Plant Metabolomics and the Golden Age of Dutch painting

Prof. dr Robert D. Hall

Inaugural lecture upon taking up the post of Special Professor in Plant Metabolomics at Wageningen University on 24 April 2014

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Ladies and gentlemen, welcome! I feel very privileged that you all have taken the time off to be here today and join me in this ceremony. I would like to give a special welcome to the rector and my colleague professors on the podium and also my scientific and non-scientific colleagues, friends and family in the audience. My aim this afternoon is to educate, stimulate and maybe even entertain you and I hope that by the end of this oration at least you will understand what this word metabolomics actually means and why it is now central to my world.

Mr Rector, I would like to start by expressing a deep-felt honour to be accepted for this position as Professor of Plant Metabolomics within The Plant Sciences Group. Not only was Wageningen recently internationally-recognised as being the best in the world for Agroscience education and research but also, the Plant Science Batchelor's programme has been voted for the 9th time in succession as being the best Batchelor's programme in the Netherlands. I greatly appreciate the trust bestowed in me and the belief that I have been considered to have something to contribute to this organisation. I shall do my utmost to advance the research and teaching strength of this University whenever possible.

Ladies and gentlemen, perhaps you found my title intriguing – I hope so - because that was of course my intention! Many of you who know me will know that I have many hobbies, mostly related to art and culture. But considering how much free time I spend on my work, science is in fact my biggest hobby of all. And while we shall touch on a number of important topics during this oration, and I shall illustrate my passion for the important and exciting field of plant metabolites, my aim is that you will even learn something more than just about science and that I can trigger your thoughts on broader issues. I hope the little diversions from science into the wonderful world of art will help keep your attention - and that you don't find it too contrived.

Figure 1. Danica Camancho, born in The Philippines on 1st July, 2011. The 7 billionth world citizen!

Please let me begin by placing our work in its broadest societal context - which centres around crop production. Danica Camancho (Fig. 1) was born in the Philippines on July 1st 2011 to become the 7 billionth person on the planet. And as many of you know, while it has taken us a few million years to reach a population of 7 billion, by 2050 the World Health Organisation predicts an extra 2 billion people will be living here. This drastically-expanding population not only needs to be fed but also, will need things like paper, wood and cotton clothing all of which also come from crop plants. But there are some even more staggering figures which must also be considered. Despite our highly advanced civilization, still today more than 850 million people do not get enough to eat every day while, at the same time mainly in other countries, one billion people are now medically overweight. Another 500 million are officially 'clinically obese'. This situation is almost incredible. It is going to be a major challenge to solve this combined problem of food production and food distribution but I believe we are up to this challenge.

"All plant scientists have an ethical, social and corporate responsibility to tackle pro-actively these future threats to our global society"

We all, but scientists in particular, have a moral obligation to tackle this huge dichotomy – and to come up with sustainable preventative solutions and avoid the problem escalating further as our population grows. But this does not mean that I believe we should all work on applied research. On the contrary, we must retain a healthy balance between fundamental and applied research to guarantee sustainable long term research lines. My personal choice has always been for applied research –

right from my PhD - but the recent cut backs in opportunities for more fundamental research in The Netherlands, of the type funded e.g. by the Netherlands Genomics Initiative, has brought our national research programmes out of balance. This is especially true for fundamental science, and unrealistic demands are being placed on industry. I very much hope that this situation can be corrected soon, before too much long term damage is done, so that the Netherlands, and also Wageningen University, remain at the very top of the Agricultural sciences.

What we need are new crop varieties for food and feed which deliver higher yields, in a smaller production area and with better quality. We also need to think about developing crop products which better suit our increasingly sessile, desk-driven life style and hence, reduce the problem of overweight. Furthermore, these new varieties need to be grown in a more sustainable and environmentally-friendly manner, through reducing the need for agrochemicals such as fertilizers and pesticides, and hence decreasing the strain on our environment. This is a very tall order indeed!

"To achieve such goals we need a much better understanding of the molecular basis of cell physiology and especially, plant metabolism"

We must expand our basic knowledge in order to achieve these goals and to have an even better understanding of how plants grow. And because a great many of the reasons we use crop plants specifically relates to the biochemicals they contain, it is essential that we build up a better understanding of how, when and where plants synthesise and store key metabolites.

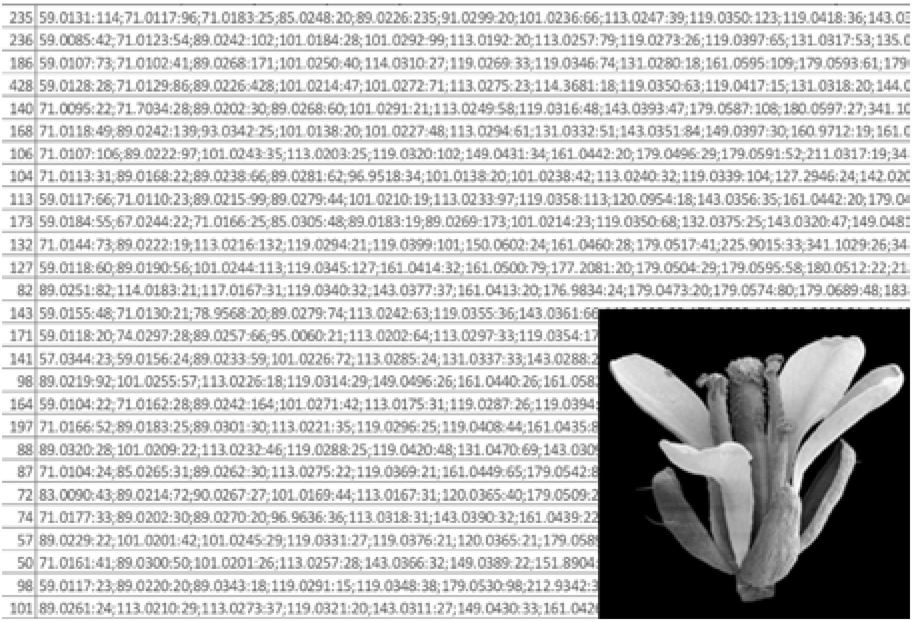
What is metabolomics?

It is now time to introduce what we mean by the term metabolomics. Plants produce many chemicals, which we call metabolites, and metabolomics is a relatively new technology which we use to analyse these metabolites. Metabolomics focuses on the smaller metabolites but small does not mean unimportant. This group includes nearly all the essential nutrients we need such as sugars, amino acids and vitamins etc. In addition, we also find a myriad of weird and wonderful small metabolites in plants which determine things like flavour, fragrance and colour but also whether plants are poisonous or not. This is a hugely relevant group of metabolites in a crop context.

Metabolomics is a so-called 'multi-disciplinary' science. The technology is not straightforward as you need to call on a broad background knowledge of many disciplines – from chemistry, to statistics, to computer science – but by far the most important is knowledge of biology. Metabolomics is therefore a 'team sport' as it is rare to find an individual scientist who can properly cover all these expertises. This is one of the aspects of the science which makes it so exciting to work on. Metabolomics therefore, feeds into our expanding need for biochemical knowledge and helps us to formulate hypotheses about plant metabolism which can then be investigated further in greater detail.

"Metabolomics is nothing more than a tool – it is a starting point and never an end point"

So metabolomics is actually just a tool and perhaps you are thinking that this not a proper topic for a Professorship. However, the true value is not in the technology but in the data that we can generate and how this can be interpreted to advance our knowledge of biology. So let us consider for a moment how we actually interpret the data we are exposed to – not just in science but also in our daily lives.



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101	89.0261:24;113.0210:29;113.0273:37;119.0321:20;143.0311:27;149.0430:33;161.042

Figure 2. A screenshot of ca 1% of a metabolomics dataset from a single analysis of an Arabidopsis leaf extract.

Figure 2 shows a tiny part of a metabolomics data set – just about 1% from a single analysis of an Arabidopsis leaf. It is not the most exciting slide to look at and I am sure I would lose your attention very quickly were I to proceed to describe in detail how we interpret this kind of data.

Figure 3. A typical painting from the Golden Age by Jan Davidszoon van Heem (1670) depicting a wide variety of flowers, but which also contains more information than might be first visible. The original is in the collection of the Rijksmuseum, Amsterdam.

Here (Fig 3) is a more recognisable and audience-friendly example. You might not think it but this is also a data set – this painting contains information which we can only extract if we look correctly. The way we look and interpret the things we see is wholly dependent on our using all our background knowledge combined with proper observational skills. For example, say you know nothing about plant science and I were to ask 'What do you see here?' you would probably say 'a bunch of flowers'. Which is of course true. But there is more – much more. If you are a keen gardener and have taken a good look at the painting, you should have seen that at the top left there are spring flowers such as apple blossom and tulips while at the bottom right we also have plums, a fruit of the late summer. Considering this painting comes from a time when there were no fridges or aeroplanes etc, we can already conclude one of two things – either the artist painted from memory – or (what is actually the case) – he painted different parts of the painting when different plants came into season. This painting will have taken one or two years to complete. But is that all the information presented here? Well actually no! - because we are still missing the entire point of this painting. The artist is actually telling us something but without learning his language we will never get the message. This message is actually repeated in perhaps 10 different places so let me pick just one to illustrate my point.

At the very pinnacle of the painting we have the tulip (circled). As you all know I am sure – Holland is famous for its tulips and this fame actually stems from this period in Dutch history – around the 17th century. A tulip bulb was the most prized possession you could possibly own and the ultimate type was the red and white striped variety as illustrated here. Indeed a single bulb was literally worth millions in today's terms, people were murdered for them and in Amsterdam, private armies were employed to guard them. So what is being shown here is actually not so much a flower but a representation – a symbol - of extreme beauty and extreme wealth. But the story does not end there because you need to have some background knowledge of tulip physiology (and which Dutch person doesn't?) to get the full meaning. You can see that the petals of the flower are opening widely – and anyone who has had a bunch of tulips in a vase may recognise that when the flower opens its petals like this, it is actually dying. Indeed, if you were to kick the leg of the table the vase is standing on, the petals would likely all fall to the ground. And so here is the real (Calvinistic) meaning in this painting, the information located in this dataset – it doesn't matter how beautiful or how rich you are – life is transient. We are all going to die! So probably you will now look at this type of painting in a totally different light because you now have the background knowledge to interpret fully what you see.

"Science is facts. Just as houses are made of stones, so is science made of facts: but a pile of stones is not a house and a collection of facts is not necessarily science"
Henri Poincaré, French philosopher and mathematician

So it is our ability to interpret the data which determines the value of metabolomics and not the data itself and hence it is the biologist, as with all data rich science, who must hold the lead in metabolomics research.

Developing a generic technology

Metabolomics is a technology which has very broad application – I shall only talk about plants but of course, the technology is applicable to any living system, including in the medical and microbial sciences. But here we shall solely focus on crop plants where the diversity of applications already covers topics such as seed viability, fruit ripening, flower colour, toxicity, taste and fragrance, disease resistance, etc. The technology has only been around for roughly 10 years and indeed the first metabolomics conference ever held was organised by myself and Raoul Bino in 2002 here in Wageningen. This meeting was just on plants but very soon after the broader community got together and in 2005 we had established the International Metabolomics Society and organised the first meeting in Tsuruoka, Japan. Indeed we shall go back to Tsuruoka this year to celebrate our 10th anniversary. In 2010, Prof. Thomas Hankemeier and myself organised the 6th meeting in Amsterdam which was attended by 700 people. Popularity continues to grow, primarily because of the considerable unique added value this approach gives in terms of biochemical composition and because many biologists quickly recognise how this approach can help progress their field of science.

Figure 4. Metabolomics application is centred around the use of advanced, state of the art equipment such as mass spectrometers (left and middle) and NMR machines (right).

Metabolomics is however an expensive technology. We need e.g. quite a number of machines – the mass spectrometers shown in Fig. 4 are just some of those installed with us here at the Plant Sciences Group in Wageningen. The costs range from ca. 100,000 - 600,000 €. But it can be worse! On the right is e.g. a 900 MHz NMR instrument at Kazuki Saito's RIKEN Institute in Yokahama costing I believe ca. 12M$. But these high costs are justifiable because these machines give us extended means to progress in improving our understanding of the biochemical composition of plants.

Hijacking plant metabolism

So essentially, I place metabolites completely central to our world. And plants especially, are tremendously rich sources of these small metabolites which they naturally produce to help them survive in a hostile environment. But from a crop perspective, humans have basically learned to hijack many of these metabolites and exploit them to our own benefit. As well as the nutrients in our food, plants make tasty flavour metabolites to entice us to eat them- and plants provide us with perfumes but also with poisons. Furthermore, through many and diverse chemical groups, industries have been established for producing e.g. insecticides – pyrethrin is a good example – but also pharmaceuticals. Indeed, the inspiration for between 25-50 % of our drugs has its origin in plant metabolites. For this reason, considering the Dutch government strongly encourages scientists to collaborate with industry, and I would applaud that, metabolomics gives us an entry point into many industries – not just for food but also the health, cosmetic, agrochemical and pharmaceutical industries. But while man has learned to hijack the plant as a source of interesting chemicals so also have many other organisms.

Figure 5. A detail from a painting by the Dutch artist Jan van Huysum (1723). The original is in the collection of the Rijksmuseum, Amsterdam.

Insects have also learned to recognise plants on the basis of the chemicals they produce. In Fig. 5 we see a small part of one of the most beautiful paintings in the collection at the Rijksmuseum in Amsterdam. Insects recognise flower scent and are attracted to visit the flowers to collect nectar (of course also a chemical mixture - of sugars and amino acids) and so doing may pollinate the plant. But other insects have also learned to hijack this system – but solely to their own benefit. These insects use plant chemicals to identify places where they can lay their eggs which will later hatch out into caterpillars which will then devour the plant. Remember – life is transient, even for plants!

Figure 6. A still life painting of white Asparagus by Adriane Coorte (1697). The original is in the collection of the Rijksmuseum, Amsterdam.

So the importance of plant metabolites often lies in their so-called bioactivity. This means that they have some kind of physiological effect on themselves or on other organisms. We, like insects and other animals, can recognise the chemicals which plants produce and use these chemical signals throughout our lives to identify food, toxins etc. But also, after we ingest food our bodies can again internally respond in many ways – some chemicals are taken up as food nutrients while others can induce wholly different effects. For example, white asparagus (Fig. 6) is my favourite vegetable – it is right this moment in season. As many of you will know our bodies respond to eating asparagus in quite a remarkable way. If you have ever had to go to the toilet shortly after eating asparagus you will likely remark that your urine has obtained a very characteristic odour. This comes about because asparagus, as well as containing valuable nutrients, contains several chemicals which our bodies clearly don't like. These include several sulphur-containing metabolites which immediately get broken down in the liver and excreted into the urine in the form of e.g. dimethyl sulphide and methane thiol. Being S-containing molecules they have a not-all-too-pleasant odour. There is an interesting anecdote here because for many years it was thought that some people did this and some didn't. Indeed there are scientific publications in the 1960's and 1970's stating that e.g. only 50% of Americans made smelly urine while 80% of Southern Europeans did. But it was only when someone actually did the proper experiment of getting a group of people into the lab, feeding them Asparagus and letting nature take its course, then doing the analysis, did they discover that practically everyone makes smelly urine! Those who thought they didn't make a smell actually did do so but instead, lacked a specific smell receptor in their nose. So they were unable to detect the smell and had thus been going through life in blissful ignorance of what they were doing. So while we are continually focusing on the plant angle and trying to link plant metabolism to plant genetics, in a food context, we must never forget the human genetic component in the food interaction equation. Despite being one species we can all respond and react quite differently when exposed to plant metabolites.

Stimulating inspiration

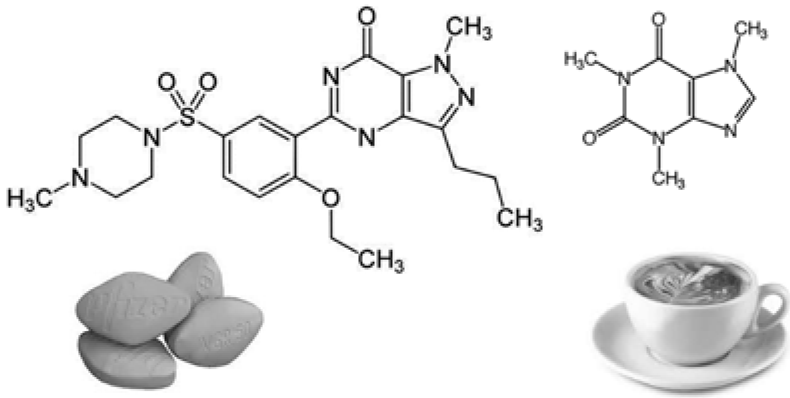

Figure 7. (Right) the chemical structure of caffeine, a well-known constituent of e.g. coffee. On the left, a much more complex molecule which has become the active ingredient of the commercial product Viagra.

Inspiration for industry

Plant metabolites have historically been the inspiration for many of the drugs we use today. In the middle ages people chewed willow twigs when they had a headache and as we now know, this worked because willow bark contains salicylates which became the active ingredients in Aspirin®. And there are a multitude of other examples. However, despite all our knowledge we can still be duped into incorrect lines of reasoning. In Fig. 7 (right) you see an interesting small and very well-known metabolite. It is caffeine and we all know that caffeine is a stimulant, a vasodilatant and also has certain addictive properties. The molecule on the left is clearly much more complex but I hope that you would agree that the right hand part is not a million miles away from caffeine – a 5 and a 6 ring both with 2 nitrogens, methyl groups etc. This molecule was actually being tested as a possible treatment for heart and vascular disease, but it was only when it got to the clinical trial stage did it become clear what its actual physiological effects are. This molecule eventually became the active ingredient in VIAGRA and the rest is history. So although we might think we know a lot about plant biochemicals and their potential effects, nature can still provide us with some surprises showing that there is still a lot to learn!

So plant metabolites still hide many surprises but this is actually something we have known for a very long time – coming back to art – many still life paintings of the Golden Age are of food. Lemon fruits (Fig. 8) were very regularly depicted as they provide for the artist a wonderful colour contrast and also, they reflect wealth as only well-off people could afford them. But in many paintings you will see that lemons are nearly always painted as being partly peeled. We all know that lemons contain a lot of acidic metabolites giving an intense sourness - and here is another example of symbolism – again a warning – no matter how nice things may look on the outside there is often a nasty surprise on the inside – even in life – it is a sort of 'don't judge a book by its cover' warning.

Figure 8. A typical still life painting of food products from the Golden age painted by Willem Kalf (1655) depicting typical foods of the time and including the lemon as a colourful, luxury item. The original is in the collection of the Rijksmuseum, Amsterdam.

Paradigm shifts in plant metabolism – fruits and seeds

Staying with fruits for a moment – fruit ripening is a developmental process which is perfectly suited for study using metabolomics. Ripening is a tremendously complex process involving an incredibly broad range of plant chemicals. Even after fruits have reached full size they have to go from a hard, astringent, greenish thing to a bright red, succulent, tasty thing. This involves changes in everything from sugars, fragrance components, pigments etc. And despite the complexity, these changes can happen phenomenally fast and in a brilliantly coordinated manner. In strawberries, this takes just 4-6 days. In tomatoes it takes a bit longer – and for some varieties, much longer indeed. While some fully-grown fruits only need about 10 days to ripen other varieties may need up to 40 days to generate ripe fruit. I am sure you realise that a farmer growing the varieties with the shorter ripening period has literally one month longer production than one who grows the slower ripening varieties. We therefore need to understand better what are the causes of these differences in ripening – where are the blockages and limitations? We need much more detailed knowledge of the molecular basis of fruit ripening and metabolomics is already being used to help us generate new knowledge which in turn, is being used to develop new tools to apply in breeding for crop varieties which have optimal ripening characteristics.

Seed germination is a similar system – here also we talk of a paradigm shift in metabolism where once again many different metabolite biosynthesis pathways are involved in the switch from a dormant seed to a viable, rapidly-growing young seedling. Here again, metabolomics is an excellent tool to use to advance our knowledge of this complex network of molecular events.
Staying with seeds, even for the most important crop on the planet – rice - we have found a significant role for metabolomics. At the start of this lecture I mentioned the dilemma of the growing global population. The fact is that the majority of the extra mouths we will need to feed will be in predominantly rice-eating countries. We drastically need better and more productive rice varieties.

"Increasing rice yield alone is not enough"

Focussing on yield is not enough. Of course if someone is starving they will eat anything. However, we have an ethical obligation to avoid reaching that stage - as plant scientists we must be pro-active in designing varieties which will meet diverse future global needs – and that does not mean a single super rice variety.

What we see in Fig. 9 is some work done by my PhD student Fe Calingacion who carried out a survey of consumer preference for rice types in Asia. We have data on many different attributes such as flavour and fragrance, starch content and even grain size and shape as is illustrated here. You might think size and shape are unimportant but that couldn't be further from the truth. Grain size and shape determine mouth feel – how a spoonful of cooked rice feels in your mouth – this is a very important attribute in the food industry. As you can see, preferences indicated by the colours and patterns, vary widely. In the Punjab region of India and Pakistan people generally only eat very long thin grains typical of Basmati rice whereas in other regions of India they prefer shorter grains.

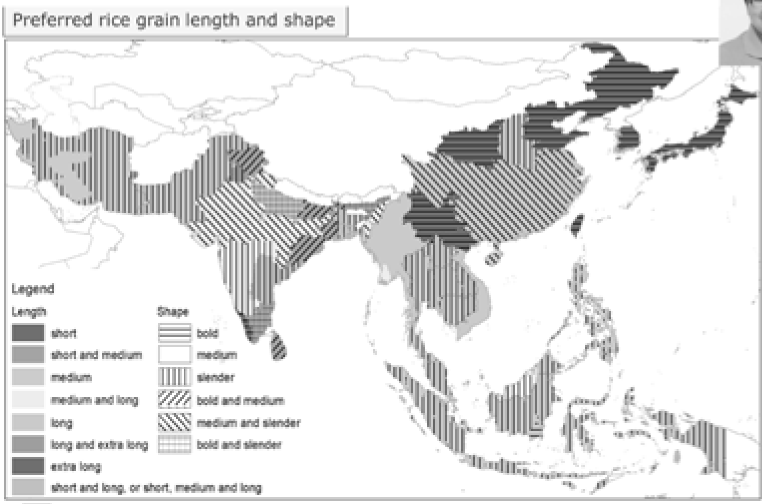

Figure 9. A map indicating consumer preference for different rice types (based on grain size and shape) in S.E. Asian regions. Modified from Calingacion et al., (2014) PLoS One 9, e85106, pp 1 – 12.

Taste is also of huge importance as we were able to illustrate in a workshop I organised in Laos in 2008 as part of the EU META-PHOR project. Here, we brought together 25 rice breeders from about 20 different countries, several of whom had never been abroad before, including breeders from Pakistan and Iran. These people had never tasted Jasmine type rice while the S.E. Asian breeders had never experienced Basmati rice. So we cooked for them Basmati and Jasmine rice both of which are fragrant rices. While the people from Iran and the Punjab found Jasmine rice tasteless, the S.E. Asian breeders unanimously found Basmati disgusting. The slightly rancid taste of Basmati, resulting from the typically long storage times needed for Basmati rice before sale was not at all to their taste. Can metabolomics play a role here in defining the basis of these differences? Most certainly! But the challenge is extensive as rice is 92 % starch and 7% protein. That leaves only 1% for the rest but we have shown it is possible to apply metabolomics to find many tasty metabolites in this 1% which define the differences between Jasmine and Basmati rices. Metabolomics can and is already being used to assist the rice breeder to also breed for quality attributes. As the first result of this, 2 new prototype varieties have been produced in Laos where high yield and good taste have now been combined for the first time.

Differences & similarities

You may have already noticed that we are fixated with differences. We want to know which differences determine that a plant is e.g. resistant to a disease, which metabolites determine good or bad taste etc? We tend to forget about the similarities but these are potentially just as important. Common features, including metabolites, determine what makes a species a species and a leaf a leaf. Using therefore, a high throughput instrumental approach also allows us to identify the common denominators. And this is important in biodiversity screening and stewarding genebank collections. However, working simultaneously with 100-1000s of metabolites makes life very complex. An instrument – based metabolomics approach with dedicated computer software is essential both to deal with the size of the challenge but also to help us overcome the bias our trained minds usually have. The human mind has a tendency often to focus either on the similarities and we fail to see differences or on the differences and we miss the similarities. So with the vastly complex information we can generate it is a characteristic of metabolomics experiments that we have to rely to a major extent, first on software tools and then on statistics to help with the initial analysis – but not the interpretation! In Wageningen, we also will continue to work on the design of such metabolomics tools to advance the use of the technology even further.

"The correct application of metabolomics implies a strong reliability on the use of dedicated in silico tools and statistical approaches for data analysis prior to their biological interpretation"

What are the new challenges?

Metabolomics is a technology which is already advancing our knowledge of plant biochemical composition. So what are the future challenges which I aim to tackle with this new approach?

Plant-pathogen and plant-insect interaction is one such topic. The document copied in Fig. 10 is the official certificate of citizenship of the United States of America which was issued to my great grandfather in New York in 1872. He, together with his two brothers, emigrated from the UK to America in the 1860's and as a result, my grandmother was born there making me and my brothers still one quarter American.

Figure 10. Official certificate of citizenship of the United States of America, issued in New York in 1872.

But my ancestors obviously did not like America because they returned to the UK in the early 1890's where some years later, my mother was born. But how on earth is this relevant to plant biology? Well, the reason of course for this emigration was that we come from the island of Ireland and as we all know, around 1850-1860 the population was devastated by the almost complete loss of its staple food, the potato. The arrival of a new aggressive variant of the oomycete pathogen *Phytophthora infestans*, causing 'late blight', meant crop production fell to just a few percent of the usual level. Almost three million people emigrated and about 1.5 million people starved to death. Today, some 150 years later, we still do not have potato varieties with sustainable resistance to late blight. This is a hugely challenging problem because the pathogen can rapidly evolve while a potato variety, as a vegetatively-propagated crop, maintains a fixed genetic composition. I look forward to working with our plant pathology colleagues, to use metabolomics as a wholly new approach to study and analyse this plant-pathogen interaction and perhaps come up with novel information which can lead to newly-designed strategies to design long term resistance mechanisms in this important crop to generate new varieties which are more sustainable than the current ones.

Screening for and preserving plant biodiversity is also a topic to which metabolomics can contribute - both for crop plants and for as yet unchartered wild species containing potentially interesting metabolites. We shall use metabolomics to find interesting new bioactives which have industrial application potential – both for food and non-food applications. But there is also a lot of hidden diversity even within existing crop varieties. We were able to show this recently within the CBSG tomato quality programme, coordinated by Arnaud Bovy. Here, we used metabolomics to analyse chemically 94 different tomato accessions and we were able to demonstrate that even within such a small collection, metabolite concentrations can vary by up to 60-80 fold. Knowing which genotypes contain the highest / lowest levels of desired / undesirable metabolites provides us with the means to design targeted breeding strategies aimed at quality attributes and optimal biochemical composition. I look forward to applying metabolomics further to support biodiversity screening goals – both in a national genebank context but especially for wild species which we risk losing before we even know what exciting metabolites they contain.

Figure 11. Colour pattern in a lily flower is clearly visible as the purple pigments are visible to the naked eye. The use of LAESI technology may make it possible to localise also metabolites which are invisible to the eye, to specific regions of a plant tissue or organs and hence, will add an extra dimension to our ability to analyse plant metabolism.

Finding out exactly where metabolites are stored in plants is also a challenge. Are they made everywhere in a tissue or organ – or just in certain cell types? And if so –

why? When we have visible metabolites such as purple anthocyanins in flowers (Fig. 11), it immediately becomes obvious that these are often only present in certain cells and regions of the flower petals. Unfortunately however, >99% of plant metabolites are not visible to the naked eye and we know little of their location. Evidence is however, growing to indicate that metabolites are often not uniformly distributed within plant tissues and organs. Mass Spectrometry imaging is therefore a potentially powerful technology which has the potential to help us locate metabolites within living tissues. We are very lucky in Wageningen that we have one of the newest instruments, based on LAESI® technology which can be used to locate metabolites within plant organs. I look forward to developing methodologies to be able to use this approach for so-called 'spatially-resolved' metabolomics.

"There are known knowns; these are things we know that we know. There are known unknowns; that is to say there are things that, we now know we don't know. But there are also unknown unknowns – there are things we do not know, we don't know. "

US Secretary of State, Donald Rumsfeld, Brussels, 2002

A major technical challenge also remains – which is that, with metabolomics, we can now detect huge numbers of metabolites. However, as these have never been characterised before we don't yet know what they are. The metabolic richness of the plant kingdom reflects its huge potential while simultaneously, emphasises our Achilles heel regarding chemical identity. This is beautifully illustrated by this brilliant quote from the US Secretary of State (above) who used it to describe hidden threats to world safety – but he could easily have been talking about metabolomics. Within Wageningen UR we shall continue to develop the dedicated tools needed for the analysis and identification of novel plant compounds with biochemical and potential industrial relevance.

"Scientists are generally poor communicators when it comes to the general public"

Another general and challenging issue – not just for metabolomicists but for all scientists - is the growing need to broadcast the importance and influence science has on all our daily lives. Scientists are generally poor communicators but it has never been more important to ensure the general public is informed and better understands what we do and how this is hugely relevant to their own quality of life. When I was Managing Director of CBSG, I also had responsibility for coordinating our communications programme with the general public. We organised many successful outreach activities via direct and indirect means, often reaching out to hundreds of thousands of people via television and daily newspapers. Even through linking state-of-the-art science with art and design (e.g. Fig. 12). However, the switch from coordinated research programmes to individual projects in The Netherlands will inevitably mean such activities will become more and more difficult. These activities cost money – through the Netherlands Genomics initiative for example, we could fund the mobile DNA labs where University students visit schools bringing advanced equipment allowing secondary school children to do advanced experiments. This hugely successful and highly-valued programme, reaches out to ca 25,000 high school pupils a year – but this does cost ca 300,000 € / year. This is still only ca 10€ / child but nevertheless such activities are now difficult to support even though as scientists we are still obliged, and correctly, to make the citizens of the future aware, enthusiastic and supportive of science.

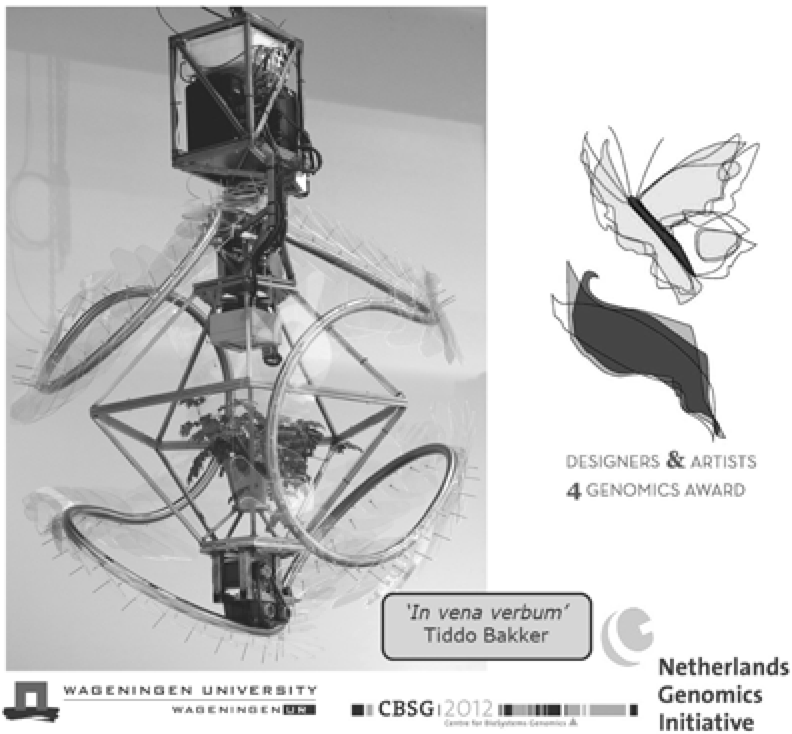

Figure 12. 'In vena verbum' A product of the interaction between scientists and an artist-designer. This mobile installation combines the use of high tech detection of plant stress with a mobile design element to visualise the stress status of the plant. 'Plants have feelings too' Designed by Tiddo Bakker with scientists Henk Jalink and Rob van der Schoor, Plant Sciences Group WUR.

But communicating science is not always easy to get right. We have been working for many years in a European consortium on the potential health importance of anthocyanins – the purple pigments found in most plants and predominantly in foods such as blackcurrants and grapes. Anthocyanins are so-called antioxidants which may influence our health in several different ways. Various experiments have shown that supplementing diets with purple rather than the normal red tomatoes can have significant influence on the incidence of cancer, but also heart disease and obesity in mice. Blood oranges have also been shown to have similar effects, indicating that it is not just related to tomato. So we wished to broadcast and generate awareness for our results and, these days, we have a potential global audience through the world of Google. So together with British and Italian collaborators, we brought out a joint Press Release when the first paper was published in Nature Biotechnology. Following Google we could see that no less than 1,000,000 extra pages on purple tomatoes appeared on Google within 48 hours - meaning that one million times someone uploaded something about our paper to the world-wide web!

Figure 13. The publication of the first results on the potential dietary importance of the purple tomato, as an anthocyanin-rich food, gained broad global attention and made the front page of many national newspapers.

But why such broad attention? – I believe there are two clear reasons - firstly the topic – the combination of food and health is always popular with journalists and editors alike. But I have to say pictures also play a very important role.

"Pictures don't just tell stories they sell stories"

The Jamie Oliver – type picture in Fig. 13 (left) was cleverly included by the John Innes Centre (Project Coordinator) together with the Press Release and this image went all around the world, getting the story onto the front pages of multiple national newspapers and into main evening news programmes. However, despite our best intentions, journalists can still demonstrate a mind of their own and decide to juice up the story just that bit too far – using PhotoShop you can make wonderful creations in the gaudiest of clearly, unnatural colours (Fig 13 (right)). These can inadvertently, or deliberately, bring across exactly the opposite message than we initially intended. Nevertheless, this should not deter us from continuing to communicate on our results. Communication on science has never been more important in this world of social media but there can be both risks and frustrations attached.

In conclusion

So to summarise – I hope that I have made you enthusiastic about the field of plant metabolites and how they play a central role in all our lives at many different levels. Plant metabolites are often the primary reason why a crop plant is actually a crop plant. We greatly need to expand our knowledge of how plants make their metabolites and I hope that I have convinced you that metabolomics has a clear role to play in expanding our understanding of when, why, where and how plants make these things that we need and exploit so extensively.

Thank you

All that remains is to thank a number of people who have played an influential role in my arrival to this position today. I would like to start with Ric de Vos and Roland Mumm together with our team of assistants at PRI. Without you all I would not be standing here today. Together we have established a fabulous facility resource and although the investments we have to make to keep up with the state of the art can be scary, we have so far succeeded in keeping ahead - both financially and scientifically. The initial role of Raoul Bino in getting us established was also hugely important for our future success. That we have, as a small group, produced over 150 publications in just 10 years is a great tribute to our team effort. At a huge risk of forgetting someone, a special mention should also go to Arjen Lommen as well as Arnaud Bovy

and Yury Tikunov who are based in other parts of our organisation and with whom we have worked very closely in the past. I would also like to thank all my long-standing colleagues both within Bioscience and within CBSG who have been such an important part of my life over the last 10 years and who have provided such a stimulating and pleasurable working environment. I would of course also like to thank Harro Bouwmeester and his colleagues at Plant Physiology for welcoming me into their group. I look forward to building up a strong relationship with you and establishing my own group over the next few years to complement your current activities and to establish collaborations within our key fields at plant physiology. And last but not least I would like to express my great thanks to Andries Koops and Ernst van den Ende for their support regarding my promotion to this position and for making it financially possible through Plant Research International funding.

Finally, I would again like to thank each and every one of you for coming today,

Ik heb gezegd!

Prof. dr Robert D. Hall

'The biochemical composition of plants determines their appearance, physiology and ability to survive and propagate in a permanently hostile environment. Furthermore, the biochemicals plants accumulate have a phenomenal influence on our daily lives. They provide the (micro)nutrients we need, determine flavour, release intense perfumes, produce lethal poisons etc. Plant metabolomics has developed into a valuable tool with which to study plant biochemistry and to help us generate a mechanistic understanding of how plant metabolism is subject to genetic and environmental influence.'

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