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Abstracts

Digital twins need kinetic modelling: the case of crown rot in the banana chain

Rob Schouten, Martijntje Vollebregt , Leo Lukasse

Here, we present the conceptual background of a digital twin that aims to predict the crown rot in banana. Crown rot is caused by a fungal complex affecting banana cultivation. Crown rot might show up at destination after weeklong transport from Central and South American countries. We present an approach that describes the crown rot incidence based on visual quality evaluations on more than 10,000 shipments. Crown rot incidence at the point of origin (Peru or Dominican Republic) was calculated based on a set of crown rot evaluations at the point of destination (The Netherlands) taking into account the shipment duration and the mode of reefer transport (MAP or CA). For this step a batch version of a fungal infection model was used, earlier succesfully applied to describe botrytis development in strawberry. The second step links the crown rot incidence at the point of origin to historical climate data using a kinetic model. This model assumes that the fungal complex can be present in two states, either inactive or active. The inactive form can become active and then either be destroyed or grow exponentially, leading to crown rot. The rate constant for the transformation from inactive to active was assumed to depend on ambient temperature (Arrhenius' Law) and relative humidity. Results show that crown rot frequency and intensity over six years can be simulated well using estimated model parameters that vary slightly for the two countries, perhaps indicative of different fungal complexes. The presented approach has the promise to predict the risk of crown rot at the point of destination roughly 40 days in advance. Validation with data sets from other banana producing countries and the creation of a digital twin dashboard that supports decisions on interventions (e.g. choice for CA or MAP transport) is in progress.

Keywords: Climate data, fungal infection, reefer transport, Optipa, batch model

A kinetic model for cross-talk between ethylene synthesis and signaling during tomato fruit ripening

Minh Viet Thao Ms. Nguyen, Maarten Hertog, Bram Van de Poel, Dinh Tran, Bart Nicolaï

Fruit ripening is a complexed developmental process tightly associated with the phytohormone ethylene. The current study aimed to develop a comprehensive kinetic model starting the transcripts to get a better insight on the entire ethylene biosynthesis and its signaling and the connection between these two pathways during tomato fruit ripening. The discrete harvested maturity stages were converted to biological ages using a biological age model. Preliminary results showed that the protein abundance of 1-aminocyclopropane-1-carboxylic acid oxidase (ACO) isoforms and their activity can be well predicted from their gene expression as the starting data. In addition, ACO1 appears to less contribute to the ethylene production compared to ACO5 and ACO6. The formation of homo- and heterodimer of ethylene receptors (ETRs) indirectly affects the stability of ETRs through binding and releasing ethylene. The putative S-(5'-adenosyl)-L-methionine (SAM) profile indicates that the ethylene production is strongly regulated by SAM via 1-aminocyclopropane-1-carboxylic acid. Meanwhile, the release of ethylene from receptor complexes (homo-/hetero-dimer ETRs, homo/dimer ETR – constitutive triple response 1) does not largely contribute to the ethylene emission. The model is further improved to fit to the profiles of signaling proteins and is being used to compare to literature data on ripening mutants and 1-MCP and ethylene treatments.

Keywords: Ethylene biosynthesis; tomato fruit; ethylene receptors

Session 1: Models for Postharvest Processes

Predictive modelling of the ripening of tomatoes

Jakub Salagovic, Pieter Verboven, Maarten Hertog, Bart Nicolaï

Fruit ripening is a complex process that transforms the fruit from unpleasant and hidden into appealing and attractive. During this development stage, the fruit undergoes dramatic changes in its flavour, aroma, colour and texture. Despite the fact that there are well-established models for yield estimation, it is still a challenging task to precisely predict the ripening process. Some models predicting quality properties for the preharvest stage exist, however mostly as empirical functions of time, selected fruit stage or final fruit properties, with little mechanistic foundation. While such models work well in the conditions that they were developed for, the results vary if the assumptions are not met – e.g. faster ripening fruit (due to temperature change), fruit not reaching expected size (due to higher crop load), etc. To minimize these effects, we propose a new approach to connect quality kinetics submodels to the fruit growth model. Based on the purely mathematical connection between fruit size properties obtained from the tomato fruit growth model and variables from the quality submodels, we were able to define the beginning of the ripening stage. Specifically, by using the sign of the second derivative of fresh weight we defined a starting point for the simulation of quality submodels. The method was tested for colour and firmness models for the period from after the cell division phase till red ripe stage. For the purpose of calibration and validation, experiments measuring fruit growth, colour, firmness, respiration and ethylene emission rate were conducted for the whole duration of fruit development in two temperature regimes. By using relative variables (e.g. derivative of fruit weight) rather than absolute ones (e.g. maximum fruit weight) together with the fruit growth model responsive to growth conditions, we obtained precise and robust predictions for both yield and quality properties of tomato fruit in various settings.

Keywords: Tomato, growth model, quality model, colour, firmness, temperature

A reaction-diffusion model for gas exchange in tomato fruit during ripening

Hui Xiao, Pieter Verboven, Bart Nicolaï

Tomato fruit has been intensively investigated as a model fruit for the study of climacteric ripening and ethylene biosynthesis and signaling pathways. Besides the burst of ethylene production, the rise of respiration is also one of the main characteristics of climacteric ripening. Plant tissues lack a circulatory system dedicated to gas transport, and O_2 acquisition and CO_2 release are accomplished by diffusion through cells and intercellular spaces. Obtaining the respiratory gas distributions within fruits has long been difficult work, but is important in understanding the gas-related physiological processes. This work aimed to establish a reaction-diffusion model to reveal the respiratory gas distributions within tomato fruits during ripening. This was achieved by the following steps: (1) obtaining tomato fruits geometry by magnetic resonance imaging (MRI); (2) determining tissue-specific and entire fruit respiration rates by depletion experiments, and characterizing them by a Michaelis-Mention kinetics; (3) implementing a diffusion-reaction model for respiratory gases within the fruit geometry and solving it locally. The model elucidates the cause of gas gradients and hypoxia within the tomato fruit from a biophysical perspective.

Keywords: Tomato fruit, respiratory gases, gas diffusion and distribution, gas exchange modelling

Modeling redox potential curves for identification of selected bacteria strains

Eya Ms. Yakdhane, Dóra Tozsér, Katalin Szakmár, Laszlo Baranyai, Gabriella Kiskó

Being time consuming is the strongest weakness of colony counting method that has led to develop new technologies. One of the newest alternative approaches is based on the redox potential, which defines the oxidative change of complex media, and it is basically related to the consumption of oxygen and nutrients, and the production of reduced molecules in the measured biological system. This study shows the characterisation and discrimination results of the redox potential curves of three different bacteria, Escherichia coli, Pseudomonas aeruginosa, and Salmonella Typhimurium. Evaluated data were acquired using a MicroTester instrument (Microtest Ltd., Budapest, Hungary), which is a multi-channel redox potential measuring device. All together 40 curves were analysed. Curve fitting and classification based on Linear Discriminant Analysis (LDA) were performed using R and RStudio free software. Three sigmoidal models were compared with first order statistical parameters to describe the unique shape of the redox potential curves (Gompertz, Rosso, and Logistic). First order statistical parameters achieved 100% accuracy with LDA. Rosso and Logistic models gave comparable results with the correct classification of 95 %. Gompertz model was the least accurate model with 92.5% correct classification. Results confirmed that each studied bacteria have a distinctive redox potential curve shape and the discrimination among them could be done based on this feature.

Keywords: Escherichia, Pseudomonas, Salmonella, multivariate classification, Rosso model, Gompertz model, Logistic model, nonlinear regression

Decrease in apple firmness during storage at room temperature – investigating the effect of orchard and harvest date using generic modelling

Pawel Konopacki, Severine Gabioud Rebeaud, Ernst Höhn, Pawel Bialkowski, Andrzej Bartosik

Apple fruits of the two cultivars ‘Golden Delicious’ and ‘Braeburn’ were harvested twice, at 10-day intervals. The ‘Golden Delicious’ apples were grown in two different orchards, and harvested on the same days, while the ‘Braeburn’ apples were grown in one orchard. After harvest, apples were stored at 10°C and 20°C for up to 113 days and up to 60 days, respectively. Firmness was measured every 3-7 days using a handheld penetrometer. An autocatalytic model of firmness senescence was applied to gathered data. The main parameters of the algebraic expression of the model are: initial and final levels of fruit firmness, initial concentration of enzymes, reaction rate constant for a given temperature. The goodness of fit for each individual combination differed between two storage temperatures, and the explained part of variance varied between 85.0% and 93.4% for data gathered during storage at 10°C, and between 73.6% and 87.6% for data gathered during storage at 20°C. When the data of both cultivars and both harvest dates gathered during storage at 10°C were combined in a single model analysis assuming that only the reaction rate constant was estimated as single common value for all data, the explained part of variance was 91.4%. The estimated values of initial enzymes concertation were higher for second harvest for all orchards studied. Also, the estimated initial and final levels of fruit firmness differed between the orchards studied. These results indicate that the autocatalytic firmness model used in the study is able to reliably reproduce the effect

of harvest dates and different orchards on the changes of firmness observed by storage specialists.

Keywords: Autocatalytic model, firmness senescence, cultivar

Real-time monitoring of heat transfer in horticultural supply chain

Tuany Gabriela Hoffmann, Ulrike Praeger, Pramod Mahajan, Martin Geyer, Reiner Jedermann, Manfred Linke

Temperature differences between produce and the environment, in the postharvest chain of fruit and vegetables, cause heat to flow from warm to cold places. At the beginning of the cooling process, heat flows from the food to the surroundings and, during the long term-storage, temperature fluctuation due to compressor on-off strategy and temperature stratification due to lack of homogenization within the cold system can take place. Temperature non-uniformities are transferred, usually delayed in time, to the fruit and vegetables in the horticultural supply chain, which can compromise food preservation. In order to monitor and analyze the impact of these temperature changes in horticultural produce supply chain, a measuring system was built based on Peltier element for detecting real-time heat exchange between apple sample and the surrounding air, during a cooling process. Peltier elements to measure the heat flow were placed at the food surface by a double-sided thermal conductive tape. Experiments were performed inside a chamber, where the air temperature and its fluctuation had a robust control. Temperature settings were chosen to represent the fluctuations observed inside real cooling facilities by a sinusoidal profile with total cycle time of 2h ranging from 1°C to 9°C. The cooling and re-warming process of an apple provided an outgoing and incoming heat flow rate in a similar quantity, around 600W/m2. A delayed thermal response in the heat flow from food was observed between 10-15min. In summary, the direct recording of the heat flow rate from horticultural produce can provide a higher-quality statement of the interaction between food and environment, once other influencing phenomena are also taken into account when measuring heat flow. The information provided by the Peltier element can be used for the modeling and design of new refrigeration systems aiming food shelf-life extension and energy saving.

Keywords: Apple, postharvest, refrigeration, heat transfer, Peltier, sensor, cold storage, cool chain.

Effect of atmospheric cold plasma pre-treatment on drying kinetics of 'Tropica' mango

Loriane Yanclo, Zinash Belay, Gunnar Sigge, Oluwafemi James Caleb

Hot air drying has been one of the most used methods to dry mango fruit. However, this mode of drying is associated with longer drying time and elevated temperature that affects the quality and nutritional characteristics of the final product. In recent years pre-treatments such as cold plasma has been introduced as a novel technology to accelerate the drying process of fresh produce and preserve the nutritional values. Therefore, the aim of this study was to evaluate the effects of cold plasma (CP) pre-treatment on the drying kinetics of mango 'Tropica' slices during convective air drying. Drying was done 60 °C and fruit without treatment was used as a control. The experimental data obtained during the drying process were fitted to seven thin layer mathematical models to describe the drying kinetics of the mango slice. Effectiveness of the models were compared based on their coefficient of determination (R^2) and room mean square error (RMSE). The results indicated that CP pre-treatment accelerated the mass transfer during the drying process, resulting in lower drying time compared to the control. Among the

tested models, logarithmic model was the most suitable to describe drying kinetics of mango slices with a correlation coefficient of R^2 equal to 0.99. This study demonstrated that CP can be used as a suitable pre-treatment to shorten the drying time and will assist future research in understanding the influence of CP pre-treatment on drying of agricultural products.

Keywords: Low-pressure cold plasma, drying rate, pre-treatment, logarithmic model

Monte Carlo simulation and sensitivity analysis of Michaëlis-Menten kinetics equation regarding the CO_2 inhibitive response on O_2 consumption

George Xanthopoulos, Charalampos Templalexis

In this study, was carried out statistical and sensitivity analysis regarding the Michaëlis-Menten kinetics equation which is used in modelling of respiration rate of agricultural produce in modified atmosphere packaging. The Monte Carlo simulation which is used to explain the impact of risk and uncertainty in prediction models, indicated that the P_{CO2} model term is the most sensitive in all the tested cases and inhibition models (competitive, uncompetitive, non-competitive, mixed). This term was modified as $P_{CO2}|^m$ incorporating an exponential term similarly to Hill equation, and substituted back to Michaëlis-Menten kinetics equation, improving its prediction stability and accuracy. The analysis was based on the respiration rate data of fresh-cut 'Romaine' lettuce (Lactuca sativa var. longifolia) treated by sodium hypochlorite (NaClO) at 100 ppm and an organic acid solution (ascorbic and citric acid, 1% w/v) and then stored for 7 days at 4.18 °C. The respiration rate (O_2 consumption and CO_2 accumulation) was significantly affected by the disinfection methods, the storage time and their interaction. The most intense changes occurred during the first six hours of the experiment while the treatment by the organic acid solution resulted to the highest R_{CO2}.

Keywords: Respiration Rate; Michaëlis-Menten kinetics; Monte Carlo analysis; Fresh-cut lettuce; Hill's equation.

A parametric sensitivity investigation of ethylene concentrations inside kiwifruit boxes under dynamic conditions

Andrew East, Carlos Lopez-Lozano, John Bronlund, Gabe Redding, Sunny-George Gwanpua

Physiological changes in fruit can be influenced by elevated ethylene packaging microenvironments. Ethylene concentrations are influenced by production rates of fruit, absorption into surrounding fruit and materials and the rate of gas transfer through packaging barriers. Packaging design usually seeks to minimise ethylene concentrations within package to maintain produce quality. Using mathematical models to predict ethylene within a package can be useful for design. Kiwifruit packaging systems are unusually complex, containing films with holes and folds which complicates prediction. In complex real-life systems, the ethylene concentration in the package is in a dynamic state due to changes in fruit ethylene production and the potential for flushing of the packaging headspace through physical manipulation in storage. Concentration gradients within the package produced by individual fruit producing ethylene and locations around designed holes further influence ethylene concentration prediction. The availability of finite element modelling (FEM) software allows for parametric sensitivity identification to develop mathematical relationships between ethylene concentrations in the box and the packaging components. The objective of this study was to predict the temporal and spatial changes in ethylene concentrations under a range of scenarios. The developed model was compared to experimental scenarios in a step-by-step validation. Ethylene gas standard of 100 uL/L concentrations were introduced at different flowrates

through a Shirasu porous glass tube into a 11 cm x 30 cm x 40 cm grated stainless steel frame encased by a film to mimic and have a known ethylene production rate. Films scenarios included a package with 8 holes of 6 mm diameter and a range of film folds. Absorption dynamics was also compared using 50 fruits inside a perfectly sealed film. The modelled simulations demonstrated that the box packaging system is highly sensitive to input parameters and could be used to explore scenarios where ethylene concentration gradients might exist.

Keywords: Ethylene, plastics, supply chain, fruit loss, packaging, shelf-life

Session 2: Sensors & Digital Transition in Horticulture

Dynamics of weed growth in an apple orchard tree strip

Roy McCormick, Anna-Lena Haug, Konni Biegert, Pol Tijskens

Applied horticultural researchers are increasingly working with plant growth and development data that take the form of repeated measures on the same experimental unit that vary over time and/or space. With the movement to a precision farming approach these types of data are more and more available from non-destructive sensing or as conducted in this work, from traditional visual assessments of the percentage weed ground cover and hand measurements of plant height. What is missing most of the time in a purely statistical analysis of data, is any biological or physiological thinking. When models can be built on a scientific understanding the analysis can potentially provide more insights into the relationships and processes active in the studied system. The inclusion of 'biological age variability' in modelling horticultural processes is one example of trying to build more scientific understanding into horticultural models. However, biological age modelling is usually not included in traditionally based statistical courses, something that can be considered a lost opportunity. The aim of this work is to compare a biological age approach to traditional mixed models (e.g. linear or generalised linear) using data from a weed control experiment conducted at the KOB in 2022. The experiment used repeated time-series assessments of three different organic mulch treatments (grass clover silage, biodegradable spray and woodchip) to determine visually the weed cover in a 0.15 m² assessment area. Assessments were conducted four times from mid-May to early August. In August, the mean weed area was 13.3, 50.6 and 69.4% for the woodchip, spray and silage mulch treatments, respectively. These data (three treatments, three blocks and three assessment positions within each block) will be fed into a) a biological age or b) a mixed linear regression model for analysis. The key features of the different modelling approaches will be discussed and compared.

Keywords: Modelling, biological age, repeated measures, weed incidence, weed growth, mulch treatment

Modelling Belgian endive growth during forcing for optimum harvest quality

Dorien Vanhees, Bert Verlinden, Emma Vandenbogaerde, Sarah Bossuyt, Eva M. Ampe, Bart Nicolaï

Belgian endive (Cichorium intybus L.) quality is determined by field and forcing conditions. Its production is characterized by a two year growth cycle in which a taproot is harvested and stored in the first year. In the second year this taproot is forced in dark conditions in which a white head is produced. Growers decide the forcing temperature settings of a hydroponic cascade system intuitively depending on root quality, variety and growing conditions during the first field year. The resulting Belgian endive head quality is mainly determined by size but also

other quality characteristics such as color or the presence of defects. Generally greater root mass initiates the growth of bigger Belgian endive heads. These heads consist of a floral stalk or pith and basal leaves. Growing Belgian endive heads with the optimum pith to leaf ratio is important to meet consumer preferences. Taproots of two varieties (Topscore, Darling) were forced in a hydroponic system at two different temperature setpoints. The air and water temperature and taproot temperature were monitored using temperature sensors during forcing. Mass and dry matter content of the taproot, lateral roots, stem and leaves were measured at several time points during growth. A state model was developed to describe plant development and growth during forcing. The model consists of a set of coupled differential equations describing changes in biomass, sugars and transport of water through four compartments: the taproot, lateral roots, pith and leaves. Inulin is converted into sucrose and redistributed from the taproot into the other model compartments, while water is taken up by developing lateral roots and redistributed over the entire plant system. The model sheds light on how the biomass is distributed to the entire plant system at different temperatures.

Keywords: Belgian endive, quality, forcing, modelling, temperature, plant growth

Prediction model for calcium content of apples at harvest

Felix Büchele, Rachael Maree Wood, Michael Blanke, Franz Ruess, Susanne Früh, Arno Bernardo Heldwein, Fabio Rodrigo Thewes, Lilian Osmari Uhlmann, Daniel Alexandre Neuwald

Climate change is responsible for major alterations in the phenology of fruit trees in Germany. This model is based on a comprehensive data set of phenology observation over the past 70 years at 3 study sites in Germany and has shown that the flowering of apple trees and subsequently the fruit development has set in continuously earlier, with serious implications for fruit quality as well as storability. Calcium (Ca) plays an important role in stabilizing cell walls in apples; sufficient supply is therefore essential for good storability and for controlling postharvest disorders. However, as Ca is phloem immobile, the transport of the mineral into the fruit occurs solely with the transpiration stream through the xylem. Calcium accumulates in the first weeks after flowering, in which the fruit shows the highest transpiration per unit (surface or mass) and subsequently the greatest transport of water. With an earlier flower onset, Ca uptake may suffer as the evapotranspiration and therefore the transport of Ca is reduced due to fewer sunlight hours in a shorter photoperiod and a smaller thermal amplitude early in the season. However, Ca deficiency and an unfavorable relation to its antagonist potassium can increase the risk of the accelerated loss of firmness or emergence of disorders such as bitter pit or flesh browning. The objective of this work was to create a model for predicting the calcium content of apple fruit at harvest, in order to support fruit production adapting to the challenges presented by climate change. In addition, new approaches to further develop the model by incorporating factors such as soil type, tree age and cultivation practices will be discussed. The prediction model is calibrated and needs to be validated with the date from this year and for the coming seasons.

Keywords: Apples (Malus domestica Borkh), calcium, climate change, early flowering, transpiration, fruit quality, storability

Simulating fruit growth and size analysis

Pol Tijskens, Rob Schouten, Roy McCormick, Tatjana Unuk, Ana Cavaco

Growth of fruit and fruit size is of major importance for growers. Growth in size during cell expansion is well known (adapted van Bertalanffy model) and well applied taking care of the

ever-present variation. Explained parts reach well over 98%. What is not very well understood is the increase in number of cells and the associated size increase, just after fruit set. It is (for the time being) just not feasible to measure these small fruit (< 5 mm) on an individual level. As a consequence, the von Bertalanffy model does not cover the behaviour right after fruit set. Very rare reports, however, indicate a gradual increase in number of cells, which keep subsequently growing in size during the cell expansion period. A kinetic mechanism is presented that includes both these concurrent processes, however, consisting of six reactions, this model becomes exceedingly complex. Hence, an analytical solution is not available. Simulation using numerical integration with various parameter values will be presented. The general behaviour is as expected, roughly as an asymmetric sigmoidal. As a comparison, the well know Richards' curve, frequently used to describe growth, is hard to apply as an analysing tool. Moreover, this function has no relation whatsoever with any kinetic mechanism. A new simplified kinetic mechanism that is suitable for data analysis is presented based on conversion of a substrate by an enzyme that increases according to an autocatalytic reaction. The resulting analytical solution can be used to analyse simulated size data, including biological variation. All simulated data on growth size fitted extremely well in the asymmetrical logistic model, with explained parts well over 99%. Behaviour of the growth mechanism, and analysis results of simulated data the developed asymmetrical sigmoidal function will be presented and discussed.

Keywords: Size growth, kinetic model, fruit, cell production, cell expansion, asymmetrical sigmoidal model

Micromechanics of apple and pear tissues for fruit growth modeling

Bart Dequeker, Hans Van Cauteren, Piotr Pieczywek, Artur Zdunek, Pieter Verboven, Bart Smeets, Bart Nicolai

Fruit firmness is an important factor in fruit quality, and is largely determined by the mechanical properties of the composing tissues. During growth and ripening, the micromechanics of the tissues of pome fruits (apple and pear) change considerably with regard to composition and structure of cell walls. The study of the mechanical properties at the cellular level of fruit tissues could aid in determining the impact of the changes in cellular structure. To this end, a hydromechanical model based on discrete element modeling (DEM) is under development, for which quantitative measures of the cellular stiffness should be obtained. To quantify the stiffness of pome fruit tissues, atomic force microscopy (AFM) was performed on apple (Malus domestica Borkh.) and pear (Pyrus communis L.) tissues. Young's modulus was identified from the indentation curves on tissue samples of 3 different maturities: young fruits (60 to 70 days after full bloom), mature fruits (130 to 140 days after full bloom) and fruits kept in shelf life conditions (20 °C, 12 days). The Sneddon model was used for extracting the Young's modulus from the indentation curves. The results showed an exponentially decaying distribution of Young's modulus values for all timepoints. For apple, the AFM measurements suggest an increase in stiffness of the cells from the early stage towards maturity, and a softening after shelf life conditions. For pear on the other hand, the average Young's modulus decreased until maturity, and decreased rapidly even further during shelf life. These results provide physiological parameters for use in hydromechanical models of pome fruit tissues during growth and postharvest handling.

Keywords: Nanoindentation, apple, pear, AFM, micromechanics, discrete element model

Modelling stomatal responses to high temperatures under a range of different vapor pressure deficits

Mehdi Bisbis, Leo Marcelis, Ep Heuvelink, Laura Cammarisano, Oliver Körner

Stomatal conductance (gs) has been identified as an indicator of several plant stresses, including heat stress. Models for gs that are coupled to photosynthesis such as the BWB-Leuning-Yin model assume stomatal closure upon a decrease in photosynthesis when all other factors are constant (e.g. Ci, VPD). However, at high temperatures, low levels of carbon fixation along with high gs for leaf cooling has been reported. This is known as a decoupling between photosynthesis and gs. To investigate the effects of temperature and leaf to air vapour pressure deficit (VPDleaf) on gs at high leaf temperatures we set up an experiment in a climate cabinet. Light response curves were measured on tomato plants at leaf temperatures of 30, 35, 38 and 42 °C as well as different VPDleaf of 0.9, 1.2, 1.5 and 2 kPa in all combinations. Data were used to fit the Farquhar type of photosyntheis model including a BWB-Leuning-Yin model for gs. Preliminary results suggest that at high temperatures photosynthesis was not only decoupled from gs, but gs rose to excessively high values. Our results also indicate that at high temperatures stomata dynamics is slowed down and becomes less responsive to different levels of VPDleaf. The consequences for the fitted model parameters were assessed and we tested whether the modified parameters result in more precise predictions of gs under heat stress conditions. These findings contribute to a more reliable simulation output that can be used in applications such as soft-sensors for early stress detection.

Robustly calibrated non-destructive sensors inform orchard management and harvest planning decisions for optimized peach fruit quality

Loannis Minas, Jake Pott, David Sterle

Improvement of peach fruit quality is impossible postharvest. Hence, optimum peach quality at harvest and during postharvest and subsequent, consumer satisfaction, is achievable through understanding the influence of preharvest and orchard factors. Growing environment, crop load management, fruit position in the canopy, cultivar and rootstock and are important preharvest factors to balance yield, quality, and maturation in peach. However, few studies have addressed how preharvest factors impact quality and metabolism on fruit of equal maturity. Accurate multivariate visible (Vis)/near infrared spectroscopy (NIRS) prediction models to non-destructively assess peach internal quality (dry matter content, DMC; soluble solids concentration, SSC) and maturity (index of absorbance difference, IAD) with a single scan were used to determine the true impact of various preharvest factors on peach internal quality. Large-scale field evaluation showed that heavier crop loads reduced peach quality and delayed maturity, upper canopy position advanced both, while extensive tree vigor as affected by cultivar or rootstock might be detrimental for peach internal quality. Overall, this talk will provide insights on how to use novel, rapid and high-throughput methods for assessing fruit quality and make informed decisions in orchard factors management to plan harvest and improve peach fruit quality.

Keywords: Canopy position; crop load; cultivar; light interception; metabolomics; near infrared spectroscopy (NIRS); Prunus persica; rootstock

Session 3: Model-based Process Control

Bridging the gap between research & practice: participatory development of a decision support system for industrial hemp production

Alwin Hopf

Industrial hemp (Cannabis sativa) is a re-emerging crop with unique agronomic challenges in both locally and globally that require location-specific studies and guidance. Digital farming tools, such as process-based crop models and decision support systems (DSS), can facilitate this process by providing researchers, extension agents and farmers with a better understanding of the farming system and crop physiology. However, digital agriculture technology in general, has experienced a low adoption rate by practitioners due to the temporal, physical and ideal disconnect between developers and users and the overall complexity of the agricultural system. The goal of this research project is, therefore, to promote sustainable production of industrial hemp in Florida through participatory development of appropriate technology, specifically a linked crop growth model with a decision support system. An accompanying needs-assessment via semi-structured qualitative interviews was included in the development process to reveal information needs and technical requirements for the agronomic modeling. Innovation diffusion and technology acceptance model (TAM) are underlying theories for the study. The findings include a description of the process-based crop model as well as results from a series of qualitative interviews with selected hemp growers in Florida, USA, who represent various demographics and types of hemp producers. The interviews reveal contrasting experiences and approaches towards the use of analog and digital information sources and extension services to gather knowledge and build up experience when adopting a new crop, such as industrial hemp. Several use-cases, limitations, and opportunities for DSS are discussed and contrasted to the currently developed prototype of a process-based model for hemp growth and development. Future work plans will center around using the crop model to 1) provide exploratory crop production system analysis tools for farmers and 2) facilitate implementation of best management practices, will be discussed. Further work including design prototyping with decision support system users will further evaluate appropriate interfaces and communication strategies for the tool.

Keywords: Co-creation of knowledge, crop modeling, plant physiology, production system analysis, cannabis sativa, industrial hemp, participative action research

Comparison of leaf reflectance indices for monitoring the water status in processing tomato

Sándor Takács, Lajos Helyes, Zoltán Pék

Water is a key resource in agriculture. The availability of this resource will be reducing in the future. Significant amount of freshwater is used in the production of irrigated crops. Better irrigation management and scheduling will lead to increased water use efficiency. Modern equipment such as thermal cameras, porometers and hyperspectral spectroradiometers are in service to plant water stress monitoring. However, research should provide data and test results on the specific use of these devices such as scheduling the irrigation of particular plants. An experiment was set up at the experimental farm of the Institute of Horticultural Sciences in Szárítópuszta, Gödöllő, Hungary in 2022. Leaves of processing tomato hybrid H1015 were measured once a week around solar noon with an ASD Handheld 2 hyperspectral spectroradiometer. The measurements were conducted in the325-1075nm spectral range in 1 nm steps (UV/VIS/NIR). The contact probe was attached to a leaf clip thus, there was not any disturbance from the environment during the measurement. There were four different water supply levels set, covering the 100%, 75%, 50% of plant's water demand (crop evapotranspiration) with drip irrigation system and these treatments were compared to a non-irrigated control. These treatments provided the different levels of water stress which could be well controlled in 2022 due to the severe drought during the growing season. The monitoring

was continued (~8 weeks) until the end of the irrigated period in which the plants received irrigation water two times per week. Irrigation was ended in the beginning of the ripening period. Different vegetation indices were computed from the reflectance data as it can be found in library of formulas in the Index DataBase (https://www.indexdatabase.de). The nomenclature of indices also follows this database. In this study, 222 indices were evaluated in total. We found 7 indices that showed the differences regarding the mean of the index values in every treatment throughout the whole monitoring period. These indices were the following: Difference 678/500, mNDVI, PSRI, SR800/960, WBI, Simple ration 355/365gk, SIPI1. Since, these indices showed differences in the means of the index values from the first week, these may be useful in the early detection of water stress as well. However, more data is needed to determine the functional threshold values of these indices.

Keywords: Irrigation, vegetation indices, spectral reflectance

Energy conservation through energy-exergy based thermal analysis and annual available of solar continuous roasting system

Muhammad Tayyab, Barbara Sturm, Sharvari Raut, Muhammad Faheem, Muhammad Mubashar, Muhammad Waqar Akram

Solar thermal concentrators have been used and reported extensively for different postharvest operations compared to roasting. However, to improve process efficiency they need to be optimized and controlled via the operating conditions. Furthermore, thermal analysis of solar based roasting is still not accomplished for process optimization. Accordingly, this study focuses on estimation of average annual available energy for roasting and energy-exergy based thermal analysis for roasting operation using Scheffler reflector and experimental energy-exergy analysis of novel solar continuous roasting system. The system consisted of a Scheffler fixed focus concentrator as primary energy source, thermal oil receiver, oil conveying unit, electric control unit and roasting drum with heating media (salt). Peanut roasting experiments were conducted at a constant temperature of 195°C of heating media. Annual available power for the solar continuous roasting system was evaluated using Simulink and Python. Based on theoretical and experimental data, it was found that a major portion of energy is lost on oil receiver and oil conveying unit. The overall variations in energy utilization, exergy efficiency, energy utilization ratio and exergy losses for oil receiver, oil conveying unit and roasting drum was found ranged in 115 to 345 W, 8.82 to 58.43%, 30 to 75% and 0.21 to 1.12 kW. The losses from oil receiver and oil conveying unit can be minimized (with improvement potential of upto 0.458 kW) by insulating the oil receiver along with installing side cone and oil-conveying unit. Thus, the results obtained from this study helps in optimizing peanuts roasting by conserving energy based on thermal analysis of the solar continuous roasting system with comprehensive and sequential procedures.

Keywords: Solar concentrators, Energy-Exergy, Thermal Analysis, Scheffler reflector, Peanut roasting

Modelling environmental indices during grapes drying as these affect Ochratoxin A development

George Xanthopoulos, Paola Battilani, Paola Giorni, Dimitrios I. Tsitsigiannis, Charalampos Templalexis, Diamanto Lentzou, Sabrina Mesisca

Drying optimization, to mitigate fungal growth and Ochratoxin A (OTA) contamination is a major challenge for raisin and currant production. Specific indices of environmental conditions

and drying properties were analyzed using two seedless grape varieties (Crimson-red and Thompson-white), artificially inoculated by Aspergillus carbonarius under open-air and tunnel drying methods. The air temperature (T), relative humidity, grape surface temperature (Ts) and water activity throughout the drying experiment, the grapes' moisture content and the fungal colonization and OTA contamination during the drying process, and their interactions were recorded and critically analyzed. Drying properties such as the water diffusivity (Deff) and peel resistance to water transfer were estimated and considered in the overall analysis. The grapes Ts was 5-7 °C higher in tunnel vs. the open air-drying; the infected grapes had higher maximum Ts vs. the control (around 4-6 °C). OTA contamination was higher in tunnel vs. open air–dried grapes, but fungal colonies showed the opposite trend. The Deff was higher in tunnel than in the open air-drying by 54%; the infected grapes had more than 70% higher Deff than the control, differences explained by the factors affecting the water transport. This study highlighted CFU and OTA indicators that affect the water availability between red and white grapes during open-air and tunnel drying, estimated by the Deff and peel resistance. The current findings raise new issues for future research.

Keywords: Aspergillus carbonarious; Ochratoxin A; open air–drying; tunnel drying; water diffusivity; grapes; water surface resistance

Session 4: Modelling & Simulation of Packaging & Storage

A model-based approach for simulation of ethylene accumulation inside perforated modified atmospheric packaging

A*kshay Dagadu Sonawane, Pramod Mahajan, Cornelia Weltzien*

The prediction of ethylene accumulation inside a perforated fruit package is key to accessing the fruit quality and ripening through its firmness. A model-based simulation provides an excellent platform to predict ethylene accumulation inside a perforated fruit package. Thus this study involved the simulation of ethylene accumulation using Matlab code which comprised the ordinary differential equations of respiration rate, the ethylene production rate, the ethylene permeance of perforated packaging, and the ethylene removal rate of scavenger ($KMnO_4$). The ethylene permeance model developed from dimensionless correlation analysis and the first-order kinetics model for the removal of ethylene using $KMnO_4$ were applied to carry out the mass balancing in Matlab. The validation experiment was performed with the avocados at different temperatures, perforation diameters, and scavenger weights. The goodness of fit (R^2) between experimental and Matlab- simulated ethylene accumulation inside the avocado package at different perforation diameters and temperatures was found to be more than 0.90. The Matlab-based simulation of ethylene accumulation would help to predict the ethylene-based quality parameter such as the firmness of fresh produce.

Keywords: Climacteric fruit; Respiration; MAP; Model; Avocado

Comparison of packaging types for thermal preservation of rambutan in the supply chain

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The main problems of rambutan export involve a rapid peel browning incidence and decay throughout its supply chain. Recently, farmers have looked for sustainable packaging as an alternative for foam boxes in packing rambutan to reduce negative impacts on environments.

In this study, corrugated fiberboard boxes with different thermal insulation materials assembled inside were designed and investigated for and their performance on cold chain management, in comparison with foam boxes under the simulated supply chain conditions. In experiment, rambutan fruits were cooled by hydrocooling at 10°C for 10 min, then packed in a perforated low-density polyethylene (P-LDPE) bags (500 g), and simulated storage at 12°C for a day before packing in the thermal-insulated boxes; 1) foam box (FB) (control), 2) metalized foam sheet (MFS), 3) prototype A as two layers of aluminum foil with expanded polyethylene (ALF+ EPE), 4) prototype B as four layers of ALF, dry-laid nonwoven (Felt), spunbond nonwoven (NW), and ALF, 5) prototype C as four layers of ALF+EPE+NW+ALF, 6) insulated bubble cushioning (IBC) and 7) corrugated fiberboard box (Kerry box) with four replications. Each thermal-insulated box was allocated with two ice bottles inside to maintain cool temperature. The simulated temperature transportation was set at 25°C for a day (as a broken cool chain condition) and at 15°C for 5 days (as shelf condition). Temperature profiles and fruit qualities (pulp and air temperature levels), thermal image and ΔGray scale were measured. The results showed that FB maintained cool air and pulp temperature levels better than other treatments, followed by prototype A, prototype B, prototype C, MFS, IBC and Kerry box, respectively. For thermal image results, FB exhibited a darker purple color (cool temperature) than the other treatments, while Kerry box exhibited a lighter yellow color (warm temperature). Rambutan fruits packed in Kerry box and IBC had highest value of ΔGray scale, followed by those in prototype C, prototype B, MFS, FB and prototype A, respectively. The period of time (air temperature at 20°C) and average pulp temperature exhibited a great linear regression model with ΔGray scale to indicate browning incidence of rambutan. In this study, the prototype A with ALF+EPE materials exhibited good potential for alternative packaging due to its performance in maintaining cool temperature and delaying postharvest losses of rambutan.

Keywords: Browning, Cool chain management, Thermal insulation material, Transportation.

Model-based gas control strategy applied to storage container for broccoli under varying temperatures

Yogesh Bhaskar Kalnar, Ali Jalali, Cornelia Weltzien, Pramod Mahajan

An airtight container equipped with a temperature sensor and gas control system has been developed for efficient storage of broccoli keeping O_2 concentration at 2% level. The system actively regulates the atmosphere inside the container in response to changes in temperature, which is modelled through the rate of change of gas composition along the supply chain. The aim of this study was to develop the model based gas control strategy under varying temperatures and implement it into the smart container for its application in the realistic supply chain. A model for predicting the respiration rates of broccoli at varying temperatures was proposed, taking into account enzyme kinetics and the Arrhenius equation. The model calculates respiration rates as a function of the O_2 concentration and storage temperature. The parameters of the enzyme kinetics model at varying storage temperatures could be predicted using the activation energy and the respiration pre-exponential factor. The control strategy includes the use of thermocouples, for continuously monitoring the temperature and response related to temperature disturbance was fed to the control unit for re-calculating the new blower ON frequency (BOF). Change in temperature was detected well in advance before it critically changes the atmosphere inside the container. Gas concentrations with optimum value of O2 for broccoli storage were tested with varying temperatures from 3 ^{o}C to 20 ^{o}C. The performance of developed system was evaluated with a commercial gas control system which showed a significant output to maintain optimal O_2, and thereby extend the shelf life of the

stored broccoli even in varying temperature conditions. The respiration rate of stored broccoli, measured in ml [O2] kg-1 h-1, was ranges between 4.0 to 14.1, 9.6 to 32.6, and 44.4 to 116.1 at temperatures of 3°C, 10°C, and 20°C respectively. The corresponding blower on frequency in seconds per hour was found to be 13, 65, and 300 for the same temperature ranges. Effect of initial O_2 pulldown on gas control strategy could also be predicted for BOF.

Keywords: Control, Respiration, Modified Atmosphere, Temperature, Modelling

Cooling regime impact on the preservation of apple fruit during long-term storage

Daniel Alexandre Neuwald, Felix Büchele, Dr. Pramod Mahahan, Tuany Gabriela Hoffmann, Roland Handschuh, Dr. Martin Geyer

The design of refrigeration systems in the commercial storage of fruit is usually based on a linear calculations of the cooling load. However, this entails that the systems are oversized for the subsequent storage period, resulting in unnecessary high costs of investment, high energy consumption and an increased need for maintenance measures. In a two-year trial, this study aimed to simulate how refrigeration systems with lower cooling capacity and consequently extended cooling periods, affect the preservation of apple fruit during long-term storage. Different apple varieties (‘Elstar’, ‘Jonagold’ and ‘Pinova’) were cooled to 1 °C in three cooling regimes (in < 2, 7 and 14 days) and were subsequently stored for 3, 6 and 9 months under controlled atmosphere of 1.0 kPa O2 and 2.5 kPa CO_2. The apple varieties showed varying quality differences under the different cooling regimes tested. However, these differences diminished over longer storage time. The results demonstrated that prolonging the cooling time to 14 days does not negatively affect the preservation of firmness, titratable acidity, total soluble solids or peel color of ‘Jonagold’ and ‘Pinova’ apples. However, the ‘Elstar’ apples were highly sensitive to cooling variations, therefore, longer cooling regimes proved detrimental in maintaining fruit firmness. Fruit mass was unaffected by cooling regimes. From a fruit quality standpoint alone, the results suggest that depending on the apple variety, extended cooling regimes do not negatively affect the preservation of apple fruit during long-term storage, thus allowing the design of refrigeration systems with lower cooling capacity, which impacts in energy saving.

Keywords: Cooling, storage, apple, refrigeration, quality, shelf life

Modelling ethylene scavenging for fresh produce

Namrata Pathak and Pramod Mahajan

Ethylene removal is an effective postharvest technique to prolong shelf life of fresh produce along the supply chain. Many ethylene scavengers, such as zeolites, potassium permanganate, and activated charcoal are used in fresh produce packaging often incorporated in sachets or embedded in material lining or in the polymer matrix itself. Limited studies have been done on implementing mathematical models to study the ethylene scavenging effect of such scavengers. This study evaluates the performance of ethylene removal by different scavengers (granules and films) at different humidity (0 % and 100 % RH) at 20 °C. The data obtained was fitted to different kinetic models. First-order kinetic model showed a good fit to the data. The model parameters provided a good basis for comparison between the different scavengers. The predictive simulation can be highly useful in selecting the best scavenger for a specific application. Furthermore, the results from this study, can be useful in developing comprehensive models to predict ethylene concentration inside fresh produce packages with active scavenging and subsequently estimate the produce shelf-life.

Keywords: Postharvest, fruit and vegetables, storage, modified atmosphere

Using a Monte Carlo approach to understand kiwifruit weight loss in packaging systems

Raquel Lozano, Bronlund John, Andrew East, Eli Gray-Stuart

Cumulative weight loss from kiwifruit packaging systems throughout the supply chain can lead to fruit losses due to shrivel. The rate of moisture loss depends on extrinsic factors including package permeability, temperature, and relative humidity. Intrinsic biological factors including the skin permeance, initial dry matter, and surface area of the fruit will also influence moisture loss and subsequent shrivel. This study used a Monte Carlo approach to generate populations of kiwifruit to account for the natural biological variability. Each kiwifruit was assigned a skin permeance and starting mass from normal distributions (historical data). As a result, moisture loss from a kiwifruit population within a packaging system can be simulated at an individual kiwifruit level. Two scenarios were investigated, the first being a standard Individual Tray packaging system consisting of 30 (100 g) RubyRed™ kiwifruit on rPET pocket packs inside a HDPE polyliner with a fixed effective permeance value, that was stored in 81% RH and 0.43 for 8 weeks. In the second scenario the same packaging system without the polyliner was used as contained 30 (100 g) SunGold™ kiwifruit were stored that was stored in 83% RH and 1.84 for 10 weeks. The results from the Monte Carlo simulation showed that the predicted kiwifruit weight loss from scenario 2 (the non-polyliner scenario) compared well to experimental data (model: 8.20 , data: 8.712.38%). However, in the polyliner scenario, the model was found to under-predict equivalent experimental results (model: 1.580.27%, data: 2.610.49%). Moisture loss is highly dependent on the polyliner effective permeance and more investigation is needed to define effective permeances for these packaging systems. This modelling methodology will be used to further understand shrivel mechanisms.

Keywords: Biological variability, packaging configuration, supply chain, postharvest storage, fruit loss

Session 5: Non-destructive Assessment - I

Sustaining low-impact practices in horticulture through non-destructive approach to provide more information on fresh produce history and quality

Giancarlo Colelli, Maria Cefola, Bernardo Pace, Francesco Serio, Francesco F. Montesano, Giovanni Attolico, Maria L. Amodio, Hassan Fazayeli, Antonio Stasi, Michela Palumbo

The general objective of the Project SUS&LOW is to enhance quality of fresh fruit and vegetables by testing and implementing low-input agricultural practices (LIP) with the support of non-destructive (ND) tools capable of evaluating in real time the quality and ”history” of the products, applying new marketing strategies which satisfy the final consumer. Results of three main work packages (WP) are reported. In WP1, specific water and nutrient administration strategies were applied to obtain greenhouse horticultural products with different levels of 'input use efficiency' (sustainability indicator of the production process). Objective of WP2 is to compare conventional analysis techniques with non-destructive techniques for the discrimination of fresh products obtained with LIP (from WP1) and for the prediction of their quality and shelf-life also applied through the packaging material. The spectra of rocket leaves were acquired and analyzed to study the impact of LIP on the variation of this parameter and to identify the spectral interval varied by the production technique. Furthermore, predictive models based on the use of computer vision systems have been developed and validated on fresh and packaged rocket to determine the quality level, the discrimination of fertilization

levels and the irrigation management systems applied during the cultivation and prediction of the main quality marker parameters (chlorophyll and ammonium content). Lastly, in the context of WP3, through an ad hoc survey, consumer behavior was analyzed with respect to the possibility of purchasing fruit and vegetable products certified for the use of LIP (WP1), identified through the possibility of using ND techniques (WP2) to implement appropriate marketing strategies. In particular, the impact of storytelling was measured together with other communication and certification strategies.

Keywords: Sustainability, quality, non-destructive, shelf-life, marketing strategies

Machine learning techniques to identify relevant colours for quality evaluation and internal parameters estimation in agricultural products

Michela Palumbo, Maria Cefola, Bernardo Pace, Giancarlo Colelli, Giovanni Attolico

Machine learning techniques are commonly used for grading and for estimating important internal characteristics of fresh fruit and vegetables in a non-destructive and contactless way. They are increasingly relevant to simplify the development of non-destructive techniques with better performance and greater flexibility in matching the requirements of different products and environments. Nevertheless, machine learning techniques may have significant computational costs and often produce models not easily understandable by humans. The research activities carried out within the PRIN project SUSTAINING LOW-IMPACT PRACTICES (LIP) IN HORTICULTURE THROUGH NON-DESTRUCTIVE (ND) APPROACH TO PROVIDE MORE INFORMATION ON FRESH PRODUCE HISTORY & QUALITY (SUS&LOW) studied machine learning models that proved to be successful in evaluating visual quality and internal parameters on rocket leaves. By analyzing these models, it was possible to identify the most informative colours selected by the ensemble methods to accomplish the tasks of interest. This result is interesting: it makes easier to understand the logic used by the machine learning technique to select the relevant features, enabling research about new simpler and faster approaches, even working on cooperation between humans and machines. Moreover, these colours suggest detailed clues about visual traits that better correlates with quality and physical or chemical characteristics: this information can be further investigated to understand its relationship with interpretable chemical and physical effects induced by senescence. Even the design of enhanced training tools for human operators working on quality control can benefit from this objective and sound clues.

Keywords: Random Forest, cluster, correlation analysis, visual quality prediction

Potential application of hyperspectral imaging and FT-NIR spectroscopy for discrimination of soilless tomato according to cultural practices and water use efficiency

Maria Luisa Amodio, Hassan Fazayeli, Danial Fatchurrahman, Francesco F. Montesano, Francesco Serio, Ingunn Burud, Giancarlo Colelli

This study was aimed to evaluate the suitability of hyperspectral imaging (HSI) and Fourier Transform (FT)-NIR spectroscopy for classifying sustainable-produced tomatoes according to a) cultural practices and b) levels of water use and fertilizer use efficiency (WUE and FUE). Three different cultivation strategies for water and fertilizer use were applied across two cultivation cycles for two varieties (cv 'Carminio', and cv 'Mose'): i) free drain open cycle cultivation (OPEN); ii) open cycle cultivation with on-demand sensor-based fertigation (SMART); iii) closed cycle cultivation (CLOSED). Reflectance spectra were acquired using HSI in Vis-NIR and NIR ranges, and a FT-NIR spectrometer, for about 300 fully ripe tomatoes per variety. Partial least

squares discriminant analysis (PLS-DA) was first aimed to discriminate the three cultivation systems, and then the levels of WUE and FUE. Model performances were higher when using FT-NIR and HSI in the Vis-NIR range, but the last one needed less latent variables. Good performance on external prediction were obtained for discriminating tomatoes from three cultural practices for each variety. In addition, an excellent performance was reached by classifying tomatoes in two different levels of WUE and FUE with accuracy, specificity and sensitivity higher than 95%. Finally, for the general models based on three levels of WUE, over the two experiments, using only 20 significant wavelengths, yielded accuracy and specificity of 89.8% and 91.7%, respectively. Results of this study indicate promising potential of these techniques for the authentication of agricultural crop grown with low inputs, which need further investigation.

Keywords: Classification, water use, FT-NIR Spectroscopy, Hyperspectral Imaging, PLS-DA

Computer vision system for non-destructively evaluating quality traits in fresh and packaged rocket leaves

Michela Palumbo, Maria Cefola, Bernardo Pace, Francesco Serio, Francesco Montesano, Giancarlo Colelli, Giovanni Attolico

Quality assessment of fresh and fresh-cut fruit and vegetables is a complex process which commonly involves the use of analytical and destructive techniques that are time consuming, expensive and require polluting reagents and sophisticated equipment. Moreover, these methodologies are not suitable for in-line application on industrial lines, where, nowadays, speed, reliability, accuracy and sustainability are required. A computer vision system (CVS) provides a suitable alternative as contactless and non-destructive methodology to achieve a consistent quality assessment of fruit and vegetables, even on packaged products. The results presented are a part of a PhD project, carried out within the PRIN SUSTAINING LOW-IMPACT PRACTICES (LIP) IN HORTICULTURE THROUGH NON-DESTRUCTIVE (ND) APPROACH TO PROVIDE MORE INFORMATION ON FRESH PRODUCE HISTORY & QUALITY (SUS&LOW), aimed to develop and validate predictive models based on the use of CVS for the assessment of the quality level (QL) and the main quality parameters of fresh and packed rocket leaves. The proposed CVS is able to automatically select, without human intervention, the most relevant colour traits using the Random Forest as machine learning model. During first experiments, CVS was applied to fresh-cut rocket leaves, obtained by low-impact agricultural practices, to objectively assess its quality levels (QL) during the storage at 10 °C according to a 5 to 1 rating scale and to discriminate the fertilization levels and irrigation managements applied during the cultivation. Promising results showed an accuracy of 95% in the QLs assessment and of about 65-70% in the discrimination of the cultivation approach. Then, five experiments were conducted to validate the CVS in estimating internal quality traits (chlorophyll and ammonia content) related to the shelf-life loss of rocket leaves, even though the package. Similar performances were obtained on packaged (Pearson's coefficient of 0.84 for chlorophyll and 0.91 for ammonia) and unpackaged products (0.86 for chlorophyll and 0.92 for ammonia). Finally, PLS models well forecasted the VQ of rocket leaves using as predictors the chlorophyll content obtained by destructive methods and by CVS on packaged and unpackaged products (R^2_v of 0.70, 0.77 and 0.80, respectively).

Keywords: Image analysis, no-destructive techniques, Random Forest model, partial lest square analysis

Effect of Nitrogen fertilization levels on quality attributes of rocket salad over storage: Modeling degradation kinetics

Aysha Saleem, Maria Luisa Amodio, Danial Fatchurrahman, Maria Gonnella , Lucia Bonelli, Andrea Peruzzi, Giancarlo Colelli

The present study focused on the interactive effect of pre-harvest factors on postharvest quality of rocket leaves (Diplotaxis tenuifolia L.), focusing on the effect of nitrogen fertilization on the degradation rate of the product. Six levels of nitrogen (70N, 98N, 126N, 154N, 182N and 210N, corresponding to the N level (expressed as ppm) in the nutrient solution), were applied with increasing fraction of NH4-N under soilless cultivation in an unheated greenhouse Puglia (South, Italy), following a randomized block design with 3 replications. Three replicates (100g each) of all 5 treatment were stored in clamshells under controlled conditions (5 °C, 99 % RH) to monitor quality changes over storage time. Vitamin C, as the sum of Ascorbic Acid (AA) and Dehydroascorbic Acid (DHAA), dry matter, texture, TSS, pH, titratable acidity, microbial population (total mesophilic count, yeast & mold), and sensory evaluation were measured during storage. For each quality attribute and N level, degradation curves were fitted with several models to find the best fit to describe kinetic. Microbial spoilage was the main responsible for loss of quality, followed by color and chemical changes. Degradation kinetics were mostly described by first order reaction. Treatment N98 showed least degradation rate for overall acceptability by maintaining good visual traits throughout 18 days storage life. Higher N levels showed higher degradation rate for Vitamin C, AA (N182) and DHAA (N210) with k values of 0.076, 0.073, and 0.099 respectively. The end of shelf-life correlated with microbial count and loss of initial vitamin C. Shelf-life prediction models were also validated within satisfactory statistical error values. Adequate N supply is a critical factor for high quality standards and guarantee at the same time the sustainability of the production. While the effect of growing factors on quality at harvest is well known, more studies are needed to model their effect on postharvest degradation rate.

Keywords: Rucola cv. Dellas, N-form, Kinetic Modeling, SLP

Session 6: Non-destructive Assessment - II

Monitoring surface changes of fresh green asparagus (Asparagus officinalis, L.) during storage using Laser Light Backscattering Imaging (LLBI)

Zinabu Hailu, Thanh Tung Pham, Maria Höhn, Le Phuong Lien Nguyen, Laszlo Baranyai

Storage conditions play the most important role in maintaining and preserving the quality of fresh horticultural produces. The evaluation of storage parameters influencing quality and safety is a very active research topic. The aim of the presented study was to follow the surface changes of asparagus using different storage conditions by means of Laser Light Backscattering Imaging (LLBI) with low power line laser module, Near Infrared (NIR) spectroscopy, and microscopic visual inspection. Green asparagus spears were stored in cooling chambers at 2, 10, and 15 °C for 12 days. The following parameters were measured: weight loss, firmness, moisture diffusion, stomata opening size and density, near-infrared (NIR) spectra in the range of740-1700 nm, LLBI profile parameters at 635 nm such as peak width at 75, 50, and 25% intensity level, and their ratios. Significant differences were found between the parameters according to the storage temperature. The principal component-based discriminant analysis model (PCA-LDA) classified the NIR dataset with an accuracy of 99.16% and the correct classification for validation was 96.66%. The effective moisture diffusivity was calculated in the

range of 2.06×10-11 m2/s to 3.144×10-12 m2/s. The stomata opening size and density were significantly different between the base, middle, and apex parts of the asparagus spears. While the weight loss and firmness increased with time, the light penetration depth measured by the scattering signal width decreased, particularly for samples stored at 15 °C. According to the results, the non-destructive technique of LLBI is a promising technique and suitable to follow the shelf life of asparagus spears.

Keywords: Diffuse reflectance, Machine vision, Quality assessment, Shelf life

A hyperspectral field spectroscopy-based method for the detection of 'Ca. Phytoplasma mali'

Cameron Cullinan, Ulrich Prechsl, Katrin Janik

Early detection of plant disease and stresses is a fundamental component of the rapid, efficient and effective management thereof. For instance, early detection allows for reductions in the amounts of pesticides and fertilizers applied as well as improvements in water-use efficiency, amongst others, thereby greatly improving the environmental costs associated with agriculture. Hyperspectral analysis of plants represents a powerful and promising technology to investigate plant disease and stresses in real-time and in a non-destructive way. This approach is particularly advantageous for latent disease with absent or weak symptoms which makes these diseases hard to detect in situ , as is often the case regarding apple proliferation. Our research group has recently focused on the spectral-based detection of 'Candidatus Phytoplasma mali'-infected apple trees. ‘Ca. P. mali’, or Apple Proliferation phytoplasma (APP), is the pathogen associated with Apple Proliferation (AP) disease, one of the most significant diseases of apple in several regions of Central Europe and North America. Importantly, there is no curative treatment for the disease and infected trees must be eradicated as early as possible after infection to prevent spread by its psyllid vectors. Recently, it could be shown that it is possible to differentiate AP-diseased apple trees from non-infected ones by the spectral profile of their leaves (Barthel et al. 2021). To do this, they used dried and processed leaves and subjected them to spectral analysis in the near-infrared light range. It, however, remains to be determined as to whether the same technology can be applied directly to fresh leaves. The current study will, thus, present results on the use of a portable spectroradiometer to take the hyperspectral profiles of fresh leaves via contact measurements in the field and the subsequent analysis of the hyperspectral profiles generated thereby to model and detect APP-infected apple trees. We also relate the detection ability of the technique to whether or not infected trees are expressing symptoms. The results presented are sought to serve as the preliminary step towards an in-field, real-time, spectral-based detection system for the detection APP-infected apple trees.

Keywords: Hyperspectral, Apple Proliferation, 'Ca. Phytoplasma mali', spectroradiometer, machine learning

Apple size estimation using Fourier analysis: Laboratory and field scale applications

Nicolas Tapia Zapata, Nikos Tsoulias, Kowshik Saha, Manuela Zude-Sasse

An important aspect of developing resilience in the context of climate crisis is through remote sensing, aiding orchard management and prediction of quality related attributes on fruit surfaces (such as size and temperature) to avoid food waste. Thereof, light detection and ranging (LiDAR) scanning has provided the ability to obtain geometric information from fruit surfaces by means of 3D point clouds. A geometric model to inform size of apples by means of

3D point clouds and comparison to 2D models (mean and maximum Euclidean distance) is presented. The proposed approach is based on an error minimization algorithm using a reference shape given by a Fourier series in spherical coordinates. The model was applied to time-series of scanned apples in laboratory and field scenarios considering different apple growing stages, ranging from 60 to 150 days after full bloom (DAFB). The goodness of the models were assesed by performing a linear regression of estimated and measured reference data. For apples scanned in the laboratory, the geometric model showed adjusted R^2 values of 0.76, compared to 0.45 and 0.02 for mean and maximum euclidean distances, respectively. For apples scanned outdoor, adjusted R^2 values of 0.32, 0.06 and 0.02 were found for the model, and the mean and maximum euclidean distances, respectively.

Keywords: Remote sensing, LiDAR, 3D point clouds, Fourier series, coefficient of determination.

Device miniaturization and non-contact approach in time domain NIRS for non-destructive assessment of fruit quality

Pietro Levoni, Fabio Negretti, Lorenzo Frabasile, Michele Lacerenza, Mauro Buttafava, Maristella Vanoli, Davide Contini, Alessandro Torricelli, Lorenzo Spinelli

Nowadays, the majority of near infrared spectroscopy (NIRS) sensors for non-destructive assessment of fruit quality employ continuous wave (CW) light sources (e.g., lamp or LED) and detectors (e.g., photodiode). CW NIRS is not capable of discriminating light absorption (due to chromophores in the fruit tissue) from light scattering (due to refractive index changes in tissue structure) phenomena. Moreover, when operating in reflectance mode, the volume sampled by CW NIRS strongly depends on optical properties and source-detector distance, resulting in a limited sensitivity to fruit pulp. The Time Domain Near Infrared Spectroscopy (TD NIRS) technique can potentially overcome such limitations. TD NIRS exploits picosecond pulsed laser sources, single-photon sensitive detectors, and fast timing electronics to acquire the Distribution of Time-of-Flight of the detected photons. By analyzing TD NIRS data, the absorption coefficient and the reduced scattering coefficient can be disentangled. Moreover, photons characterized by later arrival times, which travelled, on average, deeper into the sample, carry more reliable information about fruit pulp. The main limitations currently affecting the widespread adoption of TD NIRS devices are: the complexity of the instrumentation, the cost of the components, and the requirement for the optical probe to be in contact with the sample. In this work we show the most recent developments in TD NIRS technology in terms of device miniaturization and feasibility of non-contact measurements. Three TD NIRS devices for the assessment of fruit internal quality are presented: a multiwavelength system hosted on a 19” rack, a portable device for in-field measurements, and a non-contact prototype for fast measurements suitable to be implemented in industrial sorting lines. As an example of application in the agritech sector, we report the results of measurements on a set of Mantuan PGI pears performed by the three TD NIRS devices.

Keywords: Time Domain Near Infrared Spectroscopy, diffuse optics, non-contact, fruit quality, Mantuan PGI pear

Session 7: Models for Produce Quality

AI-based classification models for non-destructive X-ray inspection of apple fruit

Astrid Tempelaere, Pieter Verboven, Bart Nicolai

X-ray technology is being used to non-destructively evaluate the quality of fruit and vegetables, with X-ray CT collecting 3D imaging data and X-ray radiography, a 2D projection. Artificial intelligence (AI) has been proposed to quickly and accurately judge the large amount of imaging data. In our work, we developed an AI model that is able to classify the imaging data of apple fruit (Malus Domestica, cv. Braeburn) with and without internal disorders. The internal disorders in our apple fruit originated from suboptimal storage conditions, i.e., 100% N_2 and 10% CO_2 + 1% O_2, which led to disorders with a different appearance of, respectively, dark brown speckles in the fruit flesh and large brown zones around the core. AI models were developed for classifying apples with internal disorders using X-ray CT and radiography data. The complete apple fruit was used as input for the 3D ResNet50 model and radiographs were simulated from the CT data, for which another ResNet50 model was trained. The effectiveness of X-ray CT and radiography data was compared for classifying healthy and disordered fruit based on accuracy, precision, recall, and F1 score. Despite losing some spatial information, the 2D radiographs performed similarly to the 3D CT scans for classifying apples. Additionally, it was found that apples damaged by N_2 were easier to sort from healthy apples compared to those damaged by CO_2. The insights obtained from the experiments are useful towards industrial applications on fast and cheap inline sorting by X-ray technology as a similar classification performance on 2D radiography data as on 3D CT data could be obtained. In future research, the use of real radiographs for the classification task will be considered, as well as the model robustness for fruit from another season and origin.

Keywords: Internal quality; apple fruit; X-ray; deep learning; artificial intelligence; non-destructive evaluation

Analysis of the correlation between cell size distribution and fruit biomechanics of strawberry fruit

Xue AN, Gabi Wegner, Jessica Wegner, Zhiguo Li, Manuela Zude-Sasse

Bruising observed macroscopically in strawberry fruit is the result of microscopic texture and cell failures. One of the critical factors affecting fruit mechanics is the cell size, which has an impact on apparent fruit softening and quality in shelf life. In the present study, the effect of cell size distribution on tissue mechanics was analysed. The fruit cells of 'Malwina' strawberry fruit at three ripening stages (white, turning and red) were suspended in 0.3 M mannitol solution. From the suspension, the cell size distribution was measured with particle size analyzer based on laser light scattering density analysis. The compression mechanics of fruit tissue were recorded by Texture Analyzer at 1 mm·s-1. The mean cell size of white, turning, and red fruit were 179.96 µm, 263.36 µm, and 343.27 µm, respectively. However, the size ranged between 150 - 450 µm. The elastic modulus of white, turning, and red fruit were 3.907 MPa, 0.309 MPa, and 0.202 MPa, respectively. Cell size data and measured elastic modulus were used to establish the particles in a discrete element model (DEM), for simulating the compression test of strawberry tissue. The different cell size distributions were applied considering the mean and percentage of cells at maximum frequency of cell size (range 150-300) and the mean and percentage of cells > 450 µm. The compression force of simulation was compared to the measured value. Results showed that the relative errors using only the mean cell size in the three ripening stages (white, turning, red) were 8.76 %, 10.19 %, and 17.27 %, respectively. Results showed that the relative errors using the the mean and percentage of cells at maximum frequency of cell size (range 150-300) and the mean and percentage of cells > 450 in the three ripening stages (white, turning, red) were 5.68 %, 7.95 %, and 12.02 %, respectively. Concluding, the mean and percentage of cells at maximum frequency of cell size (range 150-

300) and the mean and percentage of cells > 450 µm provided reasonable information to predict the compression force.

Keywords: Cell size distribution; fruit biomechanics; strawberry fruit; discrete element model

Artificial Intelligence Based Mobile Application - BIPM ON Tomato pinworm Tuta absoluta

Pratheepa M, Subaharan K, Richa Varshney, Venkatesan T, Sushil S.N.

Tomato is an important vegetable crop growing all over the world. The South American tomato pinworm,Tuta absoluta (Meyrick) (Gelechiidae: Lepidoptera) is a devastating pest of tomato. The larval stage of T. absoluta causes damage by mining leaves, stems and buds. The larvae burrow intofruits and feed on the inner contents. The damage so caused reduces the market value of the fruits and severe infestations cause 100% yield loss. In addition to T. absoluta, tomato is damaged by Liriomyza trifolii and Helicoverpa armigera. As the damage symptoms are overlapping, identification of the pest with precision is essential to take up management measures. The diagnostic features like mining patterns of leaves helps to identify whether the pest infestation is due to Liriomyza trifolii or due to Tuta absoluta. Similarly, the hole pattern on developing fruits helps to differentiate whether the pest infestation is due to Helicoverpa armigera or due to Tuta absoluta. Tough farmers avail the services from pest management experts, exploiting the ICT will aid to developed digital platforms for identification and management of the pest. A mobile application is a novel ICT application designed to run on a mobile device such as phone, tablet which helps to disseminate the knowledge or information in an easy way and in a fast manner. In view of this, the Mobile application, named as " BIPM ON Tuta absoluta", has been developed for both knowledge dissemination of bio-intensive pest management (BIPM) and also for pest identification in the field by using artificial intelligence techniques. The diagnostic features of Tuta absoluta and the damaging patterns in the field are stored in the computer expert system located at ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, India. The expert system contains the image data set of 250 images of different category like damage symptoms, different stages of the pests, etc. Artificial intelligence (AI) based machine learning algorithms used in this Mobile app to identify whether the pest infestation is due to Tuta absoluta or by any other pest in tomato field. Hence, this mobile app 'BIPM ON Tuta absouta' can act as a handy tool to identify the pest exactly in the field, so that farmers can take up correct control measures in time. This mobile app is available online at https://mobileapptuta.nbair.res.in

Keywords: Tomato, Pest identification, Artificial intelligence, Machine learning, Tuta absoluta, Mobile app, Expert system

Classification of green coffee bean defect types using a gradient boosting-based model

Rattapon Saengrayap, Sujitra Arwatchananukul, Sirawit Saiwaeo, Sai Aung Moon, Saowapa Chaiwong, Nattapol Aunsri

The sorting of coffee beans before roasting is crucial for coffee bean quality control. The defect-sorting process typically uses experienced workers to judge the coffee beans' color, size, and shape. However, it requires time consumption and manpower. This study, therefore, proposes classification models to differentiate 19 defects to obtain high-quality coffee beans. A variety of classification models including Decision Tree, Random Forest, Gradient Boosting, Support Vector Machine, and K-Nearest Neighbors were implemented. Moreover, Contrast Limited Adaptive Histogram (CLAHE) technique was performed to enhance image quality. Data augmentation with rotation was employed to increase the data. Further, feature extraction

methods wherein the texture is represented by a Local Binary Pattern (LPB), the shape is represented by Hu's moments, and the color is defined by three-color moments (Mean, Standard Deviation, Skewness, and Kurtosis). The proposed approach achieved 88.08% accuracy using Gradient Boosting which is satisfactory for classification.

Keywords: Gradient Boosting, Coffee Defects, Enhance Image, CLAHE, Feature Extraction

Non-destructive detection of tomato chlorophyll content based on NDVI from multiple wavelength LiDAR point cloud data

Kowshik Kumar Saha, Bodo Bookhagen, Manuela Zude-Sasse

Selective harvesting of tomato (Solanum lycopersicum), considering manual or robotic picking, requests to identify fruit with optimum ripeness stage. Visual appearance of tomato fruit such as peel colour changes due to physiochemical processes during maturation. The degradation of fruit chlorophyll and development of carotenoids are liable for change of colour from green to red. The normalized difference vegetation index (NDVI) is often used for quantify the greenness of vegetation. In this study, tomato fruit NDVI was retrieved fusing backscattered intensity from two light detection and ranging (LiDAR) sensors. The LiDAR sensors provided 3D point cloud data at 650 nm and 905 nm wavelength. The fruit NDVI information was used to detect the ripening stage and chlorophyll content of the tomato fruit. Tomato fruits (n = 100) of six ripening stages (mature green, breaker, turning, pink, light red, and red) according to USDA standard, were scanned from 1 m distance using linear conveyor mounted LiDAR sensor system in the laboratory. The 3D fruit point clouds were pre-processed including calibration of intensity values using standard black and white colour coated boards. Geometric correction for calibrated intensity was performed to correct for the curvature according to the shape of each tomato. The two point clouds acquired at 660 nm and 905 nm of the same fruit were merged using a k-means based algorithm and the NDVI value was calculated for each point. Chemically analyzed chlorophyll content of tomato samples and NDVI were used to build a calibration model with high coefficient of determination (R2 = 0.75). To test the performance of the proposed method, cross validation was performed, resulting in $R^2 = 0.71$. Ripeness classification was enabled based on the fruit NDVI. This proposed approach showed promising result for non-destructive and non-contact analysis of tomato fruit pigment and ripeness.

Keywords: Tomato, LiDAR, 3D Point cloud, NDVI, Chlorophyll

Guava damage classification based on image processing and efficientNet model

Nattapol Aunsri, Saowapa Chaiwong, Rattapon Saengrayap, Sujitra Arwatchananukul,

Jutarat Rattanakaran, Sirawit Saiwae, Patteera Vipasdamrongkul, Pundao Srimunwing, Suttika Chocharat

Guava (Psidium guajava L.) grading classification and consumer perception can be justified mainly by damage on guava peel. This work investigated the damage on guava using digital image processing and deep learning technique. More specifically, two types of damages including impact and vibration were classified based on the developed approach. Simulated impact and vibration testing had been implemented in the laboratory and the guava images were collected according to the following factors: drop numbers and drop height for impact testing, and acceleration and duration for vibration testing. Image pre-processing was employed for segmentation. EfficientNet structure, one of the Convolutional neural networks

(CNNs), was developed as a classification framework. The highest test accuracy was calculated as 99.45 % for the data covering images from Day 1 to Day 4 after testing.

Keywords: Guava, CNN, Deep Learning, Impact and Vibration, Classification

Poster Session

Modelling airflow in sugar beet clamps

William English and Morteza Mousavi

The rate of airflow through a sugar beet clamp (a bulk of harvested sugar beet roots stored in the field) is central in the thermodynamic processes that occur during storage. It determines the rate at which ambient air and the air inside the clamp exchange through advection, and the rates at which heat and moisture transfer between the beets and the air. Unfortunately, the working environment has meant that direct measurement in a commercial setting has to date been beyond the available resources. Using Computational Fluid Dynamics (CFD) to model the fluid dynamics and heat transfer processes in these clamps has permitted insight to be gained. Using the open source software programs R (physical model creation, and results analysis), OpenFOAM (CFD modelling), and ParaView (results visualisation), a series of CFD models of stylised sugar beet clamps were developed. The clamp was modelled as either uncovered, or covered with the non-woven polypropylene fleece TopTex (R). Experimental data for temperature in the the clamp and ambient temperature and wind velocity was taken from experiments conducted in 2011/12. The porous medium approach was adopted, and Darcy-Forchheimer (D-F) parametrization applied. The D-F values for the clamp region were derived from previous research (Tabil et al, 2003), alternatively by applying a variant of the Ergun equation. D-F values for TopTex were supplied by TenCate Industrial Fabrics. This poster will present the results for the air flow dynamics. This project is part of a larger ongoing series looking to develop models of fluid dynamics and heat transfer processes in sugar beet clamps that will be used in research and in the information industry sends to growers.

Keywords: CFD, sugar beet

Shelf life modeling for strawberries adopted in two layered master packaging system through stagewise supply chain consisting of different temperatures

Dong Sun Lee and Duck Soon An

This study examined and constructed a comprehensive picture of shelf life as a function of presale chilled storage time and retail temperature for a master packaging system containing 6 inner primary packages of strawberries within a secondary outer bag. The system is composed of six 270 g individual primary packages of micro-perforated oriented polypropylene (30 µm thickness) contained in 50 µm thick low density polyethylene bag. Mass balance equations of O2, CO2 and N2 for the primary and secondary packages were constructed as ordinary differential equations to estimate their gas concentrations and resultant produce respiration through the presale and retail storage, which were used to predict the produce respiration. The established model was validated by comparing the experimental package atmosphere to the estimations after 15 days at 0 °C for different numbers of micro-perforations (89 µm). Shelf life was defined as time for the accumulated respiration as an index of quality loss to reach the critical limit of 0.93 mol/kg amounting to the value to be met after 10 days at 10 °C under optimal modified atmosphere of 7% O2 and 18% CO2. Dismantling of secondary master pack at point of retail display is found to result in equilibration of the primary package atmosphere

within shelf life period. The increased retail temperature may cause decreased O2 and increased CO2 concentration even after removing the layer of secondary package. Total shelf life from packaging to retail though dismantling the master pack is predicted to increase proportionally to presale chilled storage time at 0 °C, even though retail life decreases inversely proportionally to the latter with same package atmosphere at end of shelf life. Higher retail temperature greatly shortens shelf life with risk of creation of anoxic or too high CO2 concentration, where 20 °C is the highest permissible temperature.

Keywords: Strawberry, shelf life, master pack, modified atmosphere, respiration, distribution

Detection of fruit juice adulteration by laser backscattering imaging

Hoa Xuan Mac, László Baranyai, Thanh Tung Pham, Thi Thanh Nga Ms. Ha, Le Phuong Lien Nguyen

Water dilution is the most common practice of juice adulteration, raising customers' concern about health and resulting economic damage. This study focused on investigating the applicability of the non-destructive laser backscattering imaging (LBI) technique on assessment of adulteration of fruit juices with different levels of dilution with water. Orange, orange with juicy bits, grapefruit and cranberry juices of 100% fruit juice were used in the experiments and samples were diluted to 95%, 90%, 85% and 80%. Six low power laser modules, emitting at 532, 635, 780, 808, 850, 1064 nm wavelength, were used. The LBI profile was extracted from 12 bit raw images and described with the peak widths at three selected intensity level (D75%, D50%, D25%) and their ratios; the illuminated areas at selected intensity level of 50% (A50%), the ring of 25-75% and their ratio. The ring of 25-75% obtained the highest sensitivity to juice dilution at all wavelengths based on ANOVA F-value ($p < 0.001$). Diluted juices were successfully distinguished by linear discriminant analysis (LDA) at 5% (v/v) adulteration. Moreover, the type of juice was recognized by LDA with a correct classification rate above 91.6%. According to the results, laser backscattering imaging is a promising non-invasive technique for quality control and classification of fruit juices. Partial least squares (PLS) regression was applied to predict the Brix value of adulterated juices by water dilution with R^2 of 0.86 and RMSEP of 0.335.

Keywords: Juice authenticity; food adulteration; laser backscattering imaging

Modeling the ripening time of mature green tomato according to temperature and light conditions

Hyo Gil Choi

The optimal harvesting time for the market distribution of tomato fruit is usually during the turning and pink stages. If it can predict the number of days for tomato ripening stages such as turning and pink, it can efficiently produce tomato and distribute them to the market. Tomato ripening is greatly affected by temperature and light. Therefore, a model that can predict the number of days required for ripening stage of tomato fruit using temperature and light was set up. Ripening stage influenced by temperature and light is mainly from green to breaker. Even though there were differences in temperature and light in the ripening stage after breaker, the effect on the number of days required in each ripening stage was insignificant. The ripening time of tomatoes in the dark conditions was longer as the temperature was lowered, and the individual fruit variation in the number of days was large. On the other hand, in the light conditions, the number of days required for ripening was shortened, and individual fruit variation was also reduced. The results show the regression relationship between the proposed model and the time histories of the ripening stages according to temperature and light

environment conditions. This study is expected to help efficient tomato cultivation management by providing information on the control of ripening time of tomato grown in a greenhouse.

Keywords: Maturation, environment condition, post-harvest, storage

Assessment of adulteration of fruit juices by water dilution using NIR spectroscopy

Eya Ms. Yakdhane, Hoa Xuan Mac, Nga Thanh Thi Ha, Mai Sao Dam, Lien Le Phuong Nguyen, László Baranyai

Food adulteration gains interest due to its negative effects on quality in terms of nutritional value and safety. The main goal of this work was to evaluate the applicability of the near infrared (NIR) spectroscopy on assessment of adulteration of four commercial fruit juices. Samples were made of 100% juice of orange, orange with pulp, cranberry and grapefruit. Simulation of adulteration was carried out by water dilution. NIR spectra were acquired in the range of 900-1700 nm. Spectral readings were normalized with standard normal variates (SNV) technique. Spectra information was used to perform linear discriminant analysis (LDA) for classification and partial least squares regression (PLSR) for prediction of dilution level. The results indicated that NIR spectra of juices achieved accurate detection of the adulteration at correct classification of 100%. PLSR prediction models obtained high coefficients of determination of R2 > 0.985 and small root mean squared errors of RMSE < 0.88%. One PLSR model was built to test the efficiency on any of the evaluated fruit juices. This robust PLSR model showed lower performance with R2 = 0.751 and RMSE = 3.526%. Near-infrared spectroscopy was found to be effective in evaluation of juice adulteration by water dilution.

Keywords: Food adulteration, NIR, linear discriminant analysis, partial least squares regression

Modelling of stiffness of ‘Gala Irene’ apple during storage and shelf-life

Thi Thanh Nga Ha, Pham Tung Thanh, Hoa Xuan Mac, Le Phuong Lien Nguyen, Zsuzsanna Horváth-Mez337fi, Zoltán Sasvár, Mónika Göb, Tamás Zsom, Gergo Szabó, Géza Hitka

The firmness of apple is one of the most important factors for consumers´ acceptance. ´Irene´ is a new generation of Gala clone, which has no literature coverage yet. This work aimed to analyze the behavior of this cultivar in cold storage and shelf-life. Acoustic firmness (stiffness, g2/3 s-2) was measured during 7 months of cold storage and consecutive shelf-life for 7 days. Saturation model was used to estimate stiffness values. Autocorrelation test confirmed that curve fit on acquired data without systematic error (Durbin-Watson test value of 1.66). The saturation model achieved R2 = 0.9897 determination coefficient and low prediction error of RMSE = 0.4198 (with RPD = 10.56). The stiffness values continued to decrease during shelf-life but changed less with increasing cold storage time. The comparison of kinetics revealed that acoustic firmness changed in shelf-life 2.98 times faster than in cold storage. This result can contribute to Storage Time Equivalent Value (STEV) based models for apples.

Keywords: firmness, brix, postharvest, regression, Malus domestica L.

Evaluation of Coated Green Asparagus (Asparagus officinalis) Freshness using Near-Infrared Spectroscopy

Thanh Tung Pham, Hoa Xuan Mac, Thi Thanh Nga Ha, Hailu Zinabu Syium, Le Phuong Lien Nguyen, Ngoc Han Nguyen Thi, Géza Hitka, Tamás Zsom, László Baranyai

The application of near-infrared (NIR) spectroscopy for predicting green asparagus quality was investigated. In this study, green asparagus was treated with cassava starch-based coating (2%, 3% and 4% of starch) and evaluated for the changes of quality in terms of weight loss and firmness during 4 days of storage at room temperature (26±2 °C, 65-70 % RH). The coated samples significantly decreased weight loss and firmness reduction compared to uncoated samples ($p < 0.05$). At the end of storage, samples coated with 4% of starch achieved the highest quality retention efficiency compared to the remaining samples. Furthermore, NIR spectra was acquired in the range of 900–1700 nm to monitor quality. Partial least squares regression (PLSR) was performed on spectral datasets to build prediction models for quality changes at 3 locations along the asparagus. The preprocessing methods of standard normal variate (SNV), first derivative (d1) and second derivative (d2) were used for comparative analysis. The predicted performance of d1 -PLSR model for weight loss rate was the best with $R^2 = 0.94$ and RMSEP = 3.24%; $R^2 = 0.95$ and RMSEP = 3.05%; $R^2 = 0.94$ and RMSEP = 3.08% at bottom, middle and top part, respectively. The d1-PLSR model also showed the highest accuracy for firmness with $R^2 = 0.92$ and RMSEP = 4.21 N; $R^2 = 0.94$ and RMSEP = 1.59 N; $R^2 = 0.90$ and RMSEP = 0.88 N at bottom, middle and top part, respectively. This study shown the potential of NIR spectroscopy in examining the quality of coated asparagus during storage.

Keywords: Asparagus, edible coating, non-destructive test, produce quality, postharvest, machine vision

Carbon dioxide and ethylene production modelling of apricot at three maturity stages

Thi Thanh Nga Ha , Thanh Tung Pham, Xuan Hoa Mac, Gergo Szabó, Le Phuong Lien Nguyen, Zsuzsanna Horváth-Mezofi, Zoltán Sasvár, Mónika Göb, Tamás Zsom, Géza Hitka

Proper description and prediction of ethylene and carbon dioxide production is important for postharvest technology of fruits and vegetables. In this study, the ethylene production and respiration of apricot were measured at room temperature. Three maturity stages of apricot including green, yellow and light orange (overripe) were investigated each day for 25 d. Respiration and ethylene production have the same kinetics with exponential increase until the peak value, followed by decreasing trend. Gaussian and Cauchy distribution functions were applied with nonlinear least squares method. Respiration was successfully described by both functions with $R2 > 0.983$ and $R2 > 0.979$ for Gaussian and Cauchy, respectively. Low prediction error was achieved for respiration ($RMSE < 3.5$) and peak time was reasonably estimated. Ethylene readings did not reach peak value during the experiment. In the case of ethylene production, models fit to data with $R2 > 0.966$ and $R2 > 0.968$ for Gaussian and Cauchy, respectively. Prediction error increased with fruit ripeness and increasing variability of collected data. Cauchy model performed better for ethylene production in terms of peak time prediction, and its scale parameter (coefficient of kinetics) well correlated with fruit ripeness stage. According to achieved results, Cauchy distribution function can be used to predict fruit respiration and ethylene production. Function coefficients agreed with expectations such as peak time and kinetics.

Keywords: Gaussian, Cauchy, distribution function, nonlinear curve fitting, Prunus armeniaca L.

Aquaphotomics and machine learning algorithms reveal falsification of aqueous tomato powders by bulking and coloring agents

Balkis Aouadi, Juan Pablo Aguinaga Bósquez, Mariam Majadi, István Kertesz, Zoltán Kovács

Tomatoes year-round availability and subsequent processing into a wide range of marketed products makes it an indispensable culinary ingredient, the economic prominence of which entices fraudulent practices. Non-exempt from such practices are tomato powders, the subject of our current study. While existing authentication methods range in complexity and efficiency, our approach explores the suitability of Aquaphotomics, coupled with machine learning algorithms, for authentication purposes. The proposed approach entails limited preparation steps and involves no solvent extractions. As per the considered mixtures, they comprised concentrations in the range [0%-20%] of each adulterant type (bulking agent, coloring agent), added separately or concomitantly. Running PCA-LDA qualitative modeling on single adulterant mixtures allowed for recognition and prediction rates ranging from [97.76%-100%] and [88.59%-100%], respectively. Slightly lower accuracies were obtained when coupling the bulking and coloring agent. PLSR models gave good estimates of the extent of adulteration, with respective R2 and RMSECV values reaching at best, 0.98 and 0.45%w/w. The aquagrams revealed distinctive spectral patterns highlighting the gradual level of adulteration. As per the different machine learning algorithms, they showcased promising results in terms of the classification of the different sample groups and the estimation of the added adulterants, with performance accuracies that depended on the type of adulteration (single or dual),on the tomato varieties as well as the preprocessing steps.

Keywords: Tomato powder extracts; bulking agents, colouring agents, Aquaphotomics, machine learning algorithms, Adulteration

Near-infrared spectroscopy as a tool for predicting superficial scald in cv. 'Granny Smith' apple fruit

Angelo Zanella, Stefan Stürz, Nadja Sadar, Ilaria Folie

Despite a plethora of studies over the years, the physiological post-storage disorder superficial scald remains enigmatic. Various efforts to control the disorder have been tested, among them, the development of tailor-made storage technologies such as the Dynamic Controlled Atmosphere by means of Chlorophyll Fluorescence (DCA-CF), allowing to handle the problem to a certain extent. To date, it has not been possible to unequivocally reveal the underlying etiology and biochemical mechanisms leading to superficial scald. The appearance of the disorder is likely triggered by a chilling induced process in the fruit´s epidermis. One of the earliest and most widely accepted theories on superficial scald development is related to the auto-oxidation products of α-farnesene, grouped as CT trienols (CTols), which injure the cell membranes, leading to cell death of the outer cell layers, ultimately resulting in the occurrence of brown patches on skin i.e. typical scald symptoms. Recent research studies increasingly confer the crucial role in this process to the oxidation of phenolic compounds. At present different efforts are being made to predict scald susceptibility of the fruits already at harvest or at an early stage of storage. In the present work the potential of near-infrared spectroscopy (NIRS) for predicting superficial scald susceptibility in apples was investigated, applying a "black-box-approach", trying to model the information from the obtained NIR spectra (1,000–2,500 nm). The conducted partial least squares (PLS) regression provided a promising prediction performance for superficial scald development in apples, resulting in correlation coefficients of validation (rval) of 0.5. Even better rval were achieved when predicting α-farnesene and CTols in apple skin, reaching in the case of CTols an rval > 0.8. The achieved results are encouraging, revealing the potential of NIRS for non-destructive scald prediction in cultivar 'Granny Smith' apples.

Keywords: NIRS, modelling, PLS-regression, physiological disorder, spectra

Developing an electronic model-based control system for temperature-dependent gas modification in a fruit storage container

Pramod Mahajan, Ali Jalali, Manfred Linke, Cornelia Weltzien

Temperature is the most important factor affecting the quality and shelf life of fresh produce. The main temperature-dependent variable is respiration rate. Slowing down the respiration rate by decreasing O2 concentration is important for keeping quality and extending the shelf life of many horticultural products. Varying temperature conditions are often observed during the supply chain of fresh produce. This poses a big challenge in designing modified atmosphere storage and transport containers. This study developed an electronic system based on mathematical modelling to actively control CO2 and O2 concentrations inside a storage container under constant and changing temperatures. The gas concentration is modified in the container by the respiration of fresh produce and corrected solely by the periodical gas exchange between the container and the external atmosphere via a mini air blower. The operation time of the blower as a function of temperature to balance the respiratory gas exchange and keep the target gas at a predefined setpoint was calculated via mathematical simulation of the container and gas control system. Thereby, the blower ON frequency (s h-1) was modelled as a function of storage temperature, taking into account the type and amount of fruit, blower properties, tube dimension, and the setpoint of target gas concentration. This model was then used in programming an Arduino micro-controller to control the blower in response to real-time measurement of storage temperature. The gas control system then validated the storage of sweet cherries. It could maintain the CO2 concentration within the desired range for sweet cherries (12.5 ± 2.5 %) for constant temperatures of 6 °C and 17 °C and changing temperature from 17 °C to 9 °C. The blower ON frequency ranged from 32 s h-1 at 6 °C to 350 s h-1 at 17 °C. There was a good agreement between the measured and predicted values of gas concentration obtained from the simulation. The maximum RMSE value of predictions was 0.30 % at 17 °C storage temperature. The data on the validated system was further used to simulate different container sizes and products under varying supply chain conditions.

Keywords: Respiration, Modified atmosphere, Control, Simulation, Supply chain

Relationship between sensory characteristics and optical properties in 'Conference' pears

Maristella Vanoli, Fabio Lovati, Giovanna Cortellino, Marina Buccheri, Rosita Caramanico, Pietro Levoni, Lorenzo Spinelli, Alessandro Torricelli

Pears are very appreciated by consumers for their juicy-buttery texture, sweet flavour and pleasant aroma. Sweetness and juiciness are the main drivers for consumer liking while firm-grainy textures and lack of flavor are disliked by consumers. Thus, it is important that industry can provide pears of high quality to encourage pears consumption. Non-destructive techniques, such as time-resolved reflectance spectroscopy (TRS), can help producers in discriminating pears with different sensory characteristics to satisfy consumer expectations. The aim of this work was to study the relationship between sensory characteristics, quality, and optical properties (absorption and scattering) measured by TRS, in 'Conference' pears. At harvest, 240 pears were measured by TRS for absorption coefficient at 650 nm (μa650), ranked by μa650 in three maturity classes (less, medium, more mature), and randomized in four samples according to 1-MCP treatment (treated, untreated) and atmosphere (air; CA: 2 kPa O2,

1 kPa CO2). After 4 months of storage at −1°C plus 7 days at 20°C, less and more mature pears were measured by TRS at 650, 780 and 940 nm, analyzed for firmness (FF), soluble solids (SS) and acidity (TA) and submitted to sensory analysis. Cluster analysis applied on sensory attributes produced three groups, each one representing a specific sensory profile. W1 showed the lowest scores for sweetness and the highest for sourness and astringency. W2 grouped pears with the lowest scores for firmness and astringency and the highest for sweetness, aroma and acceptability together with the lowest FF, µa940 and µs780 values. W3 showed the highest scores for firmness, graininess and the lowest for juiciness and aroma coupled with the lowest TA and the highest FF, µa650, µa940 and µs780 values. Discriminant analysis based on TRS optical properties correctly classified W1, W2 and W3 profiles in 41%, 69% and 78% of the cases, respectively.

Keywords: Time-resolved reflectance spectroscopy, absorption, scattering, 1-MCP, storage atmosphere, quality

Potential use of Hyperspectral Imaging for Authentication of Rocket Leaves according to Agricultural practices

Aysha Saleem, Mojtaba Nosrati, Hassan Fazayeli, Maria Luisa Amodio, Danial Fatchurrahman, Francesco Serio, Francesco Fabiano Montesano, Giancarlo Colelli

In this study we assessed the potentiality of hyperspectral imaging for the discrimination of different management systems for water and fertilizer use on rocket leaves. Soilless cultivation of rocket leaves was conducted in unheated greenhouse testing a factorial combination of two fertilization levels (defined as ‘high’ or ‘low’, with reference to the standard dosage range recommended for the specific fertilizers used in the study) with two irrigation scheduling approaches (sensor-based, as a promising technique for optimal water supply based on real plant needs, and empirically timer-based, as an approach potentially resulting in un-efficient watering). Reflectance spectra were acquired using Vis-NIR ranges between400-1000nm and NIR ranges between900-1700nm. After pretreatment spectra were used for discriminant models of the four treatments and for ANOVA-simultaneous component analysis (ASCA) in order to understand the effect of each factor on spectral response. Comparing different treatments, PLS-DA model yielded the accuracy of 98.19%, 97.6%, and 97.2% for the cross validation, calibration and prediction system, respectively in Vis-NIR ranges while in NIR ranges the accuracy improved to 100%, 99.8%, and 99.5%. Moreover, applying ASCA significant wavelengths were selected. Results indicated promising potentiality of hyperspectral imaging for the authentication of products from low input managed agricultural systems.

Keywords: Sustainability, water use, fertilization, Non- destructive, PLS-DA, ASCA

Prediction Model for Fruiting Body Yields and Morphological Characteristics of Size, Color, or Hardness of Oyster Mushrooms at Cultivation Temperatures

Hye-sung Park, Eun-Ji Lee, Tai-Moon Ha

Oyster mushrooms are one of the most abundantly cultivated mushrooms in South Korea. Oyster mushroom cultivation accounts for the greatest number of mushroom farms and farming area. Automated large-scale production systems for mushrooms are progressing more rapidly than that for other crops. However, the application and proliferation of digital technologies that apply cutting-edge information and communications technology (ICT) are currently lacking. In the future, mushroom cultivation will likely rapidly transform into a vertical smart farm cultivation system. For this to occur, mushroom growth and development

management technology must be developed. A first-generation smart farm cultivation standard model has been developed for oyster mushroom farming. To develop a growth model applicable to a second-generation smart oyster mushroom farming system, this research collected data on temperature-related occurrence of fruiting bodies. Data on oyster mushrooms cultured at temperatures between 10-30℃ in 5℃ intervals were collected three times from May 2 to June 14, 2022. A regression analysis revealed the highest yield of oyster mushrooms were predicted for cultivation at 25℃ (y=0.7x2+28.3x-101.8, R2=0.82), followed by cultivation at 20℃ (y=0.6x2+24.9x-92.1, R2=0.88). Cultivation was the worst at a temperature of 10℃ (y=0.3x2+15.6x-80.6, R2=0.57). A regression analysis of the size, color, and hardness characteristics of the cap and stem of the fruiting body at each cultivation temperature revealed an accuracy between 57-81% at 10℃, 53-81% at 15℃, 58-88% at 20℃, 60-89% at 25℃, and 48-89% at 30℃. Repeated cultivation testing will be necessary to adjust the error value of the prediction model, so that a more accurate model will be useful for second-generation smart farms.

Keywords: Oyster mushroom, Prediction model, Cultivation temperature

Drought monitoring and prediction for mango orchard in Tamale, Ghana with earth observation data and SSP climate scenarios

Marius Hobart, Mohamad Zare, Abdul-Halim Abubakari, Gazali Issahaku, Eugene Anin-Adjei, Godwin Badu-Marfo, Michael Schirrmann

The need for better predictive drought models increases with stronger impacts of climate change on local farming in sub-Saharan Africa. In this study, long-term time series of standard precipitation index (SPI) data and temperature vegetation dryness index (TVDI) data were used to determine drought conditions through remote sensing for three subsequent years (2020-2022) on a mango orchard in Tamale (Northern Ghana). Over the same period, 52 Landsat8/9 images were obtained for calculating TVDI as an agricultural drought index. The results of satellite imagery were validated using two unmanned aerial vehicle (UAV) flight campaigns over the study area in March and October 2022. Monthly mean TVDI values are considered representative for the drought conditions in a mango orchard in Tamale, Ghana. In order to determine the relationship between agricultural and meteorological drought indices, correlation was calculated and the lag between the droughts was determined. Lag time results prove that the agricultural drought occurs after the meteorological drought. TVDI changes are complex to model because of nonlinear factors. Wavelet transform (WT) in combination with machine learning have proven to be useful for modelling TVDI changes. The hybrid Wavelet-ANFIS model was used in this study to simulate and predict the TVDI based on SPI values with several lag times as inputs. In total, 35 climate change models were applied for predicting precipitation and SPI values in different socioeconomic pathway (SSP) climate change scenarios. Coupled Model Intercomparison Project Phase-6 (CMIP6) data for time interval between2015-2050was used as input for the calibrated hybrid model to predict TVDI. Results can be applied by farmers to plan an appropriate irrigation scheduling for upcoming droughts in the arid northern Ghana. For a suitable planning in water scarcity condition, understanding the situation helps water planners have better insight about management polices to minimize losses.

Keywords: Earth observation, TVDI, Wavelet-ANFIS, drought monitoring, climate change, orchard

Temporal traits of apple chlorophyll content in NDVI analysed by means of LiDAR

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Visual monitoring of apple peel colour is widely performed subjectively to identify the harvest-ripe fruit during manual harvest. During climacteric, chlorophyll content decreases and, therefore, change of chlorophyll during fruit development can be employed as an indicator for the ripening progress. A feasible method to analyse fruit at the tree is requested in precise production management. This work presents a phenotype sensing system that integrates a light detection and ranging (LiDAR) sensor aiming to measure the number of fruit, quality-related size, and ripeness-related chlorophyll of fruit skin. During fruit (Malus x domestica Borkh. 'Gala') development (65 – 130 day after full bloom, DAFB), apples were harvested and analysed in the laboratory (n = 225) with two LiDAR laser scanners measuring at 660 and 905 nm. From these two 3D point clouds, the normalized difference vegetation index (NDVILiDAR) was calculated. After calibration, the sensor system was mounted on a circular conveyor platform, established in an experimental apple orchard, together with a real time kinematic global navigation satellite system to geo-reference the data and an inertial measurement unit to acquire orientation data. The method was tested on 3D point clouds of 12 fruit trees measured directly in the orchard, during fruit growth on five measuring dates, and validated with manual fruit analysis in the orchard (n = 4632). Point clouds of individual apples were segmented from 3D point clouds of trees and fruit NDVILiDAR were calculated. The non-invasively obtained field data showed good calibration performance capturing number of fruit NDVILiDAR, and chemically analysed chlorophyll content of R^2 = 0.78 with RMSE = 1.31 %, respectively, considering the related reference data at last measuring date 130 DAFB. The new approach of non-invasive laser scanning provided physiologically and agronomically valuable time series data on differences in fruit chlorophyll affected by the leaf area to number of fruit and leaf area to fruit fresh mass ratios. Concluding, the method provides a tool for gaining production-relevant plant data for, e.g., crop load management and selective harvesting by harvest robots.

Keywords: Apple, NDVI, 3D LiDAR point cloud, Leaf area, Chlorophyll

Potential Application of Hyperspectral Imaging for Discrimination of Chilled Tomatoes

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This study was aimed to assess the feasibility of using hyperspectral imaging for discriminating freshly harvested tomatoes from those stored under the chilling (0 °C) and non-chilling (18 °C) conditions. Color change, total carotenoid, soluble solid content (SSC), titratable acidity (TA), and electrolytic leakage (EL) were evaluated up to 14 days of storage time. Tomatoes were scanned with an hyperspectral line-scan scanner (Version 1.4, DV srl, Padova, Italy) equipped with a Vis-NIR spectrograph (400−1000 nm). Furthermore, supervised classification models were developed using Partial Least Square Discriminant Analysis (PLS-DA) for raw and pre-processed spectra for the discrimination. Tomatoes stored at chilling temperature presented a much slower color development during storage compared to those stored at higher temperature. In addition total carotenoids of chilled tomatoes stopped increasing after 4 days of storage and remained the same up to 14 days, whereas at higher temperature they gradually increased from 0.44 ± 0.003 g/kg at harvest to 1.1 ± 0.01 g/kg already after 7 days, remaining stable for up to 14 days. These chilling symptoms were confirmed by the higher EL value of chilled tomatoes. Additionally, we observed a gradual increase of SSC in both storage conditions

0 °C and 18 °C, although slower at lower temperature. Spectra obtained after image thresholding were mean-centered and used for classification models. A reliable classification of 3 different classes of tomatoes (i.e, freshly harvested tomatoes, chilled tomatoes, and non-chilled tomatoes) was achieved, yielding accuracy and specificity of 88 % and 90 % respectively.

Keywords: Chilling injury, PLS-DA, storage temperature, spectra

Effect of ultraviolet and far-red LED light added to broad spectrum white LED on lettuce production in vertical farm

Zoltán Pék, Lajos Helyes, Balázs Bence, Sándor Takács

The use of light emitting diodes (LED) as an artificial light source on vertical farms is justified by their improved cost efficiency, heat dissipation and lifetime compared to high pressure sodium (HPS) lamps. LED have been widely used as potential light sources in leafy green production as well as for the promotion of quantity and quality. While in the past LED-based light sources were built from monochromatic, usually red and blue LEDs, in recent years the use of broad-spectrum white LEDs (WL) has become increasingly popular in plant cultivation with artificial lighting. The proportion of secondary metabolic products produced in food crops increases under stress, resulting in a higher antioxidant content and healthier food. Such stress can also be caused by excessive ultraviolet-A (UV-A) radiation, which can also be produced artificially with an LED light source. By supplementing the wide-spectrum white LED light source with a far-red (FR) spectrum, the mass of biomass can be increased, and by supplementing with UV-A, the harmful nitrate content of lettuce can be reduced. The aim of this study was to investigate the effect of broad-spectrum white LED light source supplemented with UV-A or FR spectrum LEDs in a vertical farm. In this experiment, lettuce was irradiated with a WL for 16 hours per day, supplemented with a combination of UV-A and FR, compared to the popular red-blue (RB) LED light source. The four different light source resulted significant differences among SPAD values of leaves. The white LED resulted the highest, while WL+FR and WL+UV resulted significantly lower SPAD value. Also, the biomass result of lighting with WL was the highest, but not significantly different from the WL+FR and BR treatments. The WL+UV-A treatment caused a greater than 50% decrease in plant weight. Significant differences were observed in the reflectance of the leaves in the near-infrared (NIR) spectra (740-1075 nm). In summary, lettuce was more sensitive to the addition of UV-A light compared to FR; however, the addition of UV-A to WL may reduce yields significantly.

Keywords: Lettuce, LED, UV-A, far-red, vertical farm

Application of vacuum ultraviolet photolysis reactor and loss firmness prediction for stored 'Fuji' apples

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Ethylene is beneficial for uniform ripening, but if not properly managed it can induce negative impacts on fruit, such as a decline in firmness or texture profile. Fruit textural profile is one of the most important postharvest quality attributes for apples and it could be influenced by the presence of ethylene during storage. This study investigated the use of a vacuum ultraviolet (VUV) photolysis reactor to degrade ethylene during the retail storage of 'Fuji' apples at 15 °C for 28 days. A first order kinetic model was applied to describe the relationship between the measured and predicted apple firmness and used to predict the storage-life of apple fruit. The results showed that the VUV reactor was successful in maintaining low ethylene concentration in storage chamber between 2.5 – 16.2 ppm, while the ethylene concentration reached a

maximum of 181.4 ppm in the control over a period of 28 days. Firmness of apple fruit under both storages was linearly related to storage time but the apples in control lost firmness at a rate that was 2.3 times higher. It was shown that the loss of firmness followed a first order kinetic behaviour. The applied model showed that based on firmness the use of VUV reactor for ethylene removal during fruit storage could further extend the shelf-life of apple fruit by 46 days.

Keywords: Fruit texture profile, ethylene removal, firs-order kinetic, ripening, postharvest handling

Computational Fluid Dynamics (CFD) Simulation of Gas Transportation Through a Thermoresponsive Membrane for Active Packaging Design

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A packaging with a self-regulate gas permeability is favorable for the fresh produces, as they may experience a temperature fluctuation during transportation and refrigerated storage. Our team has developed smart pads of poly(N-isopropylacrylamide) (PNIPAm)-grafted nylon membranes to be used as gas regulator for a packaging for fresh produce. This membrane is thermoresponsive with an ability to change its pore size in respond to the environmental temperature. The pore size of the smart membrane could be tailored by the degree of grafting and the use of crosslinking agent. In this study, a computational fluid dynamics (CFD) simulation, Ansys Fluent 2023 R1, was used to define the numerical model. The model was employed to predict the change in gas composition ((CO2, O2, and N2) over time in the smart packaging at two different temperature (25 and 40 °C). A gas-impermeable acrylic cylindrical container was used as a packaging model of which the PNIPAm-grafted nylon membrane was placed on the top lid with an opening diameter of 0.5 mm functioning as a gas-permeable panel. The simulation results were validated by comparing with the actual experimental results obtained from gas chromatography (GC) test. A proof-of-concept preliminary pack test of a selected smart membrane with okra was carried out. The finding indicated that the packaging with PNIPAm-grafted nylon membrane could preserve the quality of the okra (green color, weight) superior to that of the okra packed in a conventional packaging.

Keywords: CFD, poly(N-isopropylacrylamide), thermoresponsive, active packaging, gas permeation, okra

Prediction of cultivation system by rapid and no-destructive tool

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Two parallel experiments, one in soil-bound and another in soilless cultivation conditions, were carried out at the Experimental Farm “La Noria” of the Institute of Sciences of Food Production (ISPA-CNR) in Mola di Bari during the2020-2021 growing season. The experiment was carried out within the SUS&LOW (SUSTAING LOW-IMPACT PRACTICES IN HORTICULTURE THROUGH NON-DESTRUCTIVE (ND) APPROACH TO PROVIDE MORE INFORMATION ON FRESH PRODUCE HISTORY & QUALITY) projects. Colour parameters and total chlorophyll content were measured on rocket leaves coming from the two growing systems. For chlorophyll analysis a no-destructive and a destructive analytic method were compared. Two PLS model were built in order to predict the cultivation system. In the first PLS the hue angle and the total chlorophyll measured using the no-destructive method were considered as predictors. In the second PLS

the x variables were the hue angle and the total chlorophyll measured using the analytic method. Both PLS were able to discriminate the cultivation system with R2 value of 0.7 (in calibration and validation) for the first PLS and 0.6 (in calibration and validation) for the second one. The first model outperformed the second since the no-destructive method used allowed to make more measurements for each replications, that were more than the replications used in the analytical method. This is due to the rapidity of the analysis that allowed to analyze more samples, catching all the variability present among samples.

Keywords: Rocket leaves, soilless growing system, partial least square regression

The modelling of ethylene scavenger reveals temperature-dependent removal rate while the removal capacity remains constant

Akshay D. Sonawane, Pramod Mahajan

Nowadays ethylene scavenger sachets are often used in fruit packages during storage and transportation to delay the ripening process by preventing ethylene accumulation. The ethylene scavenger based on potassium permanganate (KMnO4) possesses the ability to oxidise the ethylene gas in the. The effect of relative humidity on ethylene scavenging rate and capacity has been studied previously; however, the effect of temperature on ethylene scavengers is limited in the literature. Hence, this study aimed to investigate the dependency of potassium permanganate-based commercial ethylene scavenger (Ryan®) on four different temperatures (2, 10, 21, and 30 ºC) under 100 % relative humidity. The pseudo-first-order kinetics was applied to obtain the rate constant and ethylene removal capacity of the Ryan® scavenger at different temperatures. The rate constant ranged from 0.35±0.05 to 0.81±0.04 h-1, and it varied significantly with a temperature range from 10 to 21ºC. At other temperature ranges (2-10 ºC and 21-30 ºC), the rate constant did not vary significantly. The Arrhenius relationship between rate constant and temperature showed the goodness of fit (R2) of 0.89 and activation energy of 23.31 KJ mol-1, which were poor to predict the rate constant. There was no significant difference observed in ethylene removal capacity at every temperature and it was experimentally determined to be 2.84±0.03 µL gm-1 of scavenger for all temperatures. The results are useful for understanding the optimum weight of scavengers needed in the long storage of ethylene-sensitive fruits inside a package.

Keywords: Climacteric fruit; Respiration; Ethylene scavenger

Characterization of biodegradable packaging materials

Tilahun Seyoum Workneh and Asavela Notshweleka

Physical, mechanical, and water barrier properties were evaluated for biodegradablepaper tray and synthetic materials such as polystyrene and polypropylene. The packaging was stored at two different storage conditions suchas 12°Ccombined with 80% RH and at ambient 20℃ for 28 days. Cold storage conditions decreased the tensile strength ofbagsby 3.5% compared to ambient storage conditions. The changes in the tensile strength of conventional packagingwerenot significant (P > 0.05) when stored under cold conditions.Polypropylene had tensile strengths ranging from 93.6 to 95.6 MPa and 111.57 to 111.6 MPa while Paper Tray had tensile strengths ranging from 54.3 to 54.31 MPa.Thepaper trayshowed the highest tensile strength whenkeptat both 12℃ and 20℃ for 28 days. The highest modulus of elasticity (1.9-1.5 Nm-2) was observed in Polypropylene and Polyethylene Plastic. The Fourier Transformed Infrared (FTIR) showed a similar spectrum for biodegradable packagingmaterialswith a broad absorption band ranging from 3339.0–3200.0 cm-1. Among the main absorption peaks were a

strong-intensity absorption peak centred around1025.1-1001.0cm-1 which can be attributed to the C–O bond stretching of C–O–C groups in thehydro-glucosering. The highest Water Vapor Transmission Rate (WVTR) was observed in paper tray (264.7 gm-2 day-1) due to plasticized NC-sorbitol coated substrate with three layers. Biodegradable packaging materials had the highest WVP, while conventional materials had the lowest values of WVP. Papertraymaterial showed thegreatestsolubility due to its hydrophobic nature. Overall, the addition of plasticizer improved the mechanical properties anddecreased wateruptake.Plasticizing agents are recommended for biodgradable packaging to prevent softening.

Keywords: Tomatoes, biodegradable, packaging, storage, transportation

Detection of hidden bruises in plums using hyperspectral imaging and a 3D convolutional neural network

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Mechanical damages in plums can cause commodity losses, and it is therefore of interest to detect them prior to arriving at the consumer. However, in early stages, or if the skin is dark as with the Presenta variety used in this study, it is not possible to visually identify the bruised fruit. Hyperspectral imaging can solve that problem thanks to its ability to detect internal information of the fruit. A pendulum device was used to artificially induce the bruises. Three different angles were used to produce three different bruising levels: low (20º), medium (30º) and high (40º). Images of 306 non-bruised plums and 153 with low, medium and high bruising levels each were taken. Images were acquired directly after bruising and 24 and 48 hours later. A pushbroom camera (Specim FX10e, Specim, Oulu, Finland) was used for collecting hyperspectral images with a spectral range of 400-1000nm. Raw images were corrected with the white and dark reference. All plum images (765) were divided into train (70% of the images), validation (10% of images) and test (20% of images). The computer vision problem of image classification is normally solved with two-dimensional Convolutional Neural Networks (2D-CNN). We propose a 3D customized CNN which is designed for 3-dimension data and allows obtaining more spectral information than 2D CNNs. Images were resized to 128 x 128 pixels, and data augmentation was applied to avoid overfitting. The model is composed of 3 convolutional layers followed by 3 max pooling layers and two final dense layers for classification and was trained for 800 epochs. An 87% test accuracy was obtained. This result shows that it is possible to detect invisible bruises even if bruises are very soft, proving that this technology is able to predict damages before they are visible by the human eye.

Keywords: Detection; hidden bruises; plums; convolutional neural networks

CFD optimization algorithm for a moving boundary problem of isothermal drying

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A moving-boundary Finite Element Method model describing fruits isothermal drying was solved as an inverse problem to estimate water diffusivity and peel resistance considering product shrinkage. The water diffusivity and peel resistance were estimated by the Levenberg-Marquardt optimization algorithm based on the experimental drying curves. The surface resistance regarded as the sum of the peel and the boundary layer resistances, the latter being negligible compared to the former. The Deff was 1.20-4.69×10−9 m2/s for peeled figs and 1.38-4.46×10−9 m2/s for unpeeled. The peel resistance was 14.18-39.37×105 s/m for unpeeled figs and 4.98-8.62×105 s/m for peeled figs. The ratio of the surface resistances

(rpeel|unpeeled/rsurf|peeled) showed no significant variation between the 45 °C and 55 °C (the surface resistance of the unpeeled figs is about 5-fold of the peeled figs), on the contrary between 55 °C and 65 °C this ratio gradually reduced to half, due to the reduction of the surface resistance of the peel in the unpeeled figs. Considering the resistance of the figs' peel as the difference of the respective resistances between unpeeled (peel) and peeled (cortex) figs, the derived peel resistance was found to be reduced by 62% as the drying temperature increases from 45 °C to 65 °C and by 55% as the drying temperature increases from 55 °C to 65 °C. This response can be attributed to peel disintegration or other micro structural changes taking place during drying.

Keywords: Figs, Water diffusivity, Surface resistance, COMSOL, Inverse method

Development of an innovative evaluation and information platform to increase the sustainability of food packaging solutions along value chains

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Packaging plays a critical role in preserving food quality, but its negative environmental impact has raised concerns and led to calls for reducing packaging and promoting the use of biodegradable or alternative materials. However, these alternative materials may not always provide the necessary barrier properties, which can result in suboptimal food quality and shorter shelf life, leading to increased food rejects and compromised overall sustainability. Determining which packaging is truly sustainable is challenging, as current online tools for assessing food packaging sustainability often do not consider the food waste prevented by packaging. The project 'PackAn' aims to develop an innovative evaluation and information platform to evaluate the holistic sustainability of packaged food, by considering the corresponding structure of the supply chain, the impact of the packaging on the shelf life of the food and the associated amount of food waste. Thus, a sub-part of this project aims at modelling shelf life elongation due to packaging in fresh produce in supply chains. These results will be integrated in an overall algorithm into a comprehensive tool that evaluates the holistic sustainability of a food packaging for specific products within individual supply chains. This innovative information and evaluation tool aims to support stakeholders in the food value chain and provide decision support for implementing truly sustainable packaging approaches in the future. The present work will highlight the considerations for modelling and algorithm development for the information and evaluation tool and the overall project will be presented. PackAn(01.012.2023–30.11.15, FKZ: 281A709A20): The project is supported by funds of the Federal Ministry of Food and Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support programme.

Keywords: Modelling, recyclable, biodegradable, fresh produce

Effect of caseinate based edible coating on quality indices of minimally processed pears during storage time

Marika Valentino, Stefania Volpe, Elena Torrieri

Pear is an important fruit due to its high nutritional antioxidant properties and unique phyto-constituents made numerous medicinal properties. Edible coating is a good technology to prolong the shelf life of fruits, improving chemical-physical properties, reporting the ability of

this technological strategy to retard changes in moisture, oxygen, aromas and solute transport. However, edible coating can be used as carrier transfer of antioxidants, antimicrobials, colorants, flavours, fortifying nutrients, and spices in film formulation. The aims of this work was study the effects of coating developed with sodium caseinate, guar gum, beeswax and antioxidant compound (propyl gallate) on minimally processed pears (MPP). Thus, (i) respiration and transpiration rate was used at preliminary study conduced, whereas (ii) quality indices were used to evaluate the effect of coating at 20°C at 95% RH for 9 days. Pears were washed, dried and coated by dipping method. Samples without coating were used as control. Quality indices, including weight loss, firmness, soluble solids content, titratable acidity, pH, colour, antioxidant capacity, total polyphenol content and vitamin C content, were measured at set intervals during storage. Coating reduced by 50% O2 consumption and CO2 production than control samples at 4, 10 and 20°C. Furthermore, active coating was able to preserve firmness, antioxidant capacity and total polyphenol content about 30% than uncoated samples. In conclusion, edible coating is able to preserve physical and nutritional properties of MPP. Firmness, antioxidant capacity and total polyphenol could use to describe how changes at different storage condition by kinetic modelling.

Keywords: active coating, respiration rate, antioxidant capacity, firmness, total polyphenols content

Mathematical modeling of the production of house crickets for food purposes

Marios Psarianos, Oliver Schlüter

House crickets will play a major role in the future agri-food systems due to their high nutritional value and low environmental impact, but also their already practiced consumption as food and feed in different parts of the world and their acceptance as novel food in the EU. The potential of producing cricket-based ingredients is explored throughout the production chain, starting from the cultivation of insects, following the production of cricket ingredients at post-harvest stages. Throughout these stages, novel production methods are introduced to enhance the process efficiency and product quality. Mathematical models are used to describe different stages throughout the production chain, in order to understand them deeper and influence them efficiently. A production chain is considered, in which crickets are reared using a standard system (32 ^{o}C, 65% humidity, 8 h photoperiod) with and without the additional exposure of narrowband UV-B irradiation. The weight and survival rate of the crickets are modelled with a sigmoidal and exponential model, respectively. Post-harvest, insects are dried using a drying oven at 60 ^{o}C until equilibrium of the moisture ratio, followed by a pre-treatment with pulsed electric fields (PEF) (4.4 kV/cm, 500 pulses). The drying curve of crickets dried with and without the PEF treatment was modelled with various mathematical models (Newton, Page, Henderson and Pabis, Logarithmic, Medilli, Wand and Singh) (Erbay&Icier, 2010) that are used commonly to describe drying curves of foods. Finally, the dried crickets were used as a basis for the solid-liquid extraction of fat using hexane. The extraction yield (g fat/100 g) was expressed mathematically in dependency of time to optimize the duration, using an exponential growth. In all cases, the models showed a good fit to the data and reproducibility to the experimental replications with high R^2 (>0.90) values and low χ^2 and RMSE values (<0.1).

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