

The Future for Metabolomics

Metabolomics, a new technology, is a promising tool for food processors, food quality and safety laboratories, food chain providers, and also plant breeders.

by Gerard Klein Essink and Dr. Robert D. Hall

There is an ever-growing demand for better tasting, healthier and safer foodstuffs which better meet the needs of both industry and the consumer. This demand goes hand in hand with a strong desire to develop new tools to monitor and improve the quality of what we eat. Metabolomics, a new technology, is a promising tool for food processors, food quality and safety laboratories, food chain providers, and also plant breeders. The importance of this technology has been recognised by the EU Research division a few years ago, which is why they funded a multi-national metabolomics initiative focused on plant ap-

plications (www.meta-phor.eu). Metabolomics (see box), allows us to analyse the biochemistry of complex mixtures and to filter out the key information of greatest relevance. Metabolomics has already gained attention in the medical world where it is under assessment as a tool for disease diagnosis, disease prevention and also intervention. In the plant field, however, major challenges are faced with crops which are renowned for their biochemical complexity and metabolite mixtures which change with development, age, environment etc. The biochemical composition determines the quality of our food in terms such as nu-

tritional value, taste, fragrance and appearance, which is also a key factor in determining important food properties such as shelf life, nutritional stability and market value. European and global food policies continually demand even stricter monitoring and control of food quality (and safety) and there is a growing need for new tools to help us define and understand what we actually mean by 'quality' and how this can be effectively monitored.

Breeding Healthier Foods

In most diets, plant products provide the main part of human food intake, and the link between food and health

is becoming increasingly clear. Metabolomics can play an important role in improving the healthy value of plants. With metabolomics, a comprehensive set of biomarkers can be generated, which can be used to understand and monitor the interaction between food intake/uptake and human health. These data can provide essential indicators as to how food should be produced and offered to meet modern health needs. Metabolomics is predicted to become a cornerstone in this field. Metabolomics shall be employed to direct breeding strategies to enhance specific desired balances of food components in fresh food which have been identified as being more optimal. In addition, the technology shall prove pivotal to the further optimisation of food processing methods to help generate or preserve the desired nutritional balance in longer shelf-life strategies. However, before all this is possible in the most optimal way, the technology requires further development and fine-tuning.

Case 1 – Metabolomics and shelf life:

Having a better understanding of which processes are involved in product deterioration, and how these might be counter-acted, increases the supplier's ability to predict the maximum shelf life of a particular batch of product more reliably and to e.g. compensate for environmentally or source – related batch differences. In the META-PHOR project for

What is Metabolomics?

Metabolomics is an advanced, specialised form of analytical biochemistry. The technology focuses on the detection of small molecules which often play key roles in e.g. food quality, disease resistance, antioxidant activity etc. Important small metabolites include e.g. organic acids, amino acids, sugars, volatile metabolites and a myriad of secondary metabolites such as alkaloids, phenolic components and also pigments such as carotenoids and anthocyanins.



The aim of the approach is to gain the broadest possible overview of the biochemical composition of complex biological samples in just one or a small number of analyses. Chromatography (Liquid or Gas) are usually used to separate complex plant extracts into the individual components; Mass Spectrometry (MS) is then used to detect and if possible, quantify the metabolites present. Alternatively, Nuclear Magnetic Resonance (NMR) may be used. Metabolomics is primarily distinguished from more established technologies by the high throughput nature of the approach

which also generates a complex dataset per analysis. As a consequence, the technology relies heavily on recent advances made in bioinformatics and Information Technology in order to process, store and mine the complex data matrices for biological information. Metabolomics is usually used either for 'fingerprinting' samples to perform comparative analyses to detect differences or for 'profiling' where individual differential metabolites, perhaps linked to key quality traits, are identified for further analysis.

example, it could be shown that the transition between material before/after the quality limit is very short and the switch to a lower quality product (with developing off-flavours etc.) occurs in a rapid time-frame. The quest is on to link this transition to key predictors (biomarkers) present in the initial starting material as it arrives at the processing factory. A series of such biomarkers, identified through metabolomics, can then be used for a batch-wise determination of shelf-life.

Case 2 – Buying Foods: Is what you see what you get?:

Consumers demand year-round availability and consequently, foods are transported all over the world, blends are made of different oils from different origins to manage price volatility, guarantee availability etc. Quality control for food buyers is important and aspects of authentication grow in importance. The principle: what you see is what you get does not apply any more. More checks are needed to ascertain if the product value meets the specifications and if the reported source is indeed correct. Metabolomics is a rapid analysis tool and has a clear added value role in aspects of food authentication. What we need are so-called biomarkers for source, quality etc. Do these coffee

beans really come from Colombia? Is this red wine really from France etc.? Such biomarkers are already being identified for various plant products and with metabolomics potentially being a rapid authentication analysis tool, standardised applications in the food industry for the tracing and tracking of primary products are not far off.

Case 3 – Buying Foods: The risk of adulteration:

How pure is my product? Exclusive, high quality products justifiably command higher prices. Long

Metabolomics has been used to detect the use of cheaper apple puree to bulk up strawberry puree samples and to detect even small amounts (10%) of sunflower oil in virgin olive oil samples.



grain, fragrant Basmati rice is generally four times more expensive than non-fragrant long-grain rice. Extra virgin olive oils from certain regions of Italy and Spain have been developed for the high price range speciality market. The same is true for other quality products such as coffee, tea, wine etc. Adulteration of expensive products with cheaper variants is a common phenomenon used by unscrupu-

lous suppliers to bump up profit margins. For example, research has shown that Basmati rice is renowned for not being fully pure. Once again metabolomics has a role to play in providing a rapid screening tool for risks of adulteration. The technology has for example been used to detect the use of cheaper apple puree to bulk up strawberry puree samples and also to detect even small amounts (10%) of sunflower oil in virgin olive oil samples in an analysis lasting less than 2 minutes. Brucker has also developed their SGF Profiling

technology specifically for the authentication of fruit juices but of course, this technology can be adapted and rolled out for many other approaches.

Meta-Phor Project

An EU funded project started in October 2006 and was called METAPHOR (Metabolomics for Plants, Health and Outreach). The META-PHOR remit was defined as follows: To

generate knowledge on those metabolites in our food which determine key characteristics such as nutritional value, quality and health by developing the advanced tools required for their detection. This knowledge will facilitate better monitoring of the food production chain and will create new opportunities for targeted strategies for breeding, storage and processing. Work on dedicated strategies for the biochemical fingerprinting and profiling of plant metabolites has been carried out in the past years. Broad application of metabolomics is currently restricted by a poor ability to generate, process and store data in a standardised manner. Incomplete compound databases also limit metabolite identification. META-PHOR brought together key experts with proven track records, in a coordinated, multidisciplinary approach to deliver a phenotyping platform with potential for high throughput analysis. Statistics, bioinformatics and software tools will be developed and a sustainable database of plant metabolites will be initiated. META-PHOR focussed on three crops - Brassica (Broccoli), melon and rice. The project was designed to enable the research to cover the full range of key metabolite groups and micronutrients of importance to plant biology, crop quality and nutrition and which are key components regarding e.g. biofortification and nutrigenomics issues (see table 1).

Uniting Research

A key product of the META-PHOR project was to unite the main research groups in Europe in order to bring this new technology to the next level. Many new approaches and improved Standard Operating Practices have been generated for the three targeted crops but these methodologies are already being widely applied to a much broader range of plant materials. Key chemical com-

Table 1: Summary of the Key Groups of Metabolites Present in the Crops Chosen Which are Linked to Nutrition, Health Promoting Effects and Quality

Crop	Key Phytonutrients	Relevance	Profiling Technology
Broccoli	Phytosterols Glucosinolates Flavonoids Vitamins Folate	Health Applications Potentially Anti-Cancer Antioxidants, Health Nutritional Value Health Benefits	GC-MS / NMR LC-MS / FT-MS / NMR LC-MS / FT-MS / NMR LC-PDA-MS NMR / LC-MS
Melon	Isoprenoids Flavonoids Sugars Volatiles	Antioxidants/Quality Antioxidants, Health Flavour/Taste Fragrance	LC-PDA-MS LC-MS / FT-MS / NMR LC-MS / GC-MS GC-MS LC-PDA-MS
Rice	Micronutrients Volatiles Vitamins	Nutritional Value Quality/Market Value Nutritional Value	LC-ICP-MS GC-MS LCMS / GCMS

Note: GC-MS: Gas Chromatography-Mass Spectrometry; NMR: Nuclear Magnetic Resonance; LC-MS: Liquid Chromatography-Mass Spectrometry; FT-MS: Fourier Transform-Ion Cyclotron-Mass Spectrometry; LC-ICP-MS: Liquid Chromatography-Inductively Coupled Plasma-Mass Spectrometry.

ponents linked to taste, flavour, nutritional value etc. have been characterised and we now have a better understanding as to how metabolomics approaches can better be applied in an industrial context.

Vegetable Potential

Potato and tomato crops represent two of the world's top four most consumed vegetables, with varieties having been bred to grow in a wide range of climatic conditions with highly varying temperatures, degrees of humidity, soil composition, day length etc. Considering their importance, it is therefore not surprising that both have already been the subject of extensive metabolomic investigations.

Potato Metabolomics

In particular, the development of a better potato, via the introgression of different metabolite contents and diversities, with a view to developing new varieties has been addressed by

different groups working with wild species collections. For example, the Commonwealth Potato Collection – 1,500 accessions of about 80 wild and cultivated potato species – was sub-sampled and analysed by Gas Chromatography-Mass Spectrometry (GC-MS) focussed metabolomics. These analyses clearly showed that specific taxonomic groups segregated on the basis of their biochemical composition (e.g. amino acids, sugars). Others have utilised alternative metabolomics technologies, to assess compositional differences in existing potato cultivars. The levels of the amino acids isoleucine, tyrosine and phenylalanine were found to be higher in certain cultivars – an important finding as these amino acids are associated with flavour/aroma, post cooking blackening and bruising.

In addition, metabolomics on potato is also revealing chemical links to quality issues not

previously recognised, thus emphasising the value of this broad approach.

Tomato Metabolomics

Tomato is perhaps the most widely studied crop using metabolomics technologies. Investigations into varietal differences, cultivation influences, genetic modification have all greatly advanced our knowledge of the biochemical composition of the tomato fruit and how this is altered by environment and genetics.

Key components playing determinant roles in taste characteristics – both positive and negative – have been identified and can be used as quality predictors. The influence of seasonality and growth conditions on fruit quality has revealed extensive, previously unknown changes and help us explain better why e.g. batch/source differences are so frequently observed even when using the same hybrid variety.

The Way Forward

So, is there a future for metabolomics? Yes! The technology is still under development but is already well established in many fields. The amount of data which can be generated, analysed and turned into a biologically-relevant knowledge is huge. Companies, which are leading in the analytical field (like LECO, Bruker, ThermoFisher and Waters) continue to develop advanced technologies and some have started to build their own databases for metabolites in plants, which is of great help to scientists to further develop know-how and applications of the various technologies. ♦

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