-income countries, as on an epidemiological scale there are not many severe deficiencies identified. On the other hand, there are particular groups even in western society that are prone to deficiency, e.g. iron deficiency among certain groups of women, and relatively low intake of Calcium, Vitamin A and C (Table 2.4) that might cause problems for some groups. Moreover, identifying and recording clinical deficiencies is relatively easy compared to identification of marginal effects on general well-being that might be related to low intake. Just as it is hard to identify possible relations of low mineral and phytochemical intake with noncommunicable diseases, e.g. diabetes, cardiovascular diseases and specific forms of cancer. These diseases reveal only through long exposure to certain food types or diets, and scientific debate on causal relations of many specific minerals and phytochemicals is still ongoing. Although there is consensus that sufficient intake of fruit and vegetables will lower risks of susceptibility to these diseases. Not only in the Netherlands, but world wide consumption of fruit and vegetable is already too low, and the current decrease in crop nutritional value will certainly not help to improve health and wellbeing of our society.

Malnutrion in low-income countries is an alarming problem. Plant scientists and human nutritionists try to address the problem by increasing, i.e. biofortifying, the main crops with minerals and phytochemicals that are causing the biggest health issues, e.g. Zn and Vitamin A. There are well documented success stories of biofortification (see HarvestPlus), but also here pressure to produce enough food might lead to a lower nutritional content of non-targeted plant chemicals and thus care should be taken to maintain nutritious crops.

From a consumer perspective, nutrition has seen increased attention in recent years, especially in Western societies. Consumers use different strategies to improve their health through nutrition, for example by supplements, through consumption of "super foods", or through certain diets. Food companies use this trend to promote "functional foods", foods with additional health promoting effects beyond the normal nutritional content. Scientific evidence on the effectiveness of functional foods and super food is scarce however. However, specific groups can benefit from tailored or personalised nutrition. Therefore, these developments will become more prominent in our society because knowledge on our own personal physiology increases. At present, companies and universities perform a substantial amount of time and money on researching human genome – microbiome – plant microbiome and plant metabolomics interactions. Many things can be measured, but to have truly personalised nutrition it will take a lot of time and money to make progress. Nevertheless, for certain societal groups and diseases there are clear dietary guidelines and here growers and breeders already might step in and help to develop, e.g. iodine, potassium or iron fortified crops.

In such an endeavour the advantages of greenhouse and indoor growing modules are great. As reviewed by Rouphael et al., (2018), full control over environmental conditions, as is the case in vertical farming systems, can significantly increase phytochemicals and essential and /or beneficial micronutrients in vegetables (biofortification), e.g. 3 to 5 times higher iron and zinc content (Ortiz-Monasterio et al. 2007). Vitamin C and other anti-oxidants can be increased by more than 30% by changing fertilizer concentration or by 300% when choosing a different cultivar (Figure 5.12). Anthocyanins levels can be significantly increased by changing light and temperature (Liu et al. 2018). Iodine and Selenium can be added to the nutrient solution to precisely control I and Se content in lettuce leaves. Shelf life of lettuce can be extended by more than a week by increasing light intensity (Minqian and Woltering, unpublished, 2019).

Thus, full environmental control can potentially enhance phytochemical and micro nutrient (Zn, Fe, I, Se, Vitamin C, etc.) content in plants. But optimal growth conditions will lead to a dilution effect and thus whether this boost in phytochemical and micronutrients is achieved depends on many factors. That is e.g. high CO_2 and fast-growing cultivars can both negatively impact plant mineral content, light treatments can both elevate and decline Vitamin C levels, depending on day length intensity and light quality. This complexity holds even more for open field agriculture as described in §5.3 and §5.4. Farmers that want to enhance the nutritional value of their crops really need to take many factors into account. Monitoring and measuring will be key in supporting this important endeavour.

Consumer, retail and governmental awareness and measurements of the nutritional value can be a powerful tool to support the agricultural sector in guarding and improving the nutritional quality of their crops.

References

Jarrell WM, Beverly RB. 1981. The Dilution Effect in Plant Nutrition Studies In: Advances in agronomy. New York, 197–224. DOI: 10.1016/S0065-2113(08)60887-1

Liu Y, Tikunov Y, Schouten RE, Marcelis LFM, Visser RGF, Bovy A. 2018. Anthocyanin Biosynthesis and Degradation Mechanisms in Solanaceous Vegetables: A Review. Frontiers in Chemistry 6: 2895–2905. DOI: 10.3389/fchem.2018.00052.

Ortiz-Monasterio JII, Palacios-Rojas N, Meng E, Pixley K, Trethowan R, Peña RJJ. 2007. Enhancing the mineral and vitamin content of wheat and maize through plant breeding. Journal of Cereal Science 46: 293–307. DOI: 10.1016/j.jcs.2007.06.005.

Reeve JR, Hoagland LA, Villalba JJ, et al. 2016. Organic farming, soil health, and food quality: Considering possible links. Elsevier Inc. DOI: 10.1016/bs.agron.2015.12.003

Rouphael Y, Kyriacou MC, Petropoulos SA, De Pascale S, Colla G. 2018. Improving vegetable quality in controlled environments. Scientia Horticulturae 234: 275–289. DOI: 10.1016/j.scienta.2018.02.033.