Good afternoon, everyone. Welcome. And thank you all for being here. So today I'm going to present my work, Lighting Strategies to Enhance Crop Quality in Controlling Environmental Agriculture. Let's explore together how to grow better quality. So across human history and human culture, there's one thing we all shared. When we want to keep a moment of beauty, we use sculpture and art. We hope we can frozen it in time. So it's actually the same for our food.

When we have a plate of nice salads, we like the flavor, the nutrition, the attractive appearance, and we hope this quality can be preserved in time. And this is where food and art are sharing the same challenge, the time. And this is also what we're going to discuss today, how to make sure we have good quality of lettuce and good quality of tomato in our plate, and hope it can last longer. So the first question, what is quality? Quality can be summarized very simple. So quality is you and me as consumers.

We care the most. So when you pick up a tomato, you see it's a nice, red, mature color. Your smell is a strong tomato flavor, I mean, aromas. And, yeah, of course, your taste is juicy and crisp, and also the well-balanced weight and sour taste. All of these are very important quality aspects. And in our research, we define the texture, the appearance, the smell as overall sensory quality or overall visual quality, and smell the taste as flavor. And, of course, nutritional value is also very important, although we can only recognize from the nutrient label, we cannot measure by ourselves. All these good qualities, they cannot last long. If you bring yourself home, you place on the table, next to your window, it's warm and sunny, then all the good quality is going to lose within one day. So when the quality no longer makes you satisfied, you are not willing to pay for it. We say it's the end of shelf life. In our research, we use the score of overall visual quality to define it. When the score drops below the threshold of consumer satisfaction, we see the shelf life finished. Shelf life is very important. It not only reflects the value in the distribution chain, it also helps reduce food waste and lose. There are already many post-harvest strategies to help us slow the quality decay, just like the referred rate at your home. But can we act even earlier? Can we switch our focus from slow the decay to build up the quality before harvest? So can we grow for better quality? When we talk about grow, light naturally becomes our focus. The artificial lighting used in vertical form and greenhouses allow us to play with the spectrum, the intensity, photo-period, position of the lens, direction of the light, many of them. And the question is, can light help us grow better quality? Well, the answer is yes. Highlight intensity generally brings better quality crops. It brings delicious, nutritious, attractive products. And behind that, there's actually the level of primary and secondary metabolites are being affected. On one hand, it's very important for us, consumers, to reflect on the nutrient labels. On the other hand, it's also important for plants. Because just like antioxidants, it helps crop to better cope with the unpredictable post-harvest storage. So that's why it brings longer shelf life. So for the highlight, do we need to apply it all the way along the growth or a short-term highlight already being effective enough to improve the quality? To answer this question, we bring this experiment. We grow lettuce for five weeks in standard condition and only in the last week we give different light treatments. We call it end-off production lighting. And then the product is just harvested and put in the dark storage. So we use these little cubes to indicate the light intensity we give during the growth. Then in the end-off production lighting, we either raise it or reduce it or keep the same. And we see the effect of the end-off production lighting on the nutritional quality, the visual quality, and the shelf life. The result is quite exciting. If you look at the plant at the right column, you see a plant just experienced for one-week highlight. It's already held in the box after three weeks dark storage. It looks much more green and less browning, less yellowing. So that is the effect of short-term highlight. And behind the nice photo is actually the vitamin C and sugars are improved and the improved level at harvest can be maintained during storage. And the visual quality decay slows down and we have longer shelf life. But you may

notice there's one important thing we didn't mention yet. Our plant lives in a daily light dark rhizome. So if we increase light intensity with a fixed photo period, then we actually give more light to the plant. We call it daily light integral. We still use these little cubes. The volume is the amount of light we give to the plant. The height is light intensity and the width is photo period. So when you increase the height, you have larger volume, higher daily light integral. And of course, you can keep the volume the same by adjusting the height and the width together. So the light intensity and the photo period together. So the question is, what's the improvement we saw in the letters? Is that from high light intensity or from high daily light integral? So again, we run the experiment with end of production lighting. This time we give different levels of light intensity, different hours of photo period and different days of end of production lighting treatment. So in this way, we can compare the daily light integral and the cumulative light sum. So that means we add one more dimension to this little cube. That's the days of end of production lighting. So we compare different level of DLI. We compare same DLI reached by different intensity and photo period. And we compare the same cumulative light sum reached by high or low DLI that applied short or long number of days in the treatment. So the result shows high DLI is the key to improve letters quality. With high DLI, you always get more sugars and vitamin Cs. And with the same DLI, the longer photo period combined with lower intensity, always perform better than the other way around. And the quality can respond to high DLI very fast within two days. And last, if your DLI is low, you extend the treatment duration to reach a higher cumulative light sum that will not help you to get better quality. So in practice, maybe you can consider to keep your light turned on for the last two days. Then you can have better quality without ending more lamps. So we know the good quality of letters. Now let's switch our focus to tomato. In tomato production, there's a common practice to increase the electrical conductivity in the nutrient solution to reach a better quality. But the drawback is also very clear, the yield reduction. So with all the information about light and quality, can we combine the light and the EC to achieve a better quality without losing the yield? So to do this experiment, we'll work with dwarf tomato. As you can see from the photo, dwarf tomato is a compact plant with short production cycle, can deliver many types of fruits. And now it's switched from hobby plants to more and more to the production type of crop because it's feeding the multi-layer production, low labor, depend and easier facilitate the sensor-based phenotyping and harvesting. So in this experiment, we apply the EC and light treatments all the way through the growth to cover from flower to fruit harvest range. So we have four levels of light intensity and four levels of electrical conductivity. We look at the effects of their combination, yield, nutritional quality, visual quality, shelf life, but importantly, we also evaluate the flavor. So we measure the sweetness, the acidity, juiceness, firmness, as input for a flavor model. In this model, we are able to give a flavor score based on Dutch consumer preference. About the results, let's start with the reference treatments. So no extra light and no extra electrical conductivity. So based on that, if we raise the EC level, we get better flavor and less yield as expected. And if we have high light and high EC at the same time, then we can further improve the flavor, but not much on the yield. The yield reached to a comparable level as the reference. And if we only increase light intensity, then we have more yield, but not much on the flavor. So to conclude, light is an effective tool to help us grow better quality. And a short-term applied highlight before harvest can help improve the lettuce quality fast. And the daily light integral is a key factor within it. And we combine the highlight and high EC can help us improve tomato quality without losing much yield. So now we know how to grow better quality for lettuce and tomato, and we can prepare ourselves a nice salad. That's everything about my work, and thank you all for being here and online. And thanks to my promoters, my lovely HPP colleagues, my families and friends, and my parents and my husbands. So the program. After this, I will go into defend my thesis for 45 minutes, and then the opponents will go to a secret room and discuss about the defense. If everything goes well, they will come back. I will get my degree, and the drinks and food start

at five. Thank you. Please be seated. I hereby open this ceremony convened by the Academic Board of Wageningen University in which Chen Sisi Min is offered the opportunity of defending a thesis with prepositions entitled Lighting Strategies to Enhance Crop Quality in Controlled Environment Agriculture. The defense will take place before an examining committee appointed by the Academic Board as a prerequisite for conferring the degree of doctor. Good afternoon. I'd like to welcome you all to this graduation. My name is Simon Osteen. I'm professor of animal production systems, and I'm representing the Academic Board and the Rector Magnificus today. I'd now like to call on the first examiner, who is professor Foliano, who is professor of food quality and design here at Wageningen University. The floor is yours. Thank you, Mr.

Rector, respected candidate. It was really nice to read your thesis that bring back to my studies of many years ago about the quality of the tomato, and I would like to start by opposition, asking you to ask one of your para nympha to read that loud, proposition number six. May I ask my para nymphs to read loud, proposition number six? Boundaries, rather than resources, are the key to sustain harmony in both family life and research. I was really curious about this proposition, and I became even more curious when I look at this quote on the blue pages that are on your booklet, that living with limitation makes life meaningful. It seems you have a lot to say about boundaries, limitation. Can you explain me why it's so important for you? Well, of course, a highly esteemed opponent. Thanks for your question. And it's part from my own experience and also part from the general readings. So I think boundaries is something you help you to define how to spend your time, how to face off the risks, how to distribute resource, especially when resources are limited. So that's why it's very important in both family life and research. Because, I mean, if you look at this from the science point of view, to be a scientist, I mean, having all these limitation boundaries, it's something that we don't want. As a scientist, I want to have freedom, I want to have ambition, and exactly the opposite. So how do you reconcile these two aspects? I agree with you that scientists and researchers were chasing for a certain degree of freedom. But I do think, especially in this case, boundaries are especially important. We saw lots of cases, movies on the evil scientists, they can do the worst thing over your imagination. So I think, at least for the mental level, for the responsibility of the human, of the environment, of how to use your research outcome, the boundaries are especially important. Okay, I think that you cannot put rule for the 1% of Mengele scientists that we have. We should think that 99% of scientists, they go for good even with all the ambition. Okay, we disagree. Okay, that's not a problem. Let's move on, because I have only 11 minutes. So I would like to ask more about your thesis. And I'm especially interested in this concept of nutritional quality parameters that goes in all chapter of your thesis. So you want to improve the nutritional quality, you claim the different treatment to improve this. What is the nutritional? What is within this nutritional quality parameter? In this thesis, when you talk about improving nutritional quality, which are the elements that you want to improve? In this thesis, we focus mostly on carbohydrates, include different kinds of sugars and also the vitamin C content. That's the nutritional value we define in this thesis. And we start to disagree again, because to me, sugar is not a nutritional quality. We want to reduce sugar. I don't know if you hear. So say that a tomato is better because it's more fructose or this is not what I would like to have. Maybe for taste, yes, but not for nutritional quality. I partly agree with you. Of course, we have many stories of high-sugar diets, how it influences our health. That's an important part, also in the diet guide, that we want to improve it. But for fruits and leafy veggies, especially tomatoes and lettuce, I focused on general level of sugars are not that high. If they can have high level sugar for a good flavor, then it actually promotes people to eat more of them. So if people intake more fruits and veggies, then it probably helps also with a general healthy diet. Okay, a clever answer. What about polyphenol? Yeah, polyphenol is also very important. And to be honest, in one of our chapters, we start with two cultivars of lettuce. One is green, one is purple. And we're

assuming the purple one, there's more an answer sign about that. So it's important antioxidants and attractive color. In the cultivar, later we focus on the green one. We think vitamin C is the dominant antioxidant help deal with the redox homostasis. So that's why we focus on vitamin C more. And I agree with this, because with polyphenol, they're good, but I wonder if you can sustain the claim that the more the better with polyphenols. Would you agree with this or not? That's a good point. I think in polyphenols, like the example answer sign, it's a good example that we can have more to have more antioxidants. And for some volunteers, maybe, that also promotes the taste, the experience when people are eating that. So for this part, I think we can improve the level to state that it's a good quality. And the reason why I'm challenging you about the nutritional is because you never mentioned about the nutritional quality parameter, the dietary fiber. How is that? You didn't consider or you didn't think dietary fiber is important, especially in tomato? I think for nutritional value, it's very important. Then it's back to the fundamental research question of my experiments. The core idea is we try to link pre-harvest with post-harvest. And one important thing in the post-harvest shelf life, and that's very much rely on the visual quality. That's why we think antioxidants is more important in this bridge between pre-harvest and post-harvest. But to talk about the nutritional value as a tomato product or lettuce products, I think fiber, for sure, is the important one. And also the reason people eat more veggies. Exactly. So I think that it's different if a tomato has 20% of dietary fiber on dry weight or is 25. And that's also reflect on the shelf life. And so I think this is an important parameter to consider. Increase salinity, increase also the fiber, as far as I know. So that could be, I would have expected more attention to this aspect. But okay, that's my nutritional background that he's talking. Can you go to figure eight of page 119? In chapter five is a summary figure of the effect of electrical conductivity and light, intensity of light. And if I well understood here, your idea is that both high light and high electrical conductivity is the desired condition. Am I correct?

My interpretation of this figure? Yeah, in this experiment, yes. So the suggestion is to grow the tomato in as much as possible, both high light and high conductivity. I would say not as much as possible.

There's a proper range of both easy and light. I think this map, it works for our experiments because both easy and light range is in an okay range. We didn't go to extreme, so that's why we didn't damage the photosynthesis to zero. So that's why I say it's not the higher the better. Okay, so these axes on the figure, the panel A of this figure are quantitative. So the fact that you are relatively close to the origin is with something. In the tested range. Okay, okay.

That's clear. And there is any trade-off that you can see between the, you know, the high light, high electrical conductivity. If I suppose that I want to increase a certain parameter, the flavor, for instance, there is any suggestion that I can go in one direction or in another. So if the goal of your cultivation is to reach a good quality without losing too much yield, then you can combine the high AC and high light. There do some restrictions because even on the highlights, if you apply high AC, the yield also reduces. It's just when you combine that, the average level are elevated. So that's why the final level can be comparable to the control level. We have time for a final short question. Really short. Really short. If you have to decide between changing the varieties of tomato or improving these agronomical conditions, cultivation conditions, which will be your decision? It's better to play on the genetics or on the cultivation. Oh, if I'm a grower, I think it depends on how expensive the seed is. So if the good cultivar costs too much, then I will reconsider it. But I agree that the genetic background set a potential roof for the quality that we can play with. Thank you very much. Thank you. Thank you, Professor Folliano, for your opposition. Then now I move to the second opponent, Dr. Fanetti, who is researcher in fruit physiology at the Foundation at Montmartre, in San Michaela, Al Adige in Italy. Vlogios. Respectant candidate, congratulations for the

interesting thesis and for the challenging to combine post harvest with pre harvest. Could you please read proposition number seven? Dear Perinif, could you help me read out proposition number seven? The ability to ignore is more important than the ability to learn. I agree. But can you explain a bit more? Like most of Western education is built on the ability to learn as an addictive process. But stating to the ability to ignore is more important. Why? What is the epistemological meaning of obstruction? It's also from part of my life experience and also research experience. So I think this age is an age for information booming. So we have too much things to take care of. We have too many informations of the education for several years. I thought I have ability to learn. But when I face so much informations, I realize I wanted too much. I'm curious about this, that and that everything when the dishes are all on the table. How can I choose? There's too much noise. So I think important ability is to ignore the noise and stay focused on research and also on your life development. That's where you can proceed, I think. But in the context of your research? Yes. So how the act of ignoring, especially the noise of an experiment, helped you to understand and have a good interpretation of your data. I think in my research we used to have very huge experiments. And I remember in one of the experiments I have five master students work at the same time together with me and a colleague. So it's a big team. And the original plan is huge. We want to measure everything. But it turns out we have limited time, limited human power, limited sample. We cannot do everything we want. So we need to make clear again what is exactly the research question and only do the important things around the research question. So that's the part I think we should ignore. But I'm not saying the rest of measurements are noise because I didn't measure them. If you would like now to do your PhD again and study again the interaction between pre-arvest and post-arvest, would you change something in your experimental design? Yeah, that's a very good question. I think the one thing I definitely want to do, especially with the letters experiment, is I say I try to connect pre-arvest and post-arvest. All our treatments are applied in pre-arvest. We don't have any treatment applied in the post-arvest. But if we have more stress levels in the post-arvest, then maybe we can confirm. If the improved quality ad harvest, are they really going to handle this stress? So if I want to do it again, that's the part I want to involve. But that's more content.

That means I need to smartly schedule the time and plan more. Okay, I agree. But if you want to go more deep in physiology, so we are scientists and we would like to know more about how plants or fruit react to the environment, do you think that maybe some more advanced analysis, especially in transketomic or other omics techniques, are necessary? If so, which kind of analysis do you suggest? Yes, I think they are necessary. And actually, lots of my colleagues in this group are doing this type of research now. For me, I'm interested in two things. One is more go deep, so metabolites analysis. So to have an overview, let me be able to select the traits out of the forest. And the other direction I'm interested in is not to go deep, but maybe more modeling sites, that we are able to use the data to predict what quality is going to change in post-arvest. Okay, so we can move to another question connected to that argument. In chapter five, chapter with tomato, you are suggesting that salinity can cause a decrease of firmness of tomato. And your hypothesis is calcium, the main agent. Do you think there are other possible agents that change texture apart of calcium? Yes, in the tomato experiments, yes, we raise the EC level, but we increase all the macronutrients together. So I consider it more like an osmotic stress. So the osmotic stress is more related to water uptake. So that's why I assume the calcium uptake will also be affected. And that will involve in the membrane development. So that's why I assume it goes to the firmness. But of course, on the other hand, because the water uptake are limited, so the water content of the tomato might also change. So that could be another reason that we have more concentrate and more tough tomato. Do you think that it's also possible that light mediates a bit this effect? Especially, I mean, like, can light synchronize in a different way firmness of the fruit and also the light color? Because from your experiment, it's quite clear that this decay of firmness

due to ice salinity is more common in red tomato, not in zero and so on. So it can be like a different synchronization also in the ripening of the fruit between color development and firmness decay. I think, yes, they are not developed in the same time pattern. And it's especially difficult for orange tomato, because when we harvest our samples, we set a standard, like a preliminary test to define the pigments, then take a photo, then we know when to harvest the fruits. So the color change for red tomato is quite obvious, but for orange tomato, it's quite difficult. So we might have some variation in the harvest timing. But what he also mentioned, the treatment itself might also directly have effects on the ripening speed. For this, I think it's a very interesting point. I feel I observed the difference, but because of the limitation of the sample, we are not able to quantify it in this experiment. During your thesis, often you express the content of metabolites, all for dry weight or for fresh weight. Is there a reason why you didn't mention all the data, like fresh weight or dry weight, and can have an effect on the data interpretation? I have mainly the sugars and the vitamin Cs. So in the thesis, I express them all in the fresh weight basis. But for the measurement itself, for the vitamin C, we do the analysis based on fresh frozen sample. So it's directly fresh basis. And for the sugars, it's from the freeze dried sample. So originally, the data are dry weight basis. But in able to make them comparable, people can have an idea about the content in real products. That's why we choose to have all the data on fresh weight basis. I partially agree, because sometimes the water content can be really important to understand also from quality point of view this data. For instance, in chapter five, when you compare the graph of bricks value, so total solids and total carbohydrates, you see that the trends are quite different. Usually, we connect bricks with sugar mostly. How can you explain this difference between the two graphs? I think the water content could be one thing. And for myself, I think the variation we saw from the carbohydrates or the not very nice correlation between bricks and carbohydrates is also because the reason from sampling. Because for the dwarf tomato, we have tomato in trusses and it's ripe one by one. So we always pick the red ripe tomato from the truss. So the position of the truss and the age of the plants, everything are changed. So they are same type of data, but the sample are from different bench. So that could be a reason. And we didn't have chance to test how much difference is tomato from different trusses. Thank you very much. Thank you. Thank you, Dr. Fanetti, for your opposition. Then now I'd like to invite Professor Otterson, who is professor of Applied Crop Physiology at the Faculty of Science and Technology of Aarhus University in Denmark. Thank you. I respect the candidates. It was kind of interesting to read your thesis because you walk into a scary room between production and post-harvest. I remember one of my first meetings on post-harvest many years back. You just bought the fruit and then you analyzed them. And when we produced ornamentals, we just sold them. So no post-harvest. So it's interesting to move into it. But I'm just wondering, I'm addressing mainly proposition one. Dear Peronieff, could you help me read out proposition number one? Daily light integral is the key growth factor determining vegetable quality. So you have been doing DLIs and you've been doing day lengths, intensities. Why do you conclude that DLI is the main factor? Alone, you say. I highly esteem the opponents. Thanks for your question. So I think in the setup of our experiments, when we increased the DLI, we always got good results of the nutrient content and also the visual quality. And we do test a few physiology-related traits that also related to photosynthesis and connect with DLI. So that's why we think DLI is the important factor that influenced the quality. So what about temperature and CO2 in that relation? That's a very good question. So I think DLI is the most important but not the only one that we should talk about. So we are trying to improve the quality by the last week of the production. So first I assume that the plants grow close to properly. So we have a base to boost the quality at the final stage. So that's why there I think light intensity or high DLI is the most important quality factor. If you increase the temperature in that phase also, you might have a higher nutrient uptake and sugar formation? Yes, I think that's a good point. But if you don't have enough light, only high temperature, I think you're going to damage your plant in the

final days. So that's why I think high light is a basis for creating more quality. But again, sometimes in the thesis you talk about how do you define high light actually? Because you have five or six different light levels that you work on, a PDF level. So which one is high for tomato? If you look at light response curve, you have one put in somewhere, when are you becoming tricky in terms of saturating a plant in terms of light level? Yes, we did measure the one light response curve. And the light intensity levels that we applied is in the range of exponential growth. And the higher one is actually the efficiency of photosynthesis starting getting lower. So that is the range we're aiming for. I think if for other crops or other practice, if you want to select light level for quality control, then that range is a good range to look at. But if you have elevated CO2, then you push upwards your curve? So the curve is made with 400 micromoles? Yes, if you change all the conditions at the same time, then you should reconsider what is the high intensity. In the context of this thesis, we continue everything in the growth. Keep all the conditions the same, but only change light. So that's why I think that range is proper. But if you are able to give higher temperature, higher CO2, for example, then that's also important to check another curve. But I suggest still in that range, I mean the exponential growth increase range. So I was jumping to another question that's more in general. You choose these compact tomato or dwarf tomato types, which normally grows slightly slower, the other ones, as for vertical farming. What is the biggest limitation if you want to grow these tomatoes in vertical farming systems? Do you mean the dwarf tomato? What's the limitation for tomato? I think, for my knowledge, I think there are quite limited varieties or general banks for the commercial use of dwarf tomato. The cultivar we choose, I think the best character is all fruits and flour on top. So you can easily scan the crops. It's a bit like strawberry fruit below, leaf above, the other way around. But the clear drawback is it has so many side shoots. So in this experiment, we actually pay a lot of effort in removing the side shoot every day. And that's going to not work in a practice situation, especially if you have multi-layers in a row. So I assume if we just let those side shoots grow, then it's just a bush. Then it took too many simulates to grow the side shoot, not the fruit. Or the competition from the neighbor will get worse, and maybe elongation, maybe flour adoption. These things would happen, so that's for sure not a production type. In conclusion, it's not really realistic to grow in invertible farming for the time being? I think there's a great chance, because now I do see myself a case that's growing in the greenhouse for the autonomous greenhouse challenge. No one is interpreting the crop management, just give comments to the climate control system, that it works for four to six months for one successful harvest. So I think there is a potential for that. Coming

back to the science, I'm just looking over there. You talk about carbohydrates all the time. You have figures about glucose, sucrose. When you look at the responses of the plants to change in light, you hide your life results in a higher carbohydrate. But actually, in the short term, when you look at your figure, it seems to be the glucose that's responding very fast. Yes, I think the glucose is one of the obvious parts. For example, the starch, we didn't see that obvious change with the changing light. I think, yes, one thing is because the products from photosynthesis directly link to the changing light, and the other thing might also link with the moment of harvest. Like if your harvest are late in the day, maybe there's more starch going up. If you harvest in the morning, after a few hours, light starts, then probably more glucose. I was more philosophically you were talking about post-harvest on ledges. We're going back to that. I have some figures. But how long time would you expect to have a post-harvest performance? How long time does it take from harvest to the consumer by the plants? Because you have an example of 21 days, and I couldn't imagine anyone would try to store it for 21 days, unless you were. Yes, I agree. I do have a photo for the letters stored for 21 days. But actually, the leaves in the box, it's something you're not going to buy. It still looks green, but it's not good anymore. So it's already below the threshold of shelf life. The shelf life we quantified is actually around nine days, but we do store it as a higher temperature compare. People normally do want to

speed up the experiment a bit. So for me, I think 10 days or two weeks, it's a proper range for letter storage. By the best of the post-late end-of-production treatments, how much did you increase the shelf life? I think under the treatments, compare the treatments, the higher one, we had 10, 11 days, and the lower one, we only have 3.6 days. But that was very low light levels. Yes, it's very low light levels. But if we compare with the control, it's already three or four more days. But we are not stored at four. We store at 10, so everything will speed up. Okay, thank you. Thank you, Professor Utterson, for your examination. Then now I invite the next opponent, Dr. De Beer, who is Researcher Horticulture Light at Signify in Eindhoven, the Netherlands. The floor is yours. Thank you. Respected candidates. I think you have researched a very relevant topic. Quality traits are a very important factor in reducing food waste. And we should not only look to optimize the production process, but also be conscious of the impact the production process has on post-harvest quality. So I enjoyed reading your thesis very much, where you make this link between the production and the post-harvest quality traits. I would like to ask you a question about the experiment that you described in Chapter 3. Here you describe two experiments on lettuce, where you have different end-of-production treatments. And on page 50, you describe both the cultivation conditions in the growth phase of the crop and then in Table 2, the pre-harvest treatments. In both phases, there are similarities and differences between the treatments that you apply between the two experiments. Can you please tell me a little bit more about your considerations in how you set up your experimental design? Hi, this is Diminz Alferment. Thanks for your nice word and for your question. So in the experiment in Chapter 3, the goal of the research is to test short-term highlights. It works for the quality in the post-harvest. So in the first experiment, we go into a direct and a simple setup. We have the lettuce grow standardly in the greenhouse and apply extreme light levels in the end-of-production lighting. So you can see the level 1 goes to 0, dark, and 1 goes to high. We saw some nice trends from these experiments. We see three lights of carbohydrate and vitamin C are separate. So that's why we think, what if we are able to go higher of the light intensity? What would happen? So in the second experiment, we try to control better of the growth parts and also the end-of-production lighting parts. And we do cover the range of light intensity, including the growth level light intensity, and also one level much more higher for lettuce. So we want to test what would happen if we go a bit extreme. Thank you. The main results of this experiment are shown in Figure 3 on page 57. And one thing that struck me there is if we look at Figure B, which describes your second experiment, I see that in the total ascorbic acid concentration for the treatment at 210 micromole, which is your control, we see a decrease in ascorbic acid concentration. Can you elaborate a bit more on the background of that, what's going on in the plants? Yes, thanks for your question. I think what you see, the decrease in vitamin C with the constant light level as growth, also happening in the first experiment. So the stage we apply light is already the end stage of lettuce production. So normally, lettuce may grow five weeks, around five weeks, and the treatment is applied the six weeks. So it's already mature plants that are ready to harvest. And the sample we choose is the mature leaf in the middle round of the lettuce hand. So I think with the age, with the senescence in my starts, or with less zinc strands compared to the younger leaves, then that's our expected decrease in the end coincidence. And do you think that if we would have harvested, you would have started your experiment a bit earlier? Do you think you would have had different levels of ascorbic acid? I mean, if it's related to the age of the leaf, you can imagine that if we wait longer, it goes down, if you go earlier. I do think there's a chance to move a bit earlier. And also the treatment a bit shorter, that also helps. And in another lettuce experiment, which is similar setup, we kind of forgot what I'm going to say. But yes, we've seen the fresh weight and dry weight are still growing. So it might also depend on which lettuce you work with or the growth status of your lettuce. So in the next experiment, we actually see the fresh weight, dry weight both are growing. So that could be a good moment to start a final treatment. But in these experiments, I think there's a chance to go earlier or shorter. Okay, thanks. And

one final question about this figure. I noticed that between the two experiments, there's a remarkable difference in the total ascorbic acid concentration at the time you start your treatment. And I'm sure you gave it some thought what would be the possible reason for that. Yes, then probably the answer is back to your first question. The growth phase, the condition in the growth phase are very much different. So we have the first experiment done in greenhouse. We don't have much control of the light. And it's a winter experiment. And the second experiment we apply in the vertical farms in the growth chamber. We have well control. And according to the commercial experience, we also add a little bit far red. But we have more plant density, for example. And that could be the reason makes the difference. And yeah, one more thing maybe to mention, that in the second experiment, we do face some logistic problem. So we need to transport the letters from one location to another location for the end of production lighting. So when to harvest the plant, make them ready in the crease, when to transport, when to start the end of production lighting, it's kind of complicated in between. So that's my cause, some difference. Yeah, I was wondering myself since the first experiment was executed in a research or in a greenhouse, that means you have more variation in temperature, light intensity, et cetera. And of course also there's a difference in the light source that's being used. And yeah, do you think that any of those factors are playing an important role or is it more the logistics component and the age of the plants that's affecting this difference? Yeah, I think of course the growth factors will play a role to define the starting value of the letter's quality. Thank you. Then I would like to move to the experiments that you have done on tomato. The other opponents also have addressed this experiment already. What I would like to start with is a very practical question regarding this research. You have investigated tomatoes grown under rather wide range of photon flux densities with more than factor two difference at the same plant load. And I was wondering whether the time to harvest was comparable for all the experiments or did you see that there is a big difference in ripening time, harvest time between the different treatments that you have? Yes, we do observe the difference in the ripening speed. So in practice, if the treatment are applied, then the harvest moment can be different. But in our experiments, we don't harvest the plant. We only harvest the fruits that meet the standard we set, so the right material fruit. And for the crop itself, we keep control, we do the pruning, we keep the number leaves and the truss numbers constant. So we only look at the stage of fruit. I understand. You harvest at a specific ripeness of the fruit. Yes. One of the things that I'm interested in is the light use efficiency. You have grown tomatoes under photon flux density ranging from 140 to 330 micromoles, which is quite a wide range. And if I look at the total dry weight, fruit dry weight that is produced, I do see that it's higher at a higher photon flux density, but not that much. And that means either that the light use efficiency at the higher photon flux density is quite a lot lower, or perhaps the fruits were ripened a lot faster, which still means that the total light sum is more comparable. That the light use efficiency might still be proportional.

So that's why I was wondering if there's really a big difference between the treatments and the time until you have your first ripe fruits. Is that something that you measured? That's something we didn't measure, but we do observe that. So I have a photo on page 129. So from that photo, you see the last row of the picture from the highlight intensity. Although it's from different angle, but you already see they have more red tomato compared to the low intensity one. And for the easy level, for our observation, we saw some difference, but in this experiment, we are not able to write down the number and analyze it. Okay, thank you. I noticed, yeah, of course, you already mentioned that for the tomato fruit or plants in this experiment, you really had to do a lot of pruning of the side shoots, et cetera. I noticed that in the graph that you have of figure five, that's the way the assimilates are distributed amongst the... Thanks, Dr.

de Villa, for your half question, last half question. And the examination in total, the question will be dealt with maybe after the defense. I now adjourn the meeting

because the examining committee will now withdraw for consultation. Thank you. Please be seated. I hereby reopen this meeting. The academic board of Wageningen University, represented by the deputy director of Magnificus and six committee members appointed by the academic board, having noted the content of a thesis entitled, Lighting Strategies to Enhance Crop Quality in Controlled Environment Agriculture with Propositions, having heard the defense of their thesis, has decided to confer the degree of doctor on Chiang Cizi Min, born in Yunnan, China on June 15th, 1990, and to grant to her all rights and privileges ensuing from the doctorate by law and custom. The academic board assumes that you accept your duty as a scientist to execute your future research ethically and with due diligence according to the Netherlands Code of Conduct for Research Integrity. I now invite the promoter, Professor Maseles, to present the new doctor with the degree. You've heard the decision of the academic board of Wageningen University to confer on you, Chiang Cizi Min, the degree of doctor. It is now my honor to present you with the degree signed by the deputy director of Magnificus, the promoters and sealed with the great seal of Wageningen University. I first invite you to sign the degree as well, and with this signature you declare to act according to the Netherlands Code of Conduct for Research Integrity in the future. Allow me, deputy director of Magnificus, to offer my congratulations. Dear Dr.

Min, dear Sisi, it's my honor to congratulate you, also on behalf of Professor Ernst Waltering with your doctor's title, which is the highest academic degree. I would like to extend our congratulations also to your part of seeing your parents, further family and friends. I will now give the word to Ernst Waltering for a personal word. Thank you. Dear Dr.

Min, dear Sisi, it's really a great pleasure to congratulate you with this huge accomplishment in your scientific career. So you're now a doctor, and I'm really very happy for you. And you did it very well, well deserved. So let's go somewhat back in time. So after you got your bachelor degree from the Tianjin Agricultural University in China, you came to Wageningen in 2012 for your master's study greenhouse horticulture. So we first met when you started your master's thesis work within the project of PhD student Nikos Netakas, on the effect of post-harvest lighting on tomato fruit ripening and nutritional quality. So together with Nikos you did really some pioneering work on the effect of light on tomato fruit development and especially on the fruits vitamin C content. So among others you experimented with different lighting setups and you did measurements of among others photosynthesis, sugars and vitamin C. After your graduation you wanted to follow up on this in a PhD project, focused on light and nutrient quality of fresh products. So the idea was there to write an application for a fellowship of the China scholarship council with a project focused on lettuce and luckily that was immediately granted. So in September 2015 you started your PhD. So from the earlier work with tomato and also with some lettuce cultivars it was clear that post-harvest lighting could easily boost the vitamin C content and the idea was that this should work in many crops so it would be a nice strategy to improve the nutritional quality of harvested products. Now if you think of post-harvest lighting from a logistical point of view it seems not too easy to apply this technology to fruit and vegetables in daily practice. So fresh products are usually of course stored in boxes or crates and they are also stored in cold rooms mostly in the dark. Therefore the idea was born instead of applying the light post-harvest to apply some extra light during the last days before the harvest. So in this way the plants at harvest should get an improved nutritional profile which would likely also benefit post-harvest performance. Now along the way we started to name this strategy end of production lighting and I'm not sure if we are the first one to use this word but I see it now everywhere in the literature. So the good thing of applying the extra light only during the last days before harvest is that it does not greatly interfere with the regular growing cycle and also not with the harvest planning. While it does provide the crop with some extra energy and nutrients to better survive the post-harvest phase. Now also from a financial point of view this

is a good strategy as only a few days of extra light application will not have great impact on the total electricity cost of the growth cycle. Now actually we can read it in the thesis. You showed that this strategy works at least in lettuce. So the nutritional value can be improved and the shelf life prolonged by several days as a result of end of production lighting. Philips lighting solutions now signify was also interested in this concept and this led to a fruitful collaboration with among others Celine Nicole and this gave us the possibility to execute some of the lighting experiments in the grow wise facilities in Eindhoven. Although most of the experimental work with lettuce was finished within the four years of the CSC fellowship there was for several good reasons not yet a PhD thesis at that time. So while the PhD project was temporarily slowed down you were involved as a postdoc, yes a postdoc without even having a PhD in several other projects within the chair group and you were also employed as a research fellow at the Amsterdam Institute of Advanced Metropolitan Solution. Difficult word. Among others what is interesting you acquired a project sponsored by the Chinese e-commerce platform Pin Duo Duo to improve the taste and attractiveness of tomatoes. So here you investigated the interaction between the electrical conductivity of the nutrient solution and the intensity of supplemental lighting on the food quality in both dwarf and high wire tomatoes. This was an interesting project and some of the results of these studies eventually also ended up in your thesis. Although you were busy with these new projects supervising a lot of students and actively participating year after year in several editions of the Autonomous Greenhouse Challenge on the site you steadily worked on your thesis and we had regular meetings about the progress. So I really admire your perseverance which finally led to this nice result that we are celebrating now. Apart from the beautifully designed thesis one chapter has been published in a book about new technologies during vertical farming and two chapters have already been published in international scientific journals. So another chapter from your thesis will be submitted soon. Now we learned to know you as a very accurate and serious researcher with a great eye for detail. Experiments were always well thought out and well designed and executed and you always collected and analyzed as many samples as possible within the time limits. And also all the data were always elaborately analyzed in order to get the most out of the results. Apart from being a good scientist you're really a pleasant person, a very pleasant person even to work with and you are always open to discuss your plans and results with others. Also you are very good in communication and in organizing the work, not only your own work but also other events, for instance within the chair group. And a special thank you for the interesting presence you brought back from China for us. Like cookies filled with rose petals, very interesting. They're from your hometown. And coffee with really interesting taste profiles. So you are now entering a new phase in your career. You can regard yourself as a specialist both in crop cultivation but also in post harvest quality issues and shelf life. I understood that you may want to develop a kind of China, Netherlands, interconnected value chain consultancy business. That would be very nice because you can use your knowledge about the complete chain to improve the quality and the outcome in practice. I wish you all the luck with this. Thank you. Thank you very much Professor Waldring and Professor Maseles. Dear Dr.

Sisi Min, this marks the end of the ceremony in which you successfully defended your thesis in public. And on behalf of Wageningen University, I congratulate you with your degree of doctor and I would like to include in this congratulation your parents who are watching online and your husband Xin Zhao who is here in the audience. I also want to include in this congratulation your supervisory team, Professor Waldring and Professor Maseles and further all family, friends and colleagues present here or anywhere else in the world. We are having a new doctor in our midst. Your work was following the Wageningen motto to explore the potential of nature to improve the quality of life. In your case about lighting strategies to enhance crop quality. You are proud that you connected pre-harvest and post-harvest in your studies and by doing this you broadened the concept of post-harvest research. Moreover you connected laboratory analysis to consumer perception, the

instrument to the human. And so you could deepen the understanding of shelf life and quality for lettuce and small tomatoes. Very interesting material which today made you become a PhD, the highest degree in our university system. So now you became not only a doctor but also a Wageningen graduate and both you will remain for life. So we hope you will become our ambassador for life as well and we hope to stay in contact with you in the future. Do not forget us. I wish you a lot of success in your future career and your future life and on the shorter timescale I wish you a nice and pleasant continuation of today. Next I would like to thank the members of the committee, Professor Foliano of Wageningen University, Dr.

Van Eeti of the Foundation Edmond Mach in Italy, Dr.

Otterson of Irish University in Denmark and Dr. De Baer of Signify in Eindhoven for having taken the time and the effort to review the reading version of the thesis and to participate today in the actual defense. You have fulfilled a very important task in the whole PhD process ensuring that the quality of the Wageningen thesis is maintained. Thanks a lot. Lastly I would want to thank the audience here present in the auditorium showing your interest in the ceremony, the defense by the PhD candidate and the actual promotion to doctor is highly appreciated and makes this ceremony significant. This ends the official ceremony. I hereby close the meeting.