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Trends in Recent Studies on Post-Harvest Technology

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Abstract

Purpose: This article summarizes the trends in recent research publications in relation to post-harvest technology for drying, storage, and quality, between 2005 and 2015. **Methods:** As of September 7, 2015, a search query using two keywords, drying and agriculture, on the Web of Science (Registered trademark of Thomson Reuters) resulted in 3749 articles that were published between 2005 and 2015. However, the review was restricted to research articles published in the journals Transactions of the ASABE (American Society of Agricultural and Biological Engineers) and Biosystems Engineering: Journal of European Agricultural Engineering. **Results:** The total number of articles in the two journals related to drying, storage, and quality was 500, 319, and 885, respectively. The number of articles related to drying, storage, and quality was 250, 177, and 250, respectively, in Transactions of the ASABE. The number of articles related to drying, storage, and quality was 250, 142, and 283, respectively, in Biosystems Engineering. **Conclusions:** A shift in research focus from drying and storage to quality in Transactions of the ASABE might reflect a shift toward quality-conscious consumers. It seems that ASABE members are more focused on articles related to post-harvest technologies on quality than their European counterparts. Articles were cited based on their abstract content. Readers should read the full articles for more details.

Keywords: Drying, Post-harvest technology, Quality, Research trend, Storage

Introduction

There are many aspects of post-harvest technology, including drying, storage, processing, and quality assessment. Wikipedia (https://en.wikipedia.org/wiki/Postharvest) defines the post-harvest process as "In agriculture, postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product." This definition is particularly relevant for fruits and vegetables, and their respective post-harvest technologies. This article summarizes the trends in recent research publications in relation to post-harvest technology for drying, storage, and quality, between 2005 and 2015. The review is restricted to research articles published in the journals Transactions of the ASABE (American Society of Agricultural and Biological Engineers) and Biosystems Engineering: Journal of European Agricultural Engineering. As of September 7, 2015, a search query using two keywords, drying and agriculture, on the Web of Science (Registered trademark of Thomson Reuters) resulted in 3749 articles that were published between 2005 and 2015. Articles were cited based on the content of the abstract. Readers are encouraged to read entire articles based on their interest.

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General trend in the two major journals

Table 1 summarizes the articles published in the two journals for each category and subject. The total number of articles was 500 for drying, 319 for storage, and 885 for quality.

Table 1. Number of articles for each subjects in the two journals*

Journal	Category	Subject				
		Total	Grain	Vegetables	Fruits	Others
Transactions of the ASABE	Drying	250	62	6	15	167
	Storage	177	29	6	14	128
	Quality	602	41	13	52	496
Biosystems Engineering	Drying	250	47	9	20	174
	Storage	142	17	12	27	86
	Quality	283	31	17	55	180

*as of 7 September 2015

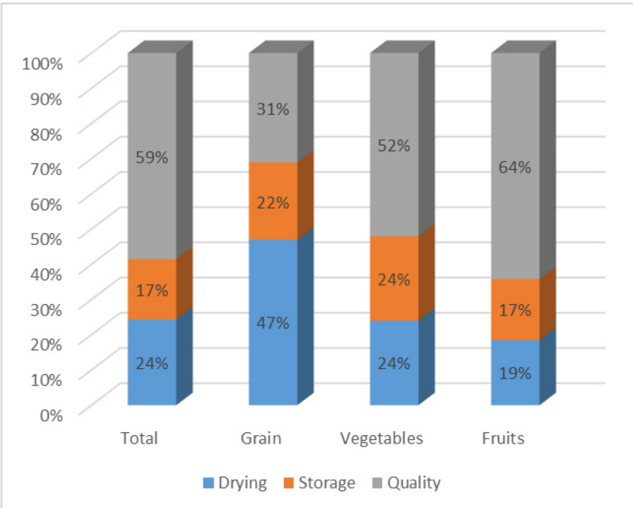

Figure 1. The ratio of subjects in the Transactions of the ASABE.

Transactions of the ASABE (American society of agricultural and biological engineers)

The total number of articles related to drying, storage, and quality in this journal was 250, 177, and 602, respectively. The first bar graph in Figure 1 shows the percentages of studies related to drying (24%), storage (17%), and quality (59%), which suggests a shift in research focus from drying and storage to quality, which might reflect a shift to quality-conscious consumers.

Among the 250 articles in the drying category, 62 articles focused on grain crops, 6 on vegetables, and 15 on fruits. Among the 177 articles in the storage category, 29 focused on grain crops, 6 on vegetables, and 14 on fruits. Among the 602 articles in the quality category, 41 focused on grain crops, 13 on vegetables, and 52 on fruits. The second, third, and fourth bar graphs in Figure 1 show the percentages of studies related to each subject area in each category.

Drying

Iqbal et al. (2015) measured airflow resistance as a function of airflow velocity for two types of chopped Miscanthus and observed that airflow resistance increases with an increase in airflow velocity, which is affected by bulk density (i.e., moisture content, particle size, and shape). The value of airflow resistance was between the ASABE standard values for ear and shelled corns (*Zea mays* L.).

Ward et al. (2013) investigated the design and fabrication of a sensor system to (1) measure the internal environment of grain bags, (2) apply the sensor system under field conditions, and (3) describe instrumentation considerations for grain bags. They concluded that in order to characterize the internal temperature of a grain bag, temperature measurements must be taken at a minimum of three depths: at the internal bag surface, within the peripheral temperature region, and within the core temperature region.

Pan et al. (2011) investigated the effect of drying bed thickness on drying characteristics and quality of rough rice (*Oryza sativa* L.) subjected to IR (Infrared) heating. They concluded that a high heating rate, fast drying, and good rice quality could be achieved by IR heating rough rice to about 60°C, followed by natural cooling with a maximum tested bed thickness of 10 mm. Ondier et al. (2010) measured the desorption isotherms of long-grain rough rice, with a moisture content of 20.6% (wet basis) and dried in a fluidized-bed system, at temperatures ranging from 60 to 90°C, and relative humidities ranging from 7 to 75%.

Bennett et al. (2007) evaluated the potential use of a combined heat and power (CHP) system that uses the combustion of corn stover to produce heat for drying and to generate electricity for fans, augers, and control components. They concluded from a sensitivity analysis that the cost of the CHP system is the most sensitive to fluctuations in fossil fuel costs, followed by the annual use of dryer equipment.

Bartosik et al. (2006) investigated the distribution of fine material in grain mass, and air velocity at the center and peripheral locations in the bin. The distribution of fine material and air velocity were quantified for 15 on-farm natural air / low temperature in-bin drying and conditioning tests. Sugiura et al. (2011) conducted a research on sweet potato (*Ipomoea batatas* L.) leaves, which are usually discarded as a byproduct of sweet potato production. They are used for animal feed, given their high polyphenol content. Since their use in animal feed requires preservation for several months, the research focused on the production of dried leaves. They reported that drying leaves with an airflow dryer at selected air temperatures resulted in substantial degradation of leaf polyphetzol content.

Isquierdo et al. (2013) investigated the effects of three dry bulb temperatures and three dew point temperatures of drying air on the drying kinetics and sensory quality of coffee (*Coffea arabica* L.). They concluded that the modified Midilli and successive residue models best describe the drying process. Shih et al. (2008) studied sequential infrared and freeze-drying (SIPFD) as a new method for producing high-quality, crispy fruit pieces at a reduced cost. They investigated the drying characteristics of strawberry (*Fragaria x ananassa* Duchesne) slices and the quality of the finished products under SIPFD.

Storage

Jian et al. (2014) investigated the heat production of canola (*Brassica rapa* L.) seeds at a moisture content of 14%. The seeds were dried using a transient method at 30°C and 20°C under airtight and non-airtight storage conditions, respectively. They observed that the measured heat production ratios were higher than or equal to theoretical values when only glucose was used as a substrate for decomposition. Lawrence et al. (2013) developed a three-dimensional transient heat, mass, momentum, and species transfer model for a stored-grain ecosystem by using the finite element method. Hourly weather data, such as ambient temperature, relative humidity, solar radiation, and wind speed, were included in the model. They concluded that the Crank-Nicolson time discretization scheme was the best among the four schemes compared.

Lawrence et al. (2011) developed a model by using energy and mass balance principles to predict the temperature and relative humidity of headspace air in a partially filled silo. They concluded that the model was sufficiently accurate and reliable to predict air temperature and relative humidity at multiple locations in the headspace region of a grain storage silo. Ragni et al. (2007) investigated the possibility of nondestructively predicting the basic quality parameters of shell eggs by using an open-ended coaxial probe dielectric measurement technique. They observed that the best frequency band for prediction ranged from 10 to 700 MHz. Ortiz et al. (2014) studied the effect of variety and storage conditions on the resistance of citrus to impact damage and observed that, to increase citrus whole fruit compression and peel puncture resistance, a low temperature and a high relative humidity should be used.

Quality

Wang et al. (2009) studied the effects of heating and storage conditions on the content of capsaicin and dihydrocapsaicin in chili pepper powder, with pungent components assayed by HPLC. They concluded that capsaicin and dihydrocapsaicin had very similar stability and showed similar reduction rates during heating and storage. These results indicate that the C=C bond in capsaicin is relatively stable and does not account for its decomposition during heating and storage. Dilawari et al. (2013) investigated the applicability of machine vision techniques to grade canola. They reported that machine vision techniques had the potential to discriminate between samples with different amounts of total dockage. However, they also reported that a model based on color information alone would not give accurate results.

Meng et al. (2013) investigated the possible application of medium-resolution imaging spectrometer, which is one of the payloads on EN VISA T, for fast measurement and monitoring of crop N status at regional to global scales. They concluded that their results would contribute toward improving N fertilizer usage by mapping large area winter wheat (*Triticum aestivum* L.) N status. Bautista et al. (2009) investigated the quantification of the effects of rice kernel properties associated with kernel moisture content distribution on milling quality as harvest moisture varied. They concluded that the optimal moisture content ranged from 18 to 22%, 19.0 to 20.4%, and 17.7 to 19.0% for long-grain rice cultivars, medium-grain Bengal rice, and long-grain rice hybrid XP723, respectively.

Pan et al. (2007) evaluated the effect of milling conditions on the milling quality of medium grain rough rice cultivar M202. They concluded that the milling quality of M202 can be predicted using nonlinear regression models, when milling and polishing conditions are known. Wang et al. (2014) estimated the light absorption coefficient mu(a), reduced scattering coefficient mu(s)', and scattering anisotropy (g) of onion (*Allium cepa* L.) tissues in the wavelength ranges of 550-880 nm and 950-1650 nm. They concluded that it is feasible to detect diseased onions by investigating their optical characteristics. They also reported that the measured optical properties of healthy and diseased onion tissues could be used in theoretical modeling and simulations of light-onion interactions to develop quality inspection systems for onions.

Nelson et al. (2006) studied possible correlations between the dielectric properties (dielectric constant and loss factor) and soluble solid (sweetness) content (SSC) of honeydew melons (*Cucumis melo*) for nondestructive sensing of maturity. The honeydew melons were grown and harvested with a range of maturities for measuring tissue permittivities. They observed that SSC could be calculated from permittivity values, independent of tissue density and moisture content. Chiu et al. (2015) studied the detection of bruised areas in Golden Delicious apples (*Malus domestica*) caused by mechanical impact by using chlorophyll fluorescence imagery. They concluded that fluoroscopic examination system for bruises could detect bruises accurately before the bruises were visible to the naked eye.

Xu et al. (2014) attempted to develop a volume measurement system for watermelons (*Citrullus lanatus*), using the principle of Helmholtz resonance, to determine the density of watermelons and classify normal and hollow watermelons. They confirmed that Helmholtz resonance has the potential for measuring the volume and internal quality of watermelon. Pan et al. (2012) investigated the heating uniformity and quality of coffee beans by using radio frequency (RF) treatments for postharvest disinfestations. They observed that RF treatments, combined with forced hot air at 48°C for 10 min, followed by forced room air cooling through a 3 cm product layer, provided good bean quality.

Guidetti et al. (2010) investigated a portable optical experimental system (Vis/NIR spectrophotometer) for nondestructive and quick prediction of ripening parameters of fresh berries and homogenized grape samples (*Vitis* spp.) in the wavelength range of 450-980 nm. They reported that the Vis/NIR portable device could be used in the wine industry for rapid assessment of grape ripeness directly in the field or upon receipt of grape shipments.

Gomez et al. (2007) investigated the use of an electronic nose (E-nose) device to monitor changes in mandarin (*Citrus reticulata*) at different picking dates. They used a specific E-nose device (PEN2) for evaluating the quality attributes of mandarin, such as firmness, soluble solids content, and acidity, and concluded that the E-nose device provides reasonably accurate predictions.

Biosystems engineering: journal of European agricultural engineering

The number of articles related to drying, storage, and quality in the journal was 250, 142, and 283, respectively. The first bar graph in Figure 2 shows the percentages of studies related to drying (37%), storage (21%), and quality (42%), respectively. A comparison of Figures 1 and 2 shows that ASABE members are more focused on post-harvest technologies regarding quality than their European counterparts. A total of 59% of ASABE articles were quality-related, while only 42% of Biosystems Engineering articles focused on quality.

Among the 250 articles in the drying category, 47 pertained to grain, 9 to vegetables, and 20 to fruits. Among the 142 articles in the storage category, 17 pertained to grain, 12 to vegetables, and 27 to fruits. Among the 283 articles in the quality category, 31 pertained to grain, 17 to vegetables, and 55 to fruits. The second, third, and fourth bar graphs in Figure 2 show the percentage of

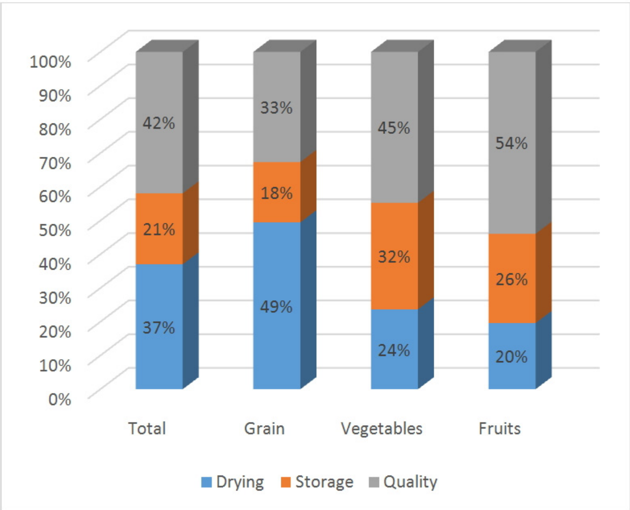

Figure 2. The ratio of subjects in the Biosystems Engineering.

studies related to each subject area in each category.

We summarize a few studies below:

Drying

Jokiniemi et al. (2014) investigated energy savings achieved at elevated drying air temperatures. In addition, they investigated energy savings achieved by manipulating drying airflow in a scaled-down mixed-flow batch grain dryer. The drying airflow was reduced gradually as the drying process proceeded, and the air temperature was allowed to rise. The relative humidity of the exhaust air was used as a control factor to adjust the airflow. Energy savings were expected at a higher air temperature and, because of the reduced airflow, at a higher exhaust air humidity. They reported energy savings of 5% for drying barley (*Hordeum vulgare* L.) and 14% for drying oats (*Avena sativa* L.). They also concluded that further research was required to determine the correct control parameters and temperature limits for each cereal species.

Khatchatourian et al. (2012) conducted a thin-layer drying experiment for soybean (*Glycine max* L.) in the temperature range of 45-120°C, velocity range of 0-3 m s-1, initial grain moisture content 0.13-0.32 dec., d.b. (dry basis) with 5-50% relative air humidity. They derived a thin-layer drying model consisting of two ordinary differential equations, which considered the influence of all the parameters studied and satisfactorily described all the experimental data.

Martinello et al. (2010) investigated two operational modes for low temperature drying of maize, produced in a typical location in Argentina. The operational modes were evaluated by simulation: (1) ambient drying, which operates by drawing air, using fans located downstream of the grain bed and (2) near-ambient drying, which, by blowing air upstream of the grain bed, takes advantage of air temperature rise through the fan. A maximum reduction in energy consumption of 30% was predicted for the near-ambient mode compared to the ambient mode, and approximately a 12% reduction in drying time.

Ghosh et al. (2008) developed a three-dimensional simultaneous heat and moisture transfer drying model for single wheat kernels. Model-predicted moisture data were compared with the results obtained from MR images, under similar drying conditions. Sampaio et al. (2007) developed a new dryer model for coffee. They observed that coffee dried with the new drying system had a high cup quality, and was classified as types 4 and 6 for natural and parchment coffee, respectively. Soysal et al. (2006) investigated parsley (*Petroselinum crispum*) leaves dried in a 900 W 2450 MHz domestic microwave oven in order to assess the effects of material load on drying time, drying rate, drying efficiency, and specific energy consumption. They reported that the value of the drying coefficient k decreased as dried material load increased.

Trivittayasil et al. (2014) studied the optimal trade-off between a fungal decay reduction and fig (*Ficus* spp.) quality. They observed that, at the lowest heating treatment group of 50°C, fungal development was achieved without significant heat injury. Janjai et al. (2008) developed a two-dimensional finite element model to simulate moisture diffusion in mango (*Mangifera* spp.) fruit during drying. They concluded that this model can be used to provide information on the dynamics of moisture movement without the need for measurements. In addition, the model can also be used to provide data to design dryers.

Storage

Arias Barreto et al. (2013) validated a mathematical model that was used to analyze grain storage conditions and determine the change in CO_2 concentration in a silo bag. The bag contained wheat from summer to winter for a typical productive region with sub-tropical, intermediate, and temperate weather conditions in Argentina. They estimated the mean dry matter loss for all storage conditions, which were compared with the critical limit for safe storage of grain and seeds. Dry matter loss did not exceed limits that would reduce commercial quality, although seeds could be affected when stored wet and during summer.

Khatchatourian et al. (2006) developed a mathematical model, an algorithm, and a software for simulating airflow and heat transfer, in aerated soybean storage under nonuniform conditions, to predict seed mass. They adapted this method for a variable section deep bed, tested the method on experimental data, and used it for modeling the thermal state of silos. Jiao et al. (2012) used a validated computer simulation model to investigate low-pressure treatment in order to determine the thickness of foam insulation required to cover hypobaric chamber walls. The goal was to stabilize the air temperature within hypobaric chambers that were housed in a cold storage room with fluctuating air temperature. The results showed that the added foam maintained the temperature variation of the hypobaric chamber wall within +/- 0.2°C, and that of the inside air within +/- 0.1°C.

Jo et al. (2013) constructed a fresh produce container system consisting of a gas diffusion tube or perforation aperture that responded to real time measured concentrations of O_2 and CO_2. They concluded that the prototype system for spinach (*Spinacia oleracea* L.) was effective in maintaining the beneficial modified atmosphere (8-9% O_2 and 10% CO_2) under both constant and varying temperatures, and thus, contributed to quality preservation. Tefera et al. (2007) studied mango (*Mangifera indica* L.) fruit at Dire Dawa, Ethiopia over a storage period of 28 days. Mango fruits were assessed for physiological weight loss (PWL), total soluble solids, titratable acidity, ascorbic acid, and marketability. They concluded that the benefits of the combined effects of postharvest treatments on mangoes included reduction in PWL, maintenance of better chemical quality, and improvement in the shelf life of mangoes.

Quality

Valiente-Gonzalez et al. (2014) investigated the design of a computer vision system that automatically evaluates the quality of corn lots, and they concluded that the method is promising as it showed a success rate of 92%. However, modifications were recommended to further improve results. Neethirajan et al. (2010) developed a CO_2 sensor, using a polyaniline boronic acid conducting polymer as the electrically conductive region of the sensor. The sensor was demonstrated as useful in detecting incipient or ongoing spoilage in stored grain. They concluded that the conducting polymer CO_2 sensor was effective, in terms of recovery time, sensitivity, selectivity, stability and response slope, when exposed to various CO_2 levels inside simulated grain bulk conditions.

Mahesh et al. (2008) investigated a near-infrared hyperspectral imaging system in order to develop classification models to differentiate wheat classes grown in western Canada. They concluded that the overall classification accuracies of 60% training, 30% testing, and 10% validation (referred to as 60-30-10), and 70% training, 20% testing, and 10% validation (referred to as 70-20-10) ANN models were above 90% for independent validation sets, using a three-layer standard and Wardnet back propagation neural network architectures. Tong et al. (2013) investigated a vision system to measure the leaf area in each cell to distinguish "bad" and "good" plugs and showed that this system of identifying seedling quality was suitable for application in automated transplanters.

Arana et al. (2005) stored samples of Fairlane and Festina nectarines, and they classified the fruits as suitable or not for the market on the basis of sensory woolliness degree. They established a correlation between woolliness and other factors such as storage time and cultivar.

Sanchez et al. (2014) investigated the applicability of near infrared reflectance spectroscopy (NIRS) technology for nondestructive measurement of melon-pulp color (a*, b*, C*, and h*), one of the main indicators of ripeness and quality. They concluded that NIRS technology is a promising tool for monitoring ripening in melons, and thus, to establish an optimal harvesting time. Cubero et al. (2014) investigated the image analysis: (1) to develop a fast and accurate method for detecting and removing pedicel in berry images, and (2) to accurately determine the size and weight of the berry. They concluded that the image analysis methodology may be easily implemented in automated inspection systems in order to accurately estimate the weight of a wide range of fruits, including wine grapes.

Abbaszadeh et al. (2013) investigated a non-destructive method for detecting the flesh texture quality of watermelons, which can be used as a ripeness indicator for sorting fruits. They showed that stepwise multiple linear regression (SMLR) models on a phase spectrum were better than other models and concluded that they can be applied to predict the quality of watermelons in industrial grading systems. Kriston-Vizi et al. (2008) investigated the use of visible imaging systems to monitor water stress on satsuma mandarin and peach (*Prunus persica*) in southwestern Japan. They found a moderately good correlation between red reflectance and leaf water potential, and between green reflectance and leaf water potential.

Kavdir et al. (2008) used parametric and non-parametric classifiers in order to classify Golden Delicious apples into three quality classes based on features such as hue angle (for color), shape defect, circumference, firmness, weight, blush percentage (red natural spots on the surface of the apple), russet (natural netlike formation on the surface of an apple), bruise content, and numerous natural defects. Some improvements were observed in separating the apples into three quality classes based on four to nine principal components, although some overlaps still existed among the classes.

Lleo et al. (2007) studied Microwave (MW) spectroscopy as an internal-quality estimating technique for peaches to establish the feasibility of MW measurements for firmness and sugar estimation. They showed that multiple linear regression models, based on return loss and reflectance variables, were not robust. They identified unstable coefficients. The most significant independent variable for estimating peach firmness is always the reflectance at 680 nm.

Conclusions

This review summarized the trends in recent studies on three categories of post-harvest technology, i.e., drying, storage, and quality, between 2005 and 2015 for two major journals: Transactions of the ASABE (American Society of Agricultural and Biological Engineers) and Biosystems Engineering: Journal of European Agricultural Engineering. The total number of articles in both the journals for drying, storage, and quality was 500, 319, and 885, respectively. The articles were cited based on their abstract content. Thus, readers should read the full articles for more details.

Conflict of Interest

The author have no conflicting financial or other interests.

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