Resolving the postharvest loss paradox

Prof.dr Ernst J. Woltering

Farewell address upon retiring as special Professor of Product Physiology and Quality at Wageningen University & Research on 8 September 2022

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Resolving the postharvest loss paradox

Dear Mr Rector Magnificus, dear colleagues, family and friends,
The title of my farewell lecture reads "Resolving the postharvest loss paradox" and is accompanied by a photograph of people enjoying themselves at the *La Tomatina* festival that is held every year on the last Wednesday of August in the city of Buñol near Valencia, Spain. At the festival people throw tomatoes at each other just for the fun of it. Although the tradition has a complex historical background, it is nowadays just a joyful event and a major touristic attraction.

The close to 200.000 kg of tomatoes that go down the drain during the festival can be considered food waste. Perfectly good and eatable food is thrown to waste.

Food waste and loss and the postharvest loss paradox

Food **waste** mostly occurs at the end of the food chain, in supermarkets, restaurants, catering services, and at the consumer home. In all these cases, good eatable food is not used for human consumption. It is estimated that in Europe, approximately 20% of the food is wasted. That means, the food is produced, stored, processed, packed, and transported in good condition to the supermarket, restaurant or consumer, but finally it is not eaten but thrown away.

Apart from food waste, there is food **loss**. We speak of food losses when food products are lost or its quality declines in the distribution chain starting immediately after harvest at the farm and in the subsequent steps from farm to market, retail or consumer. So here, the food does not even reach the consumer in acceptable quality but is lost along the way.
So, there are losses in the beginning of the Food chain and there is waste at the end of the chain.

In 2004 I was at an International Postharvest Symposium in Italy where there was a talk by Adel Kader from the University of California in Davis. He showed results of an investigation on postharvest losses that was sponsored by the Bill and Melinda Gates foundation. Among others, a slide of food spoilage in different parts of the chain and in different parts of the world was presented (Figure 1).

The slide showed that about one third of the fresh products that are produced and harvested are actually never eaten by people.

For me these figures were a bit shocking. This was the first time I realised that food losses were not just a pity for the profit of our customers - the fruit and vegetable traders - but that considerable amounts of food simply disappeared from the market in a world where close to 1 billion people suffer from hunger.
According to the table there is relatively more spoilage in the first part of the chain in developing countries whereas there is relatively more spoilage at the end of the chain in industrialized countries. Altogether, and that has now been confirmed over and over, **about one third of the harvested food crops is lost somewhere between harvest and human consumption.** If you look at the numbers behind this figure it means that about 1.3 billion tons of food with an estimated value of 700 to 800 billion Euros gets lost each year. These are huge numbers of which it is hard to imagine what it really means. If you consider the nutritional value of the lost food, I calculated that it could feed over 2 billion people.

	Industrialized countries		Developing countries	
Locations	**Range**	**Mean**	**Range**	**Mean**
From production to retail sites	2-23	12	5-50	22
At retail, foodservice and consumer sites	5-30	20	2-20	10
Cumulative total		**32**		**32**

Figure 1. Fresh product losses (% of total amount at harvest) in the chain. Source: Adel Kader, 2004.

This is where the postharvest loss paradox comes in. The slide from Adel Kader showing the postharvest losses, I have already used for almost 20 years in my presentations. Despite all the knowledge about postharvest deterioration that we developed over the last 20 years and despite the availability of an array of technical solutions to slow down the spoilage, the numbers have not really changed. Together with the postharvest loss of the food, all prior inputs are also lost. Among them are the use of land, water, fertilizer, pesticides, and energy to produce and distribute the seeds, to cultivate the plants, and to harvest, process, pack, and distribute the products. The lost food has a huge carbon footprint, but all for nothing. Please keep this in mind the next time you find out your strawberries spoiled in the fridge because you forgot to eat them.

I have always mainly been concerned with losses in the first part of the chain, during storage, processing and transport of the products. One of the most effective ways to minimize loss in this part of the chain is to make sure the product is at any time at a proper low temperature.

Harvested horticultural products are alive!

Appels, pears or lettuce, when they are harvested are not dead. In this respect these fresh horticultural products are different from fresh meat, chicken or fish. These latter products are dead and to preserve their quality they can be stored and transported at very low temperatures, even under zero. Harvested horticultural products are excised from the mother plant or from their roots but they are still alive. A harvested product transpires and breathes just like you and me, and needs energy to stay alive. A harvested product loses water, consumes oxygen, produces carbon dioxide and heath, all at the expense of the reserve carbohydrates (sugars, starch), proteins and other nutritional components (Figure 2). A harvested product, stored in the dark, is no longer supported by water and nutrients through the roots and no longer supported by sugars that are in the growing situation produced through photosynthesis. As a result, the product will quickly run out of water and energy, it will wilt and deteriorate, and will soon not be suitable for human consumption anymore. By lowering the temperature all these processes are dramatically slowed down and deterioration is postponed. Putting the products at a low temperature greatly prolongs their life, meaning that we can store or transport them for longer without quality loss.

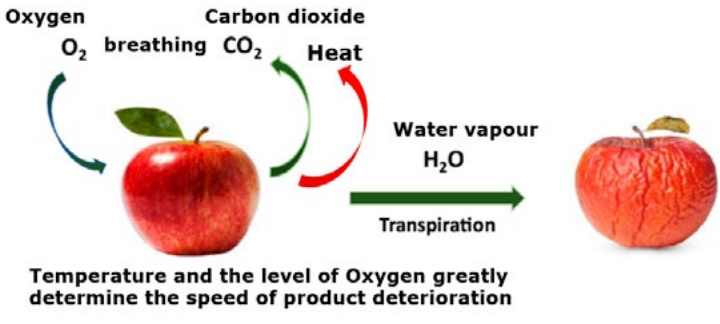

Figure 2. Fresh horticultural products are alive. Source: Bath et al. (2022), Journal of Food Science and Technology.

Of course here we have to search for the optimal temperature for each different product. Often temperatures just above freezing temperature – for instance between 1 and 4 °C - are most effective. However, some tropical products are sensitive to such low temperatures and are better stored around 8, 10 or 12 °C Another trick to further slow down the deterioration is to lower the oxygen content of the surrounding air. The products breathing is dependent on oxygen. The normal atmosphere contains about 21% oxygen. When we lower this to about 2% the lifespan of many products is greatly prolonged. We can do this in special storage rooms or we can apply low oxygen to the product that is, for instance, in a closed package.

Given all the knowledge and the available technology and protocols that are in place for different commodities it is hard to understand that there are still such huge postharvest losses. I will later elaborate some more on possible ways to resolve the postharvest loss paradox.

Let's go a bit back in time

I started my career at the Sprenger Institute in 1979. Sprenger was the first professor of Horticulture in Wageningen and the institute was named after him. I knew the institute already as the year before I did my internship there. The Sprenger Institute was a so-called DLO institute, a research institute from the ministry of Agriculture. The Sprenger Institute was entirely devoted to postharvest research such as storage and processing of a variety of fresh products, among them fruit, vegetables, flowers, and potted plants. At that time the Sprenger Institute was most famous for their commercial-scale pilot plants for making French fries and apple sauce and juice. According to the stories I heard from the older colleagues, in earlier times they were famous for their wine making and, importantly, wine tasting. The institute had newly built flower vase life rooms and storage facilities that were unique in the world. With an additional subsidy from the Dutch Flower Board we were able to also build elaborate facilities to treat products with the gaseous plant hormone ethylene, about which I will tell you more later. From all over the world fellow postharvest researchers came to visit and view our facilities.

In 1985 we celebrated the institute's 50th anniversary with the slogan: **50 years Sprenger Institute: Proof of Keepability**. Apart from being a scientist, Sprenger was also a talented amateur painter of mainly still-lives of fruit, vegetables, and flowers (Figure 3). For the occasion of this celebration, we organised an exhibition of all his paintings. The sad thing was that within 1 year after this celebration the institute was liquidated in a big reorganisation within the DLO organisation.

Figure 3. Professor Sprenger was a talented amateur painter of still-lives.

Most of the activities of the Sprenger Institute were continued in a newly found institute called Agrotechnological Research Institute, or ATO.

At ATO I was employed as junior researcher and, in collaboration with the department of plant physiology, I started a PhD research project on senescence in orchid flowers that I finalised in 1990. The ATO episode was in many aspects a demanding period. ATO was the first Wageningen research institute that had to acquire a major part, about 50%, of the research money directly from the industry. That meant doing acquisition and dealing with commercial companies a lot, rather than doing curiosity-driven research. Only much later the other DLO Institutes in Wageningen were also given a similar financial target.
At some time ATO was merged with another DLO institute, IMAG, and not long after, when there appeared to be a huge financial deficit, ATO was also liquidated. Then followed an uncertain period. ATO did no longer exist but we went on doing our things as ever before. Apparently we were doing good, as after a couple of years we were re-established, but under the new name Agrotechnology and Food Innovations, abbreviated A&F. Again some time later the name A&F was abandoned and changed into Food and Biobased research (FBR). I managed to survive all these organisational changes doing the things I thought were interesting for myself and useful for our customers. In 2007 I acquired a special professorship on Physiology and Quality of fresh products in the Plant Sciences department.

During all these years I have been working on the understanding of the ripening and deterioration of fresh products such as fruit, vegetables, potatoes, mushrooms, flowers, and potted plants, with the final aim of developing new technologies to improve the storability and maintain quality of products in the postharvest phase. During the first 15-20 years the research was mostly centered around Ethylene. Ethylene is a small gaseous molecule that can have huge effects on the quality of fresh products.

Ethylene and Banapple gas

My interest in ethylene started already long before I had ever heard the word. In the early seventies Cat Stevens had a Number-1 hit called Banapple gas.
https://www.youtube.com/watch?v=TCv8-c_m-js

Banapple gas, banapple gas.
Everybody's sniffing it, Banapple gas
All the world is stuck on it, Banapple gas
All the world is breathing, banapple gas
No one knows whats inside it, banapple gas.

I remember when I was in high school, speculating on what Baneapple gas would actually be. The artist suggested that it could make you happy and make you better and more healthy. So naturally I was thinking about some kind of gaseous drug produced by fruit. I forgot all about banapple gas till I started my internship at the Sprenger Institute in 1978. The subject of the internship was ethylene - a gas produced by ripening fruit – and therefore the banapple gas mystery popped up in my head. So I was extra motivated to find out more about ethylene.

It was already known for some time that ripening fruit, and especially rotting fruit, could produce ethylene and that there were also other sources of ethylene such as cigarette smoke and car exhaust gases. As ethylene is a gas, it easily moves through the air from one place to another. Flower and pot plant growers and traders were afraid for the possible negative effects of ethylene produced by, for instance, car exhaust gases at the Dutch flower auctions. Carnation flowers were thought to be most sensitive to ethylene; exposure to ethylene resulting in rapid flower wilting.

During my internship, my task was to find out if ethylene could damage carnation flowers and if the levels of ethylene, that regularly occur at the flower auctions, could be harmful for the flowers.

During my internship I designed and built an experimental set-up to treat flowers with ethylene and studied the effect of different concentrations of ethylene on carnation flowers. Figure 4 shows a drawing of the set-up from my original internship report and, believe it or not, these big glass desiccators are still stored at the attic of the Phenomea building. They have probably not been used during the last 35 years or so and I would suggest that it is now time for their retirement as well.

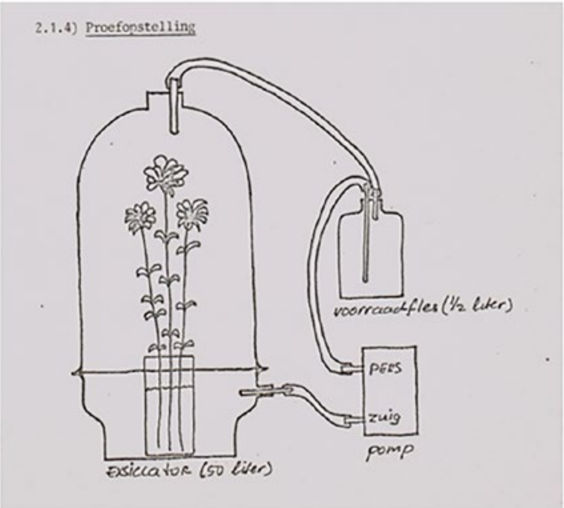

Figure 4. Set-up for treating carnation flowers with ethylene.

This was all new and very exciting. There was not a lot known about the effects of ethylene. It was clear that there was a world to discover in the ethylene field.

In the period thereafter, when I was offered a permanent position at the Sprenger Institute, a larger set-up was constructed consisting of 60 treatment chambers and the effects of ethylene on a great variety of cut flowers and potted plants was investigated. The outcome was communicated in a series of papers in professional journals to inform the industry and to help them to recognise ethylene symptoms in their daily practice and to suggest possible solutions.

Later, the collective data were re-analysed and modelled, and this actually resulted in my first scientific paper (Figure 5). Looking back, I can conclude that it was a bestseller. The paper has been cited over 600 times and as today is still cited on average 15-20 times a year.


JOURNAL ARTICLE

Role of Ethylene in Senescence of Petals—Morphological and Taxonomical Relationships

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Journal of Experimental Botany, Volume 39, Issue 11, November 1988, Pages 1605–1616, https://doi.org/10.1093/jxb/39.11.1605

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Figure 5. Elaborate description of ethylene effects in a diversity of flowers.

Ethylene is what we call a plant hormone. Similar to the hormones in the human body, small changes in the levels can have dramatic effects on an array of processes. Ethylene causes ripening, rotting, wilting, and leaf and flower drop. Most of these effects are undesirable in the postharvest phase.

At that time we knew that most plants produced tiny amounts of ethylene, but we had no idea whatsoever how it was synthesized in the plant. Also we had no clue how a gaseous molecule could have such dramatic effects on plants.

Ethylene biosynthesis and perception

The first international symposium I attended was on **Biochemical, Physiological and Applied aspects of Ethylene**, it was held in Israel in 1984. If I summarize the state of the ethylene science at that time a very simple picture emerges (Figure 6). It had been proven that the production of ethylene by plants started from a the amino acid, methionine and that ethylene gas, once produced (or from an alternative external source) would probably interact with a receptor and that this interaction would lead to the release from the receptor of a messenger molecule. This messenger molecule would lead in some mysterious way, to all these different effects of ethylene on fruit, vegetables and flowers. It is amazing that we congressed for a whole week about something we knew almost nothing about.

Figure 7 (left panel) shows what we now know about the first part of the pathway, where there was only one big question mark in 1984. Methionine is still regarded as the starting point of the pathway, but we now know that there are several intermediates produced, and that different enzymes are involved in the production of ethylene. These enzymes in themselves consist in different variants that are located in different tissues. So one variant may be active in leaves, another in fruits or roots. And we also now know that different types of stresses can have specific effects on the activity of these enzymes and thus on the amount of ethylene that is produced.

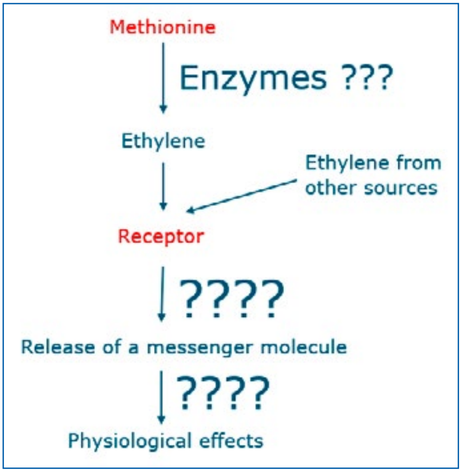

Figure 6. State of the art in 1984.

The next big question mark was the nature of the ethylene receptor. Figure 7 (right panel) shows the current knowledge of this part of the pathway. Here it turned out that the perception of ethylene by the plant cells has a high level of complexity. There are several families of ethylene receptors in plants and we now know exactly what the receptor looks like, where it, is located in the cell, how ethylene binds to it, and which signal transduction processes are involved in transferring the signal. The binding of ethylene to its receptor leads, via a complex series of interactions with other molecules, to the activation of a so-called transcription factor that regulates the activity of several thousands of genes. These genes are responsible for the different effects of ethylene on plant material.

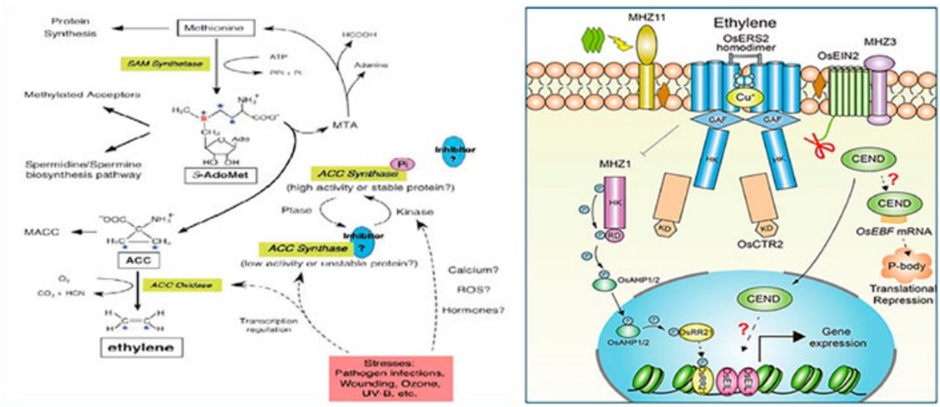

Figure 7. Current state of the art ethylene biosynthesis (left) and perception (right). Source: Jouyban Z. (2012), Ethylene Biosynthesis; Zhao et al. (2020), Journal of Integrative Plant Biology.

The revolution in plant molecular biology that took place during these years was of course of great help in identifying all the different parts of the puzzle.

I showed this to give you an impression of how science advances. What happened in the ethylene field did also happen in other plant biology fields. Sometimes I pity the current students that have to learn and understand so much more about these complex pathways and interactions than we had in the eighties when life was still relatively simple.
The advanced knowledge on these pathways not only satisfies our curiosity but has been very useful in the development of new strategies and chemicals to regulate the ethylene production and to lower the products sensitivity to ethylene that are now applied to prolong the keepability of fresh products.

Ethylene, orchids and laser photoacoustics
During my PhD I studied the senescence orchid flowers. Although orchids are tropical flowers, and you would expect huge production of the crop in, for instance Thailand or Indonesia, already in the nineties the Netherlands was the biggest producer of orchids worldwide and that is still the case. About 90% of all orchids traded in Europe are grown in the Netherlands.

Orchids are a type of flowers where the wilting is induced by ethylene. I was particularly interested in the exact sites in the flower where the ethylene was produced and how ethylene could move through the flower from one part to another. That meant we needed to measure the ethylene that was released from different parts of the flower. That required very sensitive equipment. Luckily I could establish a collaboration with the University in Nijmegen where at that time Frans Harren was also working on his PhD. He was maybe even more obsessed with ethylene than I was, but from a completely different angle. He developed a device based on laser photoacoustics that was capable of detecting very minor amounts of ethylene. This made it possible to measure the ethylene release from different parts of the flowers and elucidate some of the orchid senescence mysteries. Figure 8 shows the initial experimental set-up and the results of a long night (to monitor the complete process) we spent in the lab, doing our measurements. That night we saw things that no one had ever seen before, very tiny amounts of ethylene produced by the flower in response to removal of the pollinia. The data were the basis of my PhD thesis. It became a long lasting relation and in the end we have about 30 joint papers on volatiles, not only ethylene, produced by plants.

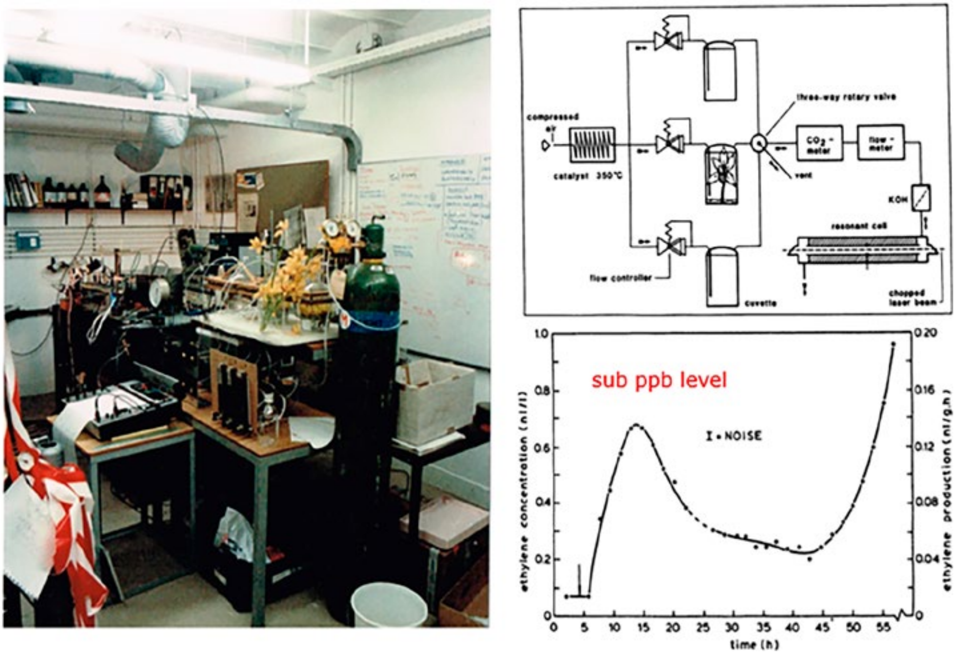

Figure 8. Laser photoacoustics to measure ethylene from orchids.

Finally after some 20 years of ethylene research I did drift to another field with close links to the processes that cause the senescence and deterioration of fresh products. This field is called Apoptosis or Programmed Cell Death. This was already a hot topic in animal science.

Programmed cell death

Every day about 100 billion cells in your body die. Actually, most of what I see from you is dead tissue (skin, hair, teeth, nails). When cells die, they do not just fall apart, but they are dismantled in an orderly way. The components of the dying cell are used to make new cells. In this way the body continuously renews itself. This process is called programmed cell death. Compare it to a house that is not simply destroyed but broken down piece by piece in an orderly way to reuse the materials to build a new house.

This process was first discovered in animal cells. In 2002, two American researchers received the Nobel Prize for their pioneering work on programmed cell death.

Also in plants, during growth, development and senescence, cells die. In many cases this has a clear function e.g. to shape the organs or to seal of areas that are infected by pathogens. But cell death is particularly undesirable in the postharvest phase where we want to keep the product alive and vital for as long as possible. Cell death, therefore, is on the basis of many postharvest problems such as the senescence of flowers and development of a variety of storage-related defects such as browning in fruit and vegetables. So naturally it was of interest to find out if the processes that were identified in animal tissues may have counterparts in plants. Over the years we acquired several national and European research grants to investigate this process. In this, the long term collaboration with Elena Iakimova from the Institute of Ornamental plants in Sofia, Bulgaria was very important.

We were able to show that some of the processes occurring in animal cell death were also responsible for cell death in plants. Elena is a very good scientist and also a good writer and thanks to that, we were able to publish over 40 papers about plant cell death. Some of the results of our work appeared on the cover of scientific journals (Figure 9). The increased knowledge of the processes that are on the bases of a number of defects in stored products opens the way to develop new strategies to slow down the senescence and prolong the life of harvested products.

Figure 9. Our cell death results on the cover of Plant Molecular Biology.

Make better plants

Finally I shifted to an alternative way of managing postharvest losses. Instead of optimizing the postharvest conditions, such as the temperature, air humidity, and ethylene levels, one can also focus on producing plants or plant products that are better capable of coping with non-optimal conditions in the postharvest phase. For this we grow plants in a controlled environment such as a vertical farm, where we have full control over all the cultivation factors. A few days before the harvest, we change the conditions in such a way that the harvested product has, at harvest, an improved intrinsic quality. Here we made the first steps in using different intensities and colours of LED light in the days before harvest to stimulate the production of sugars and vitamin-C in the plants. In this way we are able to produce, for instance, lettuce or tomatoes that can be stored for longer, also if the postharvest conditions are not optimal. This definitely is a future way to go, especially if products after harvest enter into a chain where conditions are likely to be sub-optimal.

Resolving the postharvest loss paradox

I now come back to resolving the postharvest loss paradox. As I showed you before, despite a lot of knowledge and available technology, food losses in the distribution chain are still a persistent problem. To solve this is, for sure, not easy.

Although I am a product physiologist, I don't think that more physiological knowledge is required to make big steps. We already have a lot of knowledge and there are many proven technologies available. To tackle postharvest losses I see at least four different avenues that can be explored:

- Awareness and education; investments in postharvest infrastructure
- Pre-transportation sorting; garbage in = garbage out
- Managing product flows based on product quality; digital twins
- Sustainable methodologies to improve postharvest performance: RNA technology

I will briefly discuss these avenues.

Investments in people and infrastructure

The human element in the postharvest handling of horticultural products is very important. First of all, especially in developing countries, but also in the industrialised world, it needs increased awareness and education of all players in the chain. Still today, many workers in harvesting, packaging, and transport of fresh products have little appreciation about the importance of their actions for final product quality. Along the distribution chain, workers have to understand the basics of postharvest physiology, incorporate this into protocols and work according to the protocols. The postharvest courses and on-line information about physiology, storage, transport, and packaging of fresh products, provided by Wageningen and by, for instance, University of California in

Davis greatly contribute to this. However, this still needs a lot of attention.
Apart from education, but equally important, it needs also more investments in postharvest infrastructure. Which basically means more cooling facilities and refrigerated transport. It was calculated by the World Food Preservation Center that currently, from all investments in agriculture, approximately 95% is in the crop production phase whereas only 5% is in the postharvest phase. It was also shown that return-on-investments in postharvest infrastructure are easily 10 x higher than on investments in crop production. It is very hard and needs a lot of effort to improve the overall crop yield significantly, but it is relatively easy to decrease the postharvest losses. Therefore an investment in proper cooling equipment and refrigerated transport will easily pay off.

Garbage in = garbage out
Generally, in the postharvest phase, product quality only goes down. If products have to be transported over a long distance and you want to end up with acceptable quality, it is of course evident that you should start the journey with a high quality. But what exactly is high quality? What product features actually guarantee that after the journey the product will still be good quality?

Freshly harvested mangoes or avocadoes may, from the outside, all look excellent. But, following 5 weeks in transport some of the fruit are still of good quality, but others are not, and have to be thrown away. Currently we do not have a good explanation for these differences in behaviour of individual fruit. For sure this will have to do with the history of the individual fruit during the growth. Maybe some fruit received more water or nutrients, or more sunlight, than other fruit; or maybe the position on the tree and of the tree in the orchard plays a role. Finally, the combination of these factors may determine the fruit's postharvest behaviour. Although we do not have a particular compound or process in mind that we can measure, there is an apparatus that we can use to separate the good from the bad.

The method is called near infra-red spectroscopy or NIR. The methodology is already around for over 40 years for a great many applications, but application in the fresh products field was not always that successful. Over the last 10 years, however, the number of publications on the use of NIR for measuring quality factors, such as the sugar level and firmness, in fruit is steadily increasing.

NIR spectroscopy mostly works on the basis of a light beam that is directed to the product. The light that comes back holds information about the chemical composition and structural features of the product (Figure 10). Although the principle has not changed, over the years the hardware has been improved and the mathematics involved in signal processing, has greatly advanced. By feeding the apparatus with relevant data it learns to distinguish between good and bad quality. Products of lesser quality can be directed to - more close by, or less demanding – destinations. Nowadays there are many companies offering handheld apparatus where data is stored in the cloud, allowing the collection of huge amounts of data that should make the quality predictions even better. NIR spectroscopy is fast, does not harm the product nor the environment, and can also be applied in commercial fruit sorting lines.

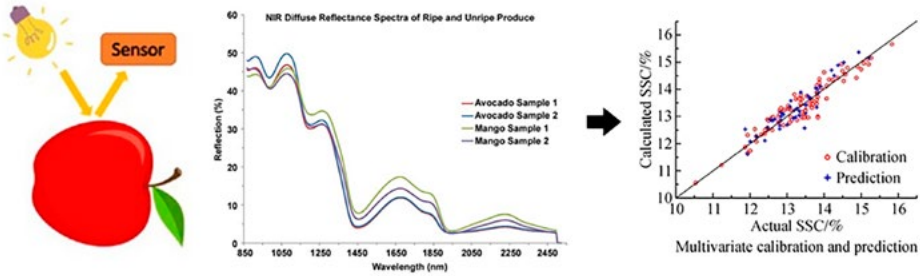

Figure 10. Principle of NIR spectroscopy, here applied for prediction of total soluble solid content (sugar + acids).

Pre-sorting products after harvest based on quality features for different destinations is not very common yet, but can greatly contribute to reducing losses. NIR and related hyperspectral imaging technology is now available and there is a lot of NIR expertise now in Wageningen-FBR. Although there are still quite some issues to solve, I am confident that the technique can greatly contribute to prevent product losses in the chain.

Digital twins

Another approach to reduce losses is to invest and apply new technologies that enable better management of product flows.

Products often have to be brought from place A where they are produced to place B where they are sold to end users. In between, they spend time in storage or transport, in a packing house or distribution centre. During this long and sometimes winding road the products may be exposed to sub-optimal conditions. We previously studied the fate of Dutch tomatoes. Dutch tomatoes are partly going to Dutch supermarkets, but they are also exported to other European countries. Tomatoes harvested in Dutch greenhouses may find their way to the supermarket within 3 days. But that was only a very small portion. On average they were on their way a little over 1 week to reach their destination even when they stayed in The Netherlands. In some export cases it took actually almost 3 weeks before the fruit ended up in the supermarket. Tomato is a fruit that is best held at a temperature of about 10 or 12 °C, but in many cases, the temperatures were either too high or too low. This results in product losses as, at the end point, the product quality may not be acceptable anymore. The tomatoes may be too soft or may lack a good taste.

Often the end users have no clue about the history of the product and what quality to expect. If we would be able to gather information about where the products are at any time in the chain and to what postharvest conditions e.g. temperature, air humidity, and ethylene, they have been exposed, we can make an **estimation** of the product quality at any time in the chain. Even better, if we can apply the above discussed NIR spectroscopy to **measure** the product quality at any time in the chain. Based on the estimated or measured product quality, alternative decisions can be made, for instance to send the product to a more nearby destination or a less demanding market or to change the conditions in the transport container. In brief, this is what we call creating a digital twin, or digital shadow of the transported load (Figure 11). Although this is in fresh product chains mostly still in the experimental phase, it is very possible that we will be able to reduce postharvest losses considerably by applying such technology.

Figure 11. Creating a digital shadow of the transported goods.

RNA technology

Finally I want to briefly discuss a new technology that can also significantly reduce the postharvest losses. Most of you are probably vaccinated against the Covid-19 virus. Here a new type of vaccines was used. So called RNA vaccines. A small piece of RNA, packed in a small lipid droplet, that codes for a small fragment of the spike protein of the Covid-19 virus, is injected in your arm. In your body the small piece of RNA serves as a template to make your cells produce a huge amount of this spike protein fragment. Thereafter, your immune system starts to react to the spike protein fragment by putting up a defence. When later the real Covid-19 virus comes along, your body is prepared to quickly inactivate the virus.

A similar type of technology, based on the application of RNA molecules, has been developed to improve certain aspects of plants (Figure 12). The lipid droplets with RNA are sprayed over the plants. The RNA is taken up and the plant cells start to produce certain proteins or enzymes that are coded by the applied RNA fragment. In a similar way, we can selectively block the activity of the plant genes of interest. In this way we can influence the metabolism of the plant in such a way that the plant becomes, for instance, more resistant to drought or other stresses. As RNA is everywhere, present in all organisms and is also quickly broken down outside the body, it can be considered a non-toxic and environmentally friendly chemical. Currently there are not yet examples of its application in the postharvest phase, but it seems an area where we can quickly apply our abundant knowledge on plant metabolism to improve the postharvest life of many fruit, vegetables, cut flowers, and potted plants. I expect it will become a hot topic soon.

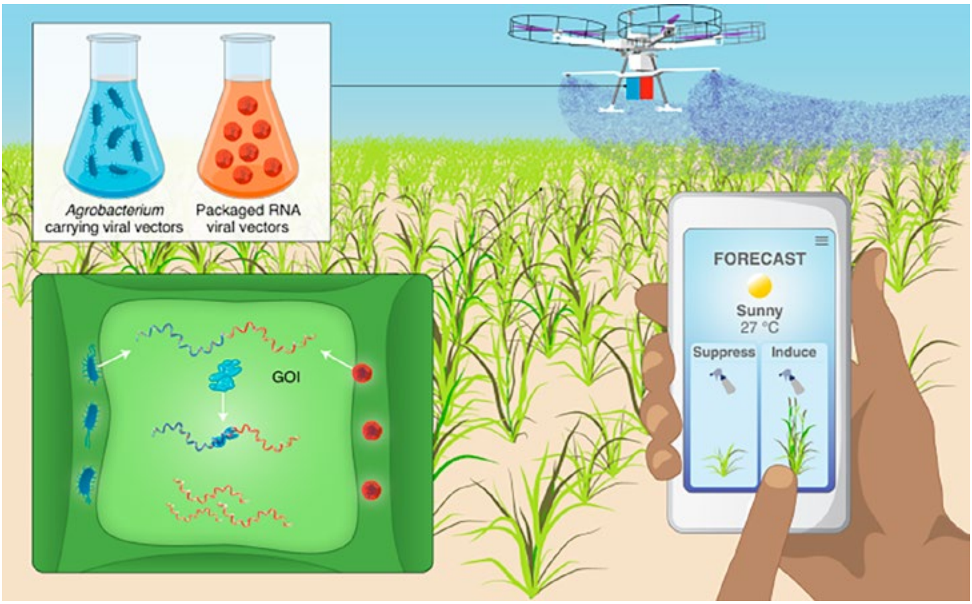

Figure 12. RNA technology to change the metabolism of plants through a simple spray treatment. Source: Massel et al. (2021), Nature plants.

Given the new perspectives on managing product quality I hereby would like to challenge my younger colleagues and students to **resolve the postharvest loss paradox** in the coming 20 years. Given the expected growth of the world population (+2 billion people in 2050!) and the needed transition to a more plant based diet **we really can no longer afford to lose so much food in the postharvest phase**.

Bob Dylan

For the last part of the lecture I want to drift away from plant science as my scientific career ends about here. Although not completely. The coming years I will stay on as a parttime volunteer in the chair group Horticulture and Product Physiology to supervise MSc and PhD students and to contribute to the postharvest courses. In addition, I will be busy with the organisation of two parallel postharvest congresses to be held here on the campus in May next year : www.wur.nl/en/show/postharvest-unlimited-conference-postharvest-ornamentals-symposium.htm.

Apart from being interested in plant science, playing and listening to music is my second love. In this, I particularly like the sixties and seventies American folk and country music from for instance Crosby Stills Nash & Young, The Band, and in particular Bob Dylan. I realise that this may not immediately ring a bell among my younger colleagues. Bob Dylan is by far the most famous artist from this time period and both his music as well as his often mysterious and cryptic lyrics were a source of inspiration for me when I started making music myself.

The attractiveness of Bob Dylan's work is **that you don't have to be a good musician nor a good singer** to be able cover his songs. So ideal material for the beginning guitar player. Bob Dylan was born under the name of Robert Allen Zimmerman and his songs are widely believed to have reflected and influenced major social movements.

He sold over 125 million albums; he did over 3000 live performances and, at the age of 80, still does about 100 shows each year. A great many books, essays, and even scientific papers (including numerous PhD dissertations) have been published about his life, lyrics, and music. He received an amazing amount of awards, among them 10 Grammy awards and in 2016 the Nobel Prize for literature. According to the Nobel committee the prize was awarded for: **having created new poetic expressions within the great American song tradition**. Bob Dylan is the only singer-songwriter that ever received this prize.

There are many publications aiming at the understanding and interpretation of his work, but they mostly come with contradicting interpretations. The interesting thing is that Bob himself very seldom gives interviews and never comments on the deeper thoughts of his lyrics, so most of the analyses of his work are purely speculative. That leaves ample room for any interpretation that suits you best.

I came across a recent linguistic analysis of his work (Figure 13). The authors used sophisticated software to qualitatively and quantitatively characterize his original song lyrics that were released between 1962 and 2012. The study reveals that, and here I quote the authors, ”Dylan’s song lyrics gravitated around social themes that primarily consisted of hardships, romance, religion, family, politics, and law, as well as oppression”. The majority of words or text phrases are actually associated with hardships and romance. This is a bit surprising as Dylan is usually characterized as a protest song writer.

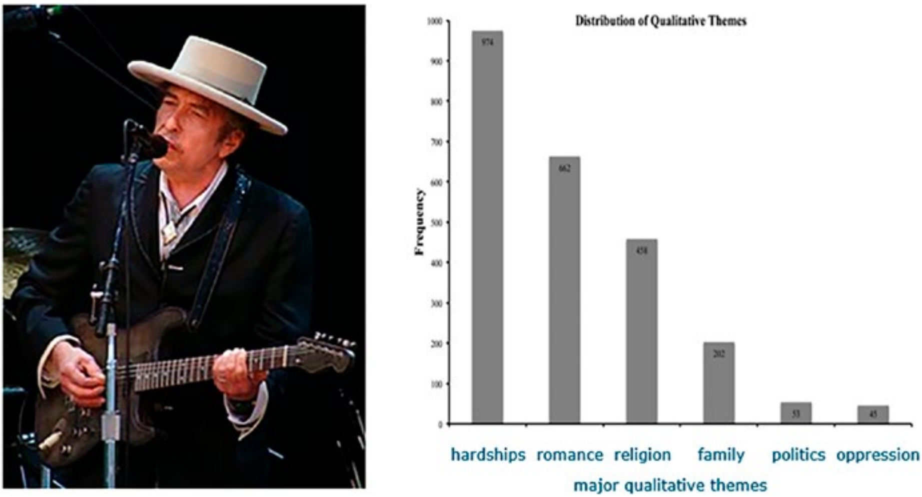

Figure 13. Linguistic analysis of Bob Dylan’s lyrics. Source: Czechowsky et al. (2016), Psychology of Aesthetics, Creativity and the Arts.

The scientific analysis now shows that most of the songs are about two themes that are actually very much entangled. **Romance**, as we all know, may often sooner or later end into **hardship**. To this respect, it seems his lyrics are not that much different from those of the majority of singer/songwriters singing about current and lost lovers.

As a scientist you are always confronted with many questions. How does it work, why is it the way it is, what can we do to change it? And, once you find some of the answers, often new questions arise. At a certain time you accept that you will never be able to understand all that's going on in a plant, an apple or in a flower. This is actually the moment when doing science becomes much more relaxed. Find satisfaction in what you **do know** and don't bother or speculate too much about **all you do not know**. In this respect the lyrics of Bob Dylan's most well-known song "blowing in the wind" very much appeal to me: https://www.youtube.com/watch?v=vWwgrjjIMXA

How many roads must a man walk down
Before they call him a man?
How many seas must a white dove sail
Before she sleeps in the sand?
How many times must the cannon balls fly
Before they're forever banned?
The answer, my friend, is blowin' in the wind
The answer is blowin' in the wind

Acknowledgement

I spent about 40 years of my working life in Wageningen. People often asked me if I didn't get bored doing the same type of work for so long a time. Of course that is a good question. The answer, at least to me, is very clear. In the basis I am a researcher and most of what I do is driven by scientific curiosity. For this, Wageningen is a fantastic place where I always experienced a great degree of freedom to pursue the issues that I considered important and interesting and where I could do work that is not only of academic interest, but also has impact in both industry and society.

During the years I served the Wageningen University and Research organisation, the work brought me to many different places in the world: all over Europe but also in United States, Mexico, South America, Africa, Indonesia, China, Taiwan, Japan, and Australia, for visiting symposia and workshops, within national and international collaborative research projects, for 2 sabbaticals – one in California, one in Spain - and within a great many bi-lateral projects with a diversity of commercial companies. I worked with many different people both in the Wageningen scene but also outside. With colleagues of the Chair group Horticulture and Product Physiology and of Wageningen-FBR, with outside collaborators, guest workers, bachelor, master and PhD students, with customers and more.

Altogether it must be thousands of different people with whom at some point in time for longer or shorter duration I shared ideas and developed new concepts for new projects, publications or applications.

I want to thank all of you for the pleasant collaboration as finally, these human interactions and the collective efforts to turn our ideas into products, are what makes you want to go to work every day and what I will miss most in the coming period I guess.

Specifically I want to thank Frans Harren and Simona Cristescu from The Molecular and Laser Physics department of the Radboud University for their continued interest and support of our work. I also would like to thank Elena Iakimova from the Institute of Ornamental Plants in Bulgaria with whom I had a long lasting collaboration in the programmed cell death field. In addition, I want to thank The Greenery, Rijk Zwaan, and Philips Research who at some point in time generously sponsored my special chair and the associated PhDs. Also special thanks to Olaf van Kooten and Leo Marcelis who greatly supported the establishment and continuation of my special chair, respectively.

I also would like to thank the frequently changing management teams of the successive research institutes where I was employed. All through the years I was allowed and

supported to develop myself in a more-or-less self-chosen direction.
Finally thanks to my family for allowing me to spend so much time on science, probably at the expense of the family life at some times.

Last couple of years I wrote a column about postharvest issues in the professional journal Groenten en Fruit. I made a collection of these columns in a small booklet (in Dutch) that is available for free!
One final word: One good thing about the new phase in my life is that I now have a single project number but with merely unlimited hours called **Retirement**.
Ladies and gentleman, thank you for your kind attention. Ik heb gezegd

Prof.dr Ernst J. Woltering and his wife (Ans) and daughters Kris (right) and Margriet (left).

About one third of the harvested food crops is lost somewhere between harvest and human consumption. It means that about 1.3 billion tons of food with an estimated value of 700 to 800 billion Euros gets lost each year. If you consider the nutritional value of the lost food it could feed over 2 billion people.
Despite all the knowledge about postharvest deterioration that we developed over the last 20 - 30 years and despite the availability of an array of technical solutions to minimize the spoilage, paradoxically, these numbers have not really changed.
Given the expected growth of the world population (+2 billion people in 2050!) and the needed transition to a more plant based diet ***we really can no longer afford to lose so much food in the postharvest phase****. We urgently need to Resolve the Postharvest Loss Paradox!*

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