A MODELLING PERSPECTIVE OF POST HARVEST STORAGE

Dev, S.R.S.*; Raghavan, G.S.V. and Dutta, B.
*Author for correspondence
Department of Bioresource Engineering,
21111, Lakeshore road,
Ste Anne de Bellevue, QC, H9X 3V9,
Canada,
E-mail: satyanarayan.dev@gmail.com

ABSTRACT

The quality and storage life of fruits and vegetables are extremely challenging to predict. Immediately after harvest, the field heat from fruits and vegetables must be removed in order to retard the degenerative biochemical activities within the produce. Moreover they need to be stored under refrigerated conditions until they are consumed. There has been an interest in the use of mathematical models for optimizing the operation, design and control of postharvest storage systems. These mathematical models are applied to predict the physical and chemical phenomena that take place during postharvest handling of horticultural products. Nowadays, with the availability of more powerful computers at a reasonable price, it is feasible to investigate the details of the flow behavior in large-scale postharvest storage systems involving refrigerated storage and modified atmospheric storage systems. In this paper an overview of advances in the application of mathematical models for predicting and optimizing fluid flow, heat and mass transfer and associated phenomena during postharvest storage of horticultural products is presented.

INTRODUCTION

Post-harvest storage systems are mostly used to preserve quality of agricultural and horticultural products by minimising respiratory heat generation, retarding the ripening process, and preventing moisture loss and microbial spoilage [1, 2]. Different methods of post harvest storage are available these include: bin storage, bag storage, controlled atmospheric storage, modified atmospheric packaging, room cooling, forced-air cooling, vacuum cooling, hydro cooling and package icing. Due to its flexibility, efficiency and low cost, forced-air cooling is the most commonly used method [3] for horticultural products. Forced-air systems commonly consist of a cooling unit assembly with cooling coils in which the refrigerant is circulated and a fan that forces cooling air over the coils and on to the stacked product.

Process and pricing knowledge at each marketing stage from the packinghouse to the retail outlet are frequently hard to determine, due to the proprietary nature of the relevant information. Based on general available knowledge, a plausible

mechanism of occurring processes has to be assumed, and tested against available data as good as possible. To ensure full generic applicability of the developed models, the conversion of mechanisms into differential equations can be and has to be conducted by applying the fundamental rules of chemical kinetics and physics. From the differential equations to practical models, useful for standard statistical analysis, is only a minor and easy step.

Of course, the selected mechanisms are most of the time massive simplifications of the real mechanisms at work. Selecting appropriate mechanisms for testing is therefore of utmost importance, but equally of utmost difficulty. These models provide information and knowledge about the evolution of properties and quality attributes and implement the use of completely different frameworks in preharvest and postharvest quality analyses [4].

Classification Postharvest storage models

Systems of modelling available today are primarily based on processes known or assumed to take place in the products. Many models are used with different pathogens to reduce fungicide application in crops such as pears, tropical fruits and vegetables. However, some models have been developed for other purposes such as those used in citrus to indicate residue levels, interaction between chemicals, and degree of sanitation needed in the packinghouse [1]. In general post-harvest storage systems are modelled based on one or more of the physical, chemical and biological phenomenon affecting the quality changes in the food material during storage [4]. These models can be deterministic, statistical or stochastic based on the modelling approach and/or data source. Figure 1 shows the general classification of post-harvest storage modelling.

Deterministic models

The resulting quality in the postharvest chain, is primarily generated during the growth of the agricultural commodity. However, quality attributes of interest for growing are not the same as for storage and consumption. As a consequence, it is not clearly known how storage and consumption quality is actually produced [5]. The fact that postharvest quality

attributes are ill defined during the growth phase and that no sufficient accurate measuring methods are available does not improve the situation. Appropriate properties can therefore not be studied directly: all growing fruits are hard and most of them are green at any stage of growth. The riddle must therefore be tackled in indirect ways. This is where deterministic simulation models are very useful.

NOMENCLATURE

DM	[mol/m^3]	Molar concentration of Dry Matter
E	[mol/m^3]	Molar concentration of Enzyme
SE	[mol/m^3]	Molar concentration of Enzyme Precursor
Ep	[mol/m^3]	Molar concentration of Inactive Enzyme Precursor
SEp	[mol/m^3]	Molar concentration of Active Enzyme Precursor
k_e	[mol/min]	Rate constant for Enzyme formation reaction
k_g	[mol/min]	Rate constant for Dry matter generation
k_{dg}	[mol/min]	Rate constant for Dry matter degeneration
k_{ep}	[mol/min]	Rate constant for Enzyme precursor formation
k_s	[mol/min]	Rate constant for Firmness decay
T	[K]	Temperature
t	[days]	Storage time
R_{thr}	[mol/m^3]	Molar concentration of Free Radicals
k_i	[mol/min]	Rate constant of influx of free radicals from photosynthesis and respiration
k_r	[mol/min]	Rate constant of scavenging
k_s	[mol/min]	Rate constant of chilling injury
Sc	[mol/m^3]	Molar concentration of scavengers
M	[mol/m^3]	Membrane Concentration
tm	[days]	Biological time
tm_{fix}	[days]	Biological time component - the same as actual time
tm_{var}	[days]	Biological time component - influenced by storage factors
k_v	[day^{-1}]	Number of tomatoes turning red per day
$Fruitnr$	-	Total number of tomatoes
a	[-]	Hunter a value
b	[-]	Hunter b value
H	[-]	Hue value of the tomatoes at time t
H_{mg}	[-]	Hue value of the mature green tomatoes storage
H_{rr}	[-]	Hue value of the red ripe tomatoes
H_0	[-]	Initial Hue value of the tomatoes taken for storage
α	[-]	[mm]
d	[mm]	Depth of Penetration of penetrometer

Figure 1: General classification of modelling of postharvest storage

Both agricultural and horticultural products can be handled either in large bulks or placed inside larger or smaller containers or packages. These handling and storage systems usually have vents that allow for the flow of cooling air to the produce. The cooling efficiency depends on the flow resistance that is induced by the container and the product as well as the distribution of macropores in the bulk [6-8]. Non-homogeneous flow of air inside the bulk may cause uneven cooling and resulting uneven product quality [9, 10]. Generally the transport phenomena (airflow, heat and mass transfer, etc.) during cooling of horticultural products are complex; mathematical models are recommended to better understand and design refrigerated as well as controlled atmospheric storage systems. An alternative potato model uses the production of volatiles in storage by potatoes to predict duration of safe storage.

As the macroscopic averaged properties obey the macroscopic equations, mathematical models are being extensively used in many desired areas to analyse or improve an existing process and design. Though it is a powerful technique to develop new designs, modelling techniques are usually computationally intensive. In the agro-food area, mathematical models are being used to optimise and develop equipment and operational strategies, and their use has grown exponentially over the last decade [1].

Mechanistic Models

Tijskens [11] modelled the postharvest quality as a function of the Preharvest Conditions. Their assumptions for the production of dry matter (DM) were
- DM is considered as the total of nutritional (sugars) and structural (cellulose, pectin) compounds.
- The accumulation of DM is catalysed by some enzyme (E) out of the daily made photosynthesis assimilates (reaction 1 in eq 1).
- The active enzyme is formed out of a limited amount of enzyme precursor (SE) by autocatalytic formation (reaction 2 in eq 1).
- The DM is concurrently converted into structural biopolymers like pectins and cellulose and consumed in maintenance and respiration reactions (reaction 3 in eq 1).

The resulting mechanism could look like eq. 1.

$$E \xrightarrow{k_g} DM + E$$
$$SE + E \xrightarrow{k_e} 2 \cdot E$$
$$DM + E \xrightarrow{k_{dg}} E \qquad (1)$$
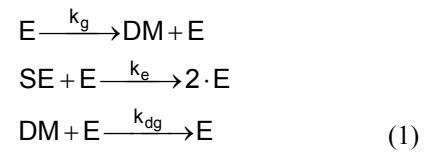
They converted this mechanism into a set of differential equations as shown in eq 2.

$$\frac{dE}{dt} = k_e \cdot E \cdot SE$$
$$\frac{dSE}{dt} = -k_e \cdot E \cdot SE$$
$$\frac{dDM}{dt} = k_g \cdot E - k_{dg} \cdot E \cdot DM \qquad (2)$$

A possible mechanism for the firmness (F) decay was also proposed by Tijskens [11], as the formation of an inactive enzyme precursor (Ep) during growth that is gradually converted into an active enzyme (E) during storage (eq 3) catalysing firmness (F) decay.
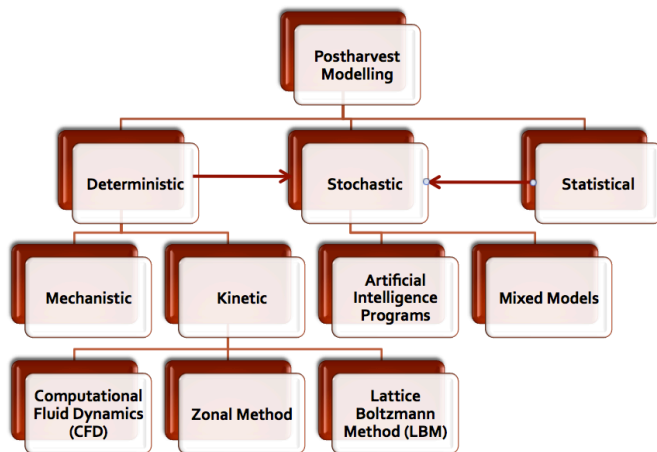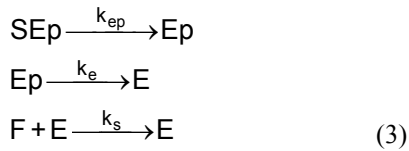
$$SEp \xrightarrow{k_{ep}} Ep$$
$$Ep \xrightarrow{k_e} E$$
$$F + E \xrightarrow{k_s} E \qquad (3)$$

The same general behaviour has been observed and described for accelerated firmness decrease in apples after prolonged CA storage as described by the equation 3 [12].

Radicals are generated in all living individuals, plant and animal, as an inherent part of respiration and photosynthesis. To prevent damage by accumulating free radicals, scavenging systems are present in all species. The occurrence and effects of chilling injury for bell peppers and cucumbers were modelled by Tijskens et al. [13] as a kind of deferred action, where the seeds of chilling injury were induced by free radicals during cold storage, which subsequently show up during post-storage shelf-life exposure.

The activity of this scavenging system, that is the specific rate constant of scavenging (k_r), multiplied by the molar concentration of the scavenging compounds (Sc) like e.g. antioxidants and specialised enzymes, almost certainly depends on the growing conditions and harvest maturity. In the case of bell peppers and cucumbers, it has been deduced that the threshold level of free radicals, that is the amount of free radical that just can be scavenged without doing damage, depends on this level of the scavenging system (eq 4).

$$R_{thr} = \frac{k_i}{k_r \cdot Sc - k_s \cdot M} \qquad (4)$$

where k_i is the rate constant of influx of free radicals from photosynthesis and respiration, k_r is the rate constant of scavenging, k_s the rate constant of formation of chilling injury, Sc is the level of available scavengers and M is the (constant) amount of membranes present. The larger the scavenging efficiency ($k_r \cdot Sc$) is the less free radicals (R_{thr}) can exert damage to the product.

Kinetic Models

Different modelling approaches have been proposed for predicting fluid flow, heat and mass transfer during cooling, storage, transportation and display of horticultural products. Three categories can be distinguished. A most common approach is computational fluid dynamics (CFD). In this method the appropriate geometry is discretised and the governing partial differential equations (Navier–Stokes equations) for conservation of mass, momentum and energy are solved [1, 3] on a discrete mesh on the geometry.

Usually a numerical method such as the finite volume method or the finite element method would be used for finding the solutions. Another popular approach is the zonal method, where the system is assumed to be a set of well mixed zones of homogeneous composition, and the representative partial differential equations are simplified as ordinary differential equations. These equations are used to describe mass and energy exchanges between zones. Finally, the third approach uses a relatively new class of computational techniques, namely the Lattice Boltzmann Method (LBM)[14,15].

In this model, instead of solving the macroscopic Navier–Stokes equations a certain volume of fluid is represented by a collection of fictive particles; during motion particles can collide on a regular lattice obeying the fundamental conservation laws [16]. LBM uses simplified kinetic models that incorporate the essential physics of microscopic processes so that the macroscopic averaged properties obey the desired laws. This is useful to build representative macroscopic equations. LBM is gaining interest as an alternative to expensive, difficult and demanding set of experiments as well as the CFD model for modelling post-harvest storage processes, due to its low computational power requirement and reasonable accuracy. Nonetheless the traditional CFD approach is the primary methodology of choice [17].

Packing houses and other essential players in the supply chain would benefit from simulation models evaluating potential investments in equipment and the adoption of procedures that improve quality levels by discarding defective items. The early removal of defective items would improve performance of the total supply chain by avoiding costs for handling, storage and transportation for defective items which are eventually discarded at some point in the supply chain. However, consistently higher prices for improved quality is needed before a business could be expected to invest in changes that reduced the amount of product shipped as a result of removing low quality items. A search of existing literature did not reveal any simulation models with adequate details of the post-harvest handling process to evaluate the feasibility of adding procedures or equipment for improved sorting of defective items.

Statistical Models

In general biological products have large variability especially within the sample population. Moreover, repeatability of the measurement is related to the measurement error induced by the equipment. Repeatability of the devices are usually defined as the standard error of mean of the multiple measurements on a single fruit divided by the mean firmness, multiplied by 100 (%). In general, variability below 10% indicate a good repeatability. Statistical models are usually empirical in nature and its accuracy generally depend on the size of sample population and the variance of the measured data. Therefore data based regression models are the most commonly used statistical models for post harvest operations.

For example, the colour of tomato changes during ripening according to a sigmoidal behaviour that frequently can be described by the statistically derived logistic function [18]. Each tomato however, has its own stage of development, expressed as biological time tm as given by (eq 5).

$$tm = tm_{fix} + tm_{var} \cdot e^{k_v \cdot Fruitnr} \qquad (5)$$

In a large dataset on truss tomatoes, the colour of tomatoes of two cultivars (Durinta and Clothilde) harvested at three development stages (green, breaker and ripe) was followed individually during storage. All data could be analysed together, only allowing for separate values for the time at harvest tm. The mean value of tm was of course highly correlated with the maturity stage at harvest: the later the harvest time, the higher the obtained tm value

Thorne and Segurajauregui Alvarez [19] applied a statistically derived logistic equation to the change of the ratio of Hunter values (a/b). Thai et al. [20] applied also the logistic equation to Hue values (tan-l(b/a)) but greatly improved the

model by application of an individual correction for biological age. Both authors, however, use the logarithmic transformation of the logistic function for Tomatoes.

Equation of Thorne et al. [19]

$$\ln\left(\frac{a/b - (a/b_{mg})}{(a/b)_{rr} - a/b}\right) = 4.54 + \frac{6.17 \cdot t}{27.5 - T} \tag{6}$$

Equation of Thai et al. [20]

$$\ln\left(\frac{H_{mg} - H}{H - H_{rr}}\right) = \ln\left(\frac{H_{mg} - H_0}{H_0 - H_{rr}}\right) + \alpha \cdot t \tag{7}$$

Many early attempts to evaluate the welfare impacts of postharvest research adopted a simple value of output model. The model used in these attempts relies on estimates of the expected change in output after the research impact and found the gains as this output change valued at the consumer commodity price. It can be readily shown that this model is a special case and implicitly makes assumptions which are, in most cases, not realistic. More importantly estimates found using this model are likely to over-estimate the research gains. Some evaluation studies still seem to adopt this simple model.

Stochastic Models

A comprehensive review of processes relevant to post-harvest handling systems was presented by Thai [21]. They pointed out the potential benefits of the systems approach to analyse post-harvest systems, and highlighted several characteristics of generic post-harvest systems. An issue related to post-harvest handling that has been largely ignored within the distribution channel is the damage to fruits or vegetables that is not apparent through immediate visual inspection [22, 23]. Damage is often latent, meaning that it will appear at some point in the system, such as in a retail outlet or consumer's home. Fruits with latent damage incur costs associated with transportation and handling in the system until the damage is detected and the produce discarded.The presence or absence of latent damage is highly stochastic due to differences in the product, position of items in a flow or container, temperature histories, and other handling conditions.

As compared to the models in literature, the utility of the model is greatly increased for application at a wider range in temperature and a wider range in initial maturity. Reliability of the parameter estimation is increased by application of non-linear regression techniques without transformation.

Decision Support Systems

The availability of experts and expertise in handling and storage of different types of grains, fresh fruits and vegetables is limited and there are a number of practical problems in applying one's expertise [24]. Furthermore, Jones [25] expressed the concern that various budget cuts may also affect the availability and quality of experts. It is, therefore, suggested that these problems can be alleviated with the development of computer systems which could be used to mimic the reasoning processes of experts [24-26]. Expert knowledge can be captured for use in the artificial intelligence tools, such as expert systems (ES), which can include knowledge from a variety of sources,

including, human experts, research results and government policy [27]. As computers are omnipresent these days, a decision support system can help in making decisions and may provide supervisory control ranging from a small house to a huge warehouse. No single approach for decision support system in this regard is proven satisfactory. Hence a synergistic combination of statistics and research developed models with a stochastic approach for the decision making process was tried and a prototype developed by Dev et al [28].

Decision support systems (DSS) are computer programs that contain the encoded knowledge of experts. This knowledge is contained in applications such as simulation models, expert systems, databases, or spreadsheets [27]. DSS are designed to automate data analysis and to perform complex decision-making through the use of human-like reasoning [29]. DSS can best be summarized as being a tool used "to increase the decision-making power of the human by providing easy access to useful data, information and knowledge" [30]. The architecture of DSS exposes the user to the decision-making process and the reasoning behind a decision. From the developers perspective, since knowledge is encoded in a straightforward fashion, it more easily allows for the discovery of weaknesses in the knowledge base and to better pinpoint areas where further research is needed [29]. Another spinoff from DSS development is that it brings researchers and producers together which increases the effectiveness of research and development [31]. Dev et al [32] developed a decision support system framework for post harvest handling and storage of fresh fruits and vegetables using a synergistic combination of stochastic and statistical approaches on pre-existing predictive models in the literature. and evaluated its effectiveness for the common green house tomato cultivar (Durintha). Figure 1 shows the conceptual framework of the DSS developed by Dev et al. [28] and Figure 3 shows the user input screen of the same DSS where the user can give subjective input.
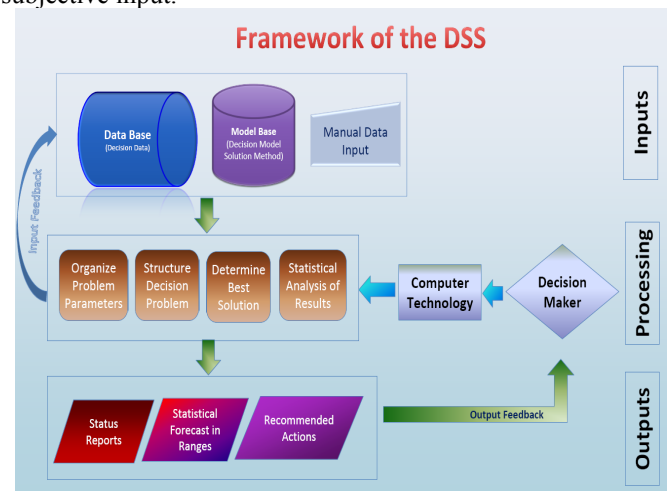

Figure 2 Framework of the DSS developed by developed by Dev et al [28].
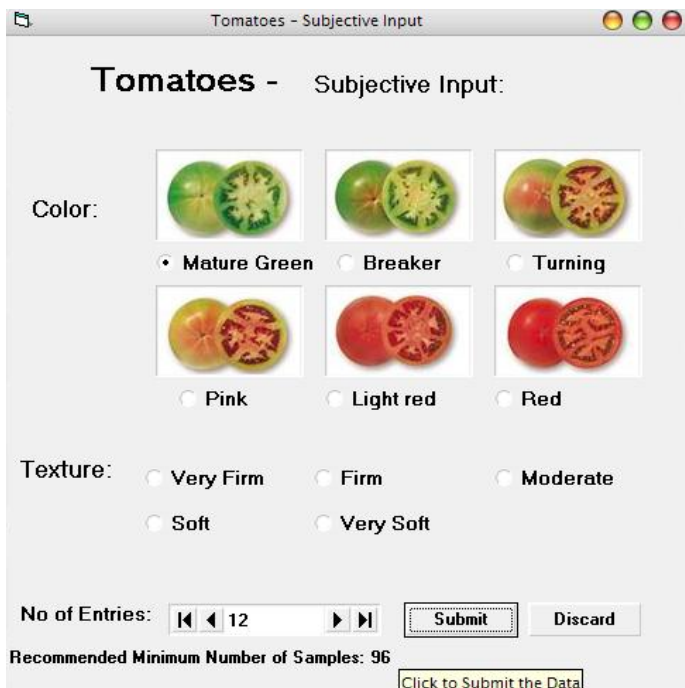
Product: **Mature GreenTomatoes**
Temperature: 18 - 24 *C / 64 - 75 *F
Relative Humidity: 42 - 70 %

You can Store Your Tomatoes for **6 - 8** Days Only

The Rec...
Product:
Tempera...
Relative
Days to I

Tomatoes – Subjective Input:

Color: Mature Green Breaker Turning

Pink Light red Red

Texture: Very Firm Firm Moderate
Soft Very Soft

No of Entries: 12 Submit Discard

Recommended Minimum Number of Samples: 96
Click to Submit the Data

Decisions and Recommendations

Based on the Information Supplied:
Product: **Mature GreenTomatoes**
Temperature: 18 - 24 *C / 64 - 75 *F
Relative Humidity: 42 - 70 %

You can Store Your Tomatoes for **6 - 8** Days Only

The Recommended Storage Conditions for Your Produce is:
Product: **Mature GreenTomatoes**
Temperature: 12.5 - 15 *C / 55 - 60 *F for 14 Days &
10 - 12.5 *C/ 50 - 55 *F thereafter
Relative Humidity: 85 - 95 %
Days to Keep: 21 - 25 Days

Figure 4 Output screenshot of the DSS [32]

$$\ln\left(\frac{}{(a_L/b_L)_{rr} - (a_L/b_L)}\right) = 4.54 + 6.17\frac{}{27.5 - T}$$

Figure 3 User interface for the DSS [26]

$(a_L/b_L), (a_L/b_L)_{mg}, (a_L/b_L)_{rr}$

The shelf life of the tomatoes were predicted using the change in colour and firmness during storage. For predicting the colour of tomatoes equation (6) [19] was used and for predicting the firmness equation (8) [33] was used

Converted values Obtained from the Points of Intersection

Thus a Decision Support System which can statistically analyse the subjective data from a sample population and predicted results and display the final result as a range instead of a single value will prove very effective and reliable. Figure 4 shows the output screenshot of the DSS [32].

CONCLUSION

There is a need to develop more holistic models for use in postharvest storage. Further development is also needed for specific models that operate in the field prior to harvest similar to those presently used. Instrumentation for the operation of these models and software needs to be kept up to date as disease control methods change. Furthermore these models should be extended to crops and diseases where they are now lacking. The example of the grain ecosystem model is the best example of how holistic postharvest storage models for other commodities should be designed. These models need to be developed with a full multidisciplinary compliment of researchers and thoroughly validated.
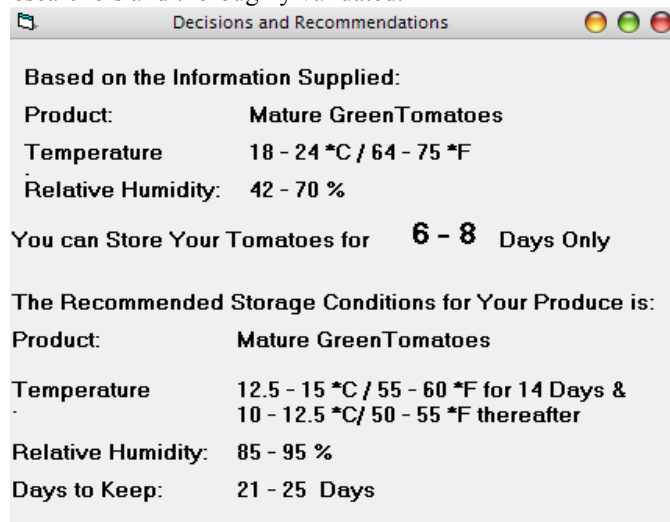
For extensive development and application of decision support systems, availability of established models itself is a big limiting factor. All the available Predictive Models used have their own limitations which in turn affect the precision of the results. Other storage conditions like Controlled and Modified atmospheric storage may be included in the calculations and recommendations.

It is clear that the application of statistics to model based decision support systems will bring out more reliable results than the ones with statistics. The recommended number of samples is based on the variance and standard deviation calculated from the available data. Also the greater the number of samples the better will be the accuracy.

REFERENCES

[1] Delele, M.A., Verboven, P., Ho, Q.T. and B.M. Nicolaï (2010). Advances in mathematical modelling of postharvest refrigeration processes. Stewart Postharvest Review, 2, 1-8

[2] Becker, B.R., Misra, A. and A.F. Brain . Bulk refrigeration of fruits and vegetables part 1: Theoretical considerations of heat and mass transfer. *HVAC & R Research* 1996, 9, 122-134

[3] Allais, I. and G. Alvarez Analysis of heat transfer during mist chilling of a packed bed of spheres simulating foodstuffs. J*ournal of Food Engineerin*g, 2001. 49, 37-47.

[4] Tijskens, L. M. M., and J. J. Polderdijk. "A Generic Model for Keeping Quality of Vegetable Produce During Storage and Distribution. *Agricultural Systems* 1996 51, no. 4 : 431..

[5] Alston, J M.. Research Benefits in a Multimarket Setting. *ACIAR ISNAR Project* Paper No 18, I*ndonesian Country Study*, July 1990.

[6] Delele, M.A., Schenk, A., Ramon, H., Nicolaï, B.M., Verboven, P. Evaluation of a chicory root cold store humidification system using computational fluid dynamics. *Journal of Food Engineering*, 2009, 94, 110-121.

[7] Delele, M.A., Schenk, A., Tijskens, E., Ramon, H., Nicolaï B.M. and P. Verboven . Optimization of the Humidification of Cold Stores

by Pressurized Water Atomizers based on a Multiscale CFD Model. *Journal of Food Engineering,* 2009, 91, 228-239.

[8] Delele, M.A., Tijskens, E, Atalay, T.A., Ho, Q.T., Ramon, H., Nicolaï, B.M. and P. Verboven. Combined discrete element and CFD modeling of airflow through random stacking of horticultural products in vented boxes. *Journal of Food Engineering*, 2008, 89, 33-41.

[9] Alvarez, G. and D. Flick (1999). Analysis of heterogeneous cooling of agricultural products inside bines. Part I: Aerodynamic study. *Journal of Food Engineering*, 39, 227-237.

[10] Alvarez, G. and D. Flick (2007). Modelling turbulent flow and heat transfer using macro-porous medium approach used to predict cooling kinetics of stacks of food products. *Journal of Food Engineering*, 80, 391-401.

[11] Tijskens, L.M.M.Quality modelling. *Acta Horticulture*, 2003, 604, pp. 123–136

[12] L.M.M Tijskens, E.P.H.M Schijvens, E.S.A Biekman, Modelling the change in colour of broccoli and green beans during blanching, *Innovative Food Science & Emerging Technologies*, Volume 2, Issue 4, December 2001, Pages 303-313

[13] Tijskens, L. M. M.; Otma, E. C.; Kooten, O. Photosystem II quantum yield as a measure of radical scavengers in chilling injury in cucumber fruits and bell peppers. *Planta*, 1994, 194, 4 Pp: 478 - 486

[14] R.G.M vanderSman. Lattice-Boltzmann scheme for natural convection in porous media. *International Journal of Modern Physics C*, 8, 4, 1997, pp. 879–888

[15] De Baerdemaeker, Josse; Nicolai, Bart; Delele, Mulugeta; Verboven, Pieter. Multiscale Modelling of Postharvest Storage of Fruit and Vegetables in a Plant Factory Context. *Proceedings of the IFAC World Congress,* 2011, Volume # 18, Università Cattolica del Sacro Cuore, Milano, Italy

[16] R.G.M vanderSman Solving the vent hole design problem for seed potato packages with the Lattice Boltzmann scheme. *International Journal of Comparative Fluid Dynamics*, 11, 3–4, 1999, pp. 237–248

[17] N.J. Smale, J. Moureh, G. Cortella, A review of numerical models of airflow in refrigerated food applications, *International Journal of Refrigeration*, Volume 29, Issue 6, September 2006, Pages 911-930

[18] L.M.M. Tijskens, R.G. Evelo, Modelling colour of tomatoes during postharvest storage, *Postharvest Biology and Technology*, Volume 4, Issues 1–2, April 1994, Pages 85-98

[19] S. Thorne, J.S. SegurajaureguiAlvarez. The effect of irregular storage temperatures on firmness and surface colour in tomatoes. *J. Sci. Food Agric.*, 33, 1982, pp. 671–676

[20] C.N. Thai, R.L. Shewfelt, J.C. Garner. Tomato colour changes under constant and variable storage temperatures: empirical models. *Transaction of ASAE*, 33 (1990), pp. 607–614

[21] C.N. Thai, Modeling quality attributes. R.L. Shewfelt, S.E. Prussia (Eds.), *Postharvest Handling: A Systems Approach*, Academic Press, San Diego (1993), pp. 167–185

[22] Judith A. Abbott, Quality measurement of fruits and vegetables, *Postharvest Biology and Technology*, Volume 15, Issue 3, March 1999, Pages 207-225

[23] Maria Eloisa G. Quintana and Robert E. Paull Mechanical Injury during Postharvest Handling of `Solo' Papaya Fruit. *Journal of the American Society for Horticultural Science*, September 1993 vol. 118 no. 5 618-622

[24] Richard A. Levins, Mark A. Varner, An expert diagnostic aid for reproductive problems in dairy cattle, *Computers and Electronics in Agriculture,* Volume 2, Issue 1, September 1987, Pages 47-56

[25] J.W. Jones, Using expert systems in agricultural models, *Agricultural Engineering*, 66 (7) (1985), pp. 21–23

[26]J.M. McKinion, H.E. Lemmon. Expert systems for agriculture. *Computers and Electronics in Agriculture*, 1 (1985), pp. 31–40

[27] Jim E. Greer, Sarah Falk, Ken J. Greer, Murray J. Bentham, Explaining and justifying recommendations in an agriculture decision support system, *Computers and Electronics in Agriculture*, Volume 11, Issues 2–3, November 1994, Pages 195-214

[28] Dev, S.R.S, G.S.V. Raghavan and Y. Gariépy. A Decision Support System for the Post harvest Handling and Storage of Fresh Fruits and Vegetables. *Presented at the NABEC Conference*, held Jul 30-Aug 2, 2006 in Montreal, QC, Canada.

[29] H.G. Allore, L.R. Jones, W.G. Merrill, P.A. Oltenacu, A Decision Support System for Evaluating Mastitis Information, *Journal of Dairy Science*, Volume 78, Issue 6, June 1995, Pages 1382-1398

[30] H.Michael Rauscher, Ecosystem management decision support for federal forests in the United States: A review, *Forest Ecology and Management*, Volume 114, Issues 2–3, 22 February 1999, Pages 173-197

[31] P.G. Cox, Some issues in the design of agricultural decision support systems, *Agricultural Systems*, Volume 52, Issues 2–3, October–November 1996, Pages 355-381

[32] Dev, S.R.S, V. Orsat, Y. Gariépy and G.S.V. Raghavan. Experimental validation of a stochastic statistical model based decision support system for postharvest storage of tomatoes. *Presented at the NABEC Conference*, held Halifax, NS, Canada, July 26-29, 2009

[33] Bart De Ketelaere, M. Scott Howarth, Leo Crezee, Jeroen Lammertyn, Karel Viaene, Inge Bulens, Josse De Baerdemaeker, Postharvest firmness changes as measured by acoustic and low-mass impact devices: a comparison of techniques, *Postharvest Biology and Technology*, Volume 41, Issue 3, September 2006, Pages 275-284