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A New Method to Quantify Postharvest Quality Loss of Cucumber using the Taguchi Approach

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Abstract
One-third of global food produced for human consumption, which amounts to about 1.3 billion tons is lost or wasted annually. A clear pathway to ensure the availability of food and alleviating poverty is to minimize the postharvest losses (PHL). Measuring these losses is an essential operational strategy to enhance postharvest management and to curtail quality loss of fresh horticultural commodities. At the present time, the literature does not offer any methodology for an effective and reliable measurement of postharvest losses of fresh produce. The aim of this study was to use the Taguchi approach to quantify postharvest quality loss of cucumber as affected by environmental factors (temperature, light, humidity) over time. The experimental design included the 4 three-level factors and an L-9 orthogonal array. The Taguchi loss function was used to quantify quality loss of fresh cucumber after each storage combination. The results revealed that fresh cucumber lost some of its quality attributes as early as immediately after harvesting. At firmness of 15.68 N, the loss was equivalent to 13.68 units. However, at 7.68 N firmness, the loss value was increased by almost 4 times (56.98 units). In terms of quality index, it was noticed that even when the score was high (QI = 9 points), the produce had lost 8.74 units of its quality. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant. When the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). The results showed how large the extent of loss could be when fresh cucumber is stored under undesirable conditions. The percent influence of studied factors on each quality attribute was also determined. For the overall quality, 46.5% of loss was due to time, followed by 18% due to temperature and 11.5% due equally to light and humidity. Finally, using a measure of goodness-of-fit of linear regression, Taguchi predictions fitted the observed data. This confirmed the ability of the Taguchi technique to predict postharvest quality loss of fresh produce in response to different combinations of factors and their levels.
Keywords: Cucumber, postharvest, quality management, loss function, Taguchi approach, quantification.

1. Introduction

Cucumber fruit (*Cucumis sativus* L.) belongs to the Cucurbitaceae plant family that can be cultivated in subtropical and tropical environments; therefore, they are native to many countries of the world (Gross et al. 2014; Ismail et al. 2010). Fresh consumption of this crop provides a variety of health benefits including valuable antioxidant, anti-inflammatory, and anti-cancer benefits (Mukherjee et al. 2013). According to FAO statistics, the global production of cucumber was 65 million tonnes in 2012 grown in an area of 2,109,650 ha (FAOSTAT, 2013). Cucumber is highly perishable crop and the environmental conditions under which cucumber is produced, transported and displayed have a significant effect on the keeping quality of this food and the amount that is lost.

The major environmental influences that change the quality of cucumber include temperature, relative humidity and light (Luning and Marcelis, 2009; Shin et al. 2007). The main quality issues in cucumber during postharvest handling are mainly fruit discoloration due to loss of chlorophyll pigments, shrivelling or wilting caused by loss of moisture which affects the firmness of the produce and physiological deterioration due to undesirable temperature (Manjunatha and Anurag, 2014). Storage of cucumber at low temperature (10ºC) was shown to induce chilling injuries (Dhall et al. 2012; Zhang et al. 2015). Other research studies have shown that for each increase of 10ºC, the rate of degradation will increase by 2 to 3 times (Kader, 2002). Relative humidity is another environmental factor that can cause serious losses of the fresh commodity (Hung et al. 2011). Laurin et al. (2005) revealed that the storage of Beit Alpha cucumber under undesirable humidity results not only in direct quantitative losses (weight loss) but also qualitative losses such as wilting, shrivelling and softening. Light is also one of the most important factors affecting the phytonutrient content in many plant products that are rich in antioxidants (such as cucumber). It can cause harmful effects on produce quality (Alcock and Bertling, 2013;

Xiao et al. 2014). Depending on the cultivar, high quality cucumber fruit should be dark green and firm with no wrinkled ends (Gross et al. 2014). The suggested conditions for commercial storage of fresh-market cucumber are for less than 14 days at 10 to 12^{o}C and 95% RH (Florkowski et al. 2014; Gross et al. 2014).

Currently there is no methodology for the effective and reliable measurement of postharvest losses of fresh produce. Not much progress has been made in this direction. During the past 30 to 40 years, research investigations were focused on developing technologies to increase the productivity of food and only few researchers were engaged in minimizing postharvest losses (Aulakh and Regmi, 2013; Buzby et al. 2009). This is mainly due to problems related to the complexity of the concept of postharvest loss, the absence of reliable and accurate data on postharvest losses, major gaps in the knowledge of measuring these losses and the multiple definitions of quality loss (Hodges et al. 2011). For many researchers, estimating postharvest losses was not following a holistic approach. Most of the studies have focused on measuring the losses only at the storage steps without incorporating other important stages along the supply chain (such as grading, packaging, transporting and processing), which can also contribute largely to postharvest losses (Aulakh and Regmi, 2013; Van Dijk and Trienekens, 2012). Existing methods to estimate postharvest losses are mainly Food and Agriculture Organization of the United Nations (FAO) initiatives and based on surveys especially in developing countries (Aulakh and Regmi, 2013; FAO, 2007, 2014; Koester, 2013). In addition, recent studies were undertaken by the FAO to estimate food losses using FAO's Food Balance Model (FBM), where food loss is calculated based on the principles of mass flow ($mass_{in} = mass_{out}$) through the value chain process (Gustavsson et al. 2011). In order to quantify these losses, this model uses the pre-set "conversion factor" for each crop, which determines the part of agricultural products that is edible, and multiply it by the loss percentage in each step of the food supply chain. However these losses have relied on assumptions and estimations; therefore, this is considered a huge "gap" in the knowledge of measuring postharvest losses.

The Taguchi approach has been successfully used by researchers in various subject areas including environmental sciences (Sadeghi et al. 2012), food engineering (Oztop et al. 2007), biotechnology (Trabelsi et al. 2006), aerospace (Singaravelu et al. 2009), sports (Burton et al. 2010), construction (Tukmen et al. 2008), energy (Zeng et al. 2010) and many others. This approach was applied as a valuable statistical tool to determine the optimum parameters of a production process and to quantify the quality loss of a manufactured product (Dingal et al. 2008; Ross, 1996). However, to the best of our knowledge, no application of this approach to postharvest technology has been reported until the present time. Considered as a pioneer in quality management, Genichi Taguchi has combined engineering and statistical methods in order to quantify commodity loss and improve its quality (Luning and Marcelis, 2009; Ross, 1996; Taguchi, 1993). For this, Taguchi proposed a mathematical formula called the "quadratic loss function". He stated that maintaining the high quality of a commodity would require reducing variations around a "target" by achieving consistency of performance (Roy, 2001). As long as quality deviates from the target specifications, there is "loss". This opposes conventional methods for quality management where product quality is only defined as "bad" or "good" and as long as the product lies within its specification limits, there is no "loss" (Emadi et al. 2008; Oztop et al. 2007). In this research study, Taguchi approach was expected to help with the identification of the most influenced environmental factors on the product quality, to provide a robust and consistent method to measure the most unseen quality losses during postharvest handling of fresh crops and to minimize the variation in product response caused by environmental factors while keeping the mean response close to target.

2. Objectives

The objectives of this work were: (1) to quantify postharvest quality loss of freshly harvested cucumber using the Taguchi approach, and (2) to predict intrinsic quality attributes as affected by environmental or uncontrollable factors as the produce moved from farm to fork.

3. Materials and methods

3.1 Plant material and storage simulation

Built on a rooftop, Lufa Farms, a local supplier in Montreal, Canada, provided year-round fruits and vegetables grown in a commercial large-scale agriculture greenhouse. Right after harvesting, fresh cucumbers were labeled and separated into experimental units of similar quantity. A storage simulation experiment was carried out afterwards in controlled environment chambers (Conviron Inc.) to evaluate the postharvest quality of fresh produce stored at different conditions of temperature (T), relative humidity (RH) and light according to the Taguchi design. With an internal capacity of 78 ft^3, the chambers were fully programmable to monitor the set factors without the need for constant adjustment. Specially designed to provide a temperature range between 10 and 45^{0}C, airflow inside the unit was distributed uniformly upward using an air distribution plenum (Conviron, 2014) that allowed up to 20 ft^3/min of air exchange. Using fluorescent and incandescent lamps, the light intensity reached up to 875 micromoles/m^2/s or 64750 lux, which is a typical average of light intensity during a sunny day.

3.2 Experimental design

A Taguchi experimental design was developed and carried out using the JMP v.11 statistical software. Since the Taguchi technique is a form of a "design of experiment" (DOE), the first step in this experiment was to select the key environmental factors along with their levels. These factors were responsible for causing variability around the quality target of cucumbers fruits along the supply process. For the purpose of this study, four factors including storage temperature (^{o}C), storage time (days), exposure to direct light related to the presence or absence of luminosity during 12hrs/day and relative humidity (%) were selected as demonstrated in Table 1. Those factors and their equivalent levels were selected based on other studies conducted by the authors in the Caribbean. According to the Taguchi design, an experiment involving 4 three-level factors and an L-9 orthogonal array was suggested. A full factorial experimental design gives $3^4 = 81$ possible combinations or experimental trials. Using fractional factorial in the Taguchi approach, only 9 experiments with different combinations were needed and conducted as shown in Table 2. To seek out the best combinations of factors/levels among the many alternatives, the JMP statistical software was used. The entire experiment was conducted in three replicates.

3.3 Quality loss function

As mentioned earlier, the loss function is a statistical tool that Taguchi developed to measure the quality loss of a commodity caused to a society when its leaves the production. In this work, loss function was used to measure the quality loss of fresh cucumber after harvesting. Quality attributes for cucumber, such as weight loss and total color difference, have "smaller the better (SB)" quality characteristics since the reduction of postharvest loss is greater when the produce still maintains its fresh color and loses less moisture during handling. However, quality parameters like firmness and quality index were best desired to have "larger the better (LB)" type of measurement because the consumer will always prefer to purchase a firmer and higher quality cucumber. Therefore, the mathematical formulas proposed by Taguchi (Ross, 1996; Taguchi, 1993) were as follow (Eq. 1 and 2):

$$L = k_L\left(y\right)^2 \text{ for smaller the better target} \quad (1)$$

$$L = k_L\left(\frac{1}{y}\right)^2 \text{ for larger the better target} \quad (2)$$

where *"k_L"* is the proportionality constant and *"y"* is the studied quality attribute (color difference, firmness, quality index or weight loss).

In all his work, Taguchi expressed the loss in monetary terms. However, for the purpose of this study, the word "*loss*" means the loss of quality and is expressed in unit scale. Using linear interpolation analysis with a minimum value of 1 and maximum value of 100, calculated values were plotted against $(1/y)^2$ and $(y)^2$ separately and the value of k_L (slope in this case) was determined from each plot. The quality loss was then calculated for any value of "y" based on the constant value of "k_L".

3.4 Percent influence

An analysis of variance was conducted using the JMP v.11 statistical software. It was necessary to determine how much influence each environmental factor caused on the quality attributes of the studied cucumber. This analysis is normally called a percent influence (P_i). The percent influence is a function of sum of squares for each factor (Ross, 1996). It was used as an indicator of the power of each factor to increase or decrease variability around the target (Ross, 1996). The total and factor sum of squares were the fundamental calculations computed by ANOVA. The percent influence (P_i) of each factor on the quality was then calculated based on the following formula (Ross, 1996; Sadeghi et al. 2012):

$$P_i = \frac{S_F - \left(V_e \times f_F\right)}{S_T} \times 100 \quad (3)$$

where S_F is the sum of squares of a particular factor, V_e is the variance for the error term, f_F is the degree of freedom of a particular factor and S_T is the total sum of squares of all factors.

3.5 Quality evaluation

Quality is an important factor in the production and marketing of horticultural products. When evaluating quality, several methods can play an important role, but the only accurate test of quality is the feedback of the buyer. For cucumber, consumers look at several quality parameters, such as good external appearance known also as quality index, color, firmness, and weight loss, before making the decision to purchase. Both initial (used as control) and final qualities after each storage combination were evaluated.

The quality index (QI) for individual produce was assessed for the parameters of symptoms of deterioration and limits of marketability using a nine point hedonic scale. A quality index (Table 3) for cucumber summarizing all these parameters was determined and the total score for each parameter was calculated.

The color of studied samples was expressed in CIELAB color space using a Minolta Spectrophotometer (CM-3500d, Japan) where L* defines lightness, a* describes the red/green coordinate and b* the yellow/blue value. The equipment was calibrated against standard ceramic white and black tiles. The total color difference (ΔE) was stated as a single value using the following equation:

$$\Delta E = \sqrt{\left(\Delta L^2\right)+\left(\Delta a^2\right)+\left(\Delta b^2\right)} \tag{4}$$

where $\Delta L=L^*-L^*_o$; $\Delta a=a^*-a^*_o$; $\Delta b=b^*-b^*_o$; and the $L^*_o a^*_o b^*_o$ values were defined as the initial color values of the freshly harvested produce. Triplicate readings were taken for each of the individual samples to obtain a better representation of its color.

Weight loss *(WL)*, another important quality attribute, was quantified using the formula:

$$WL = 100\times\left(W_i - W_f\right)/W_i \tag{5}$$

where W_i and W_f were the initial and the final weight of the produce calculated before and after treatment.

Firmness or texture evaluation was measured using the Instron Universal Testing Machine (Model 4502, Instron, Canton, MA, USA). A compression test was carried out with 5 mm diameter probe, a crosshead speed of 5 mm/min and a maximum load cell of 50N. For each replicate of the experiment, a total of three readings were acquired for every sample and an averaged firmness was registered.

4. Results and discussion

4.1 Quantification of quality loss

The first step in quantifying the quality loss was to calculate the proportionality constant "k_L" for different quality attributes. Table 4 shows the relationship between calculated values obtained by interpolation and values of $(1/y)^2$ and $(y)^2$ and their losses for LB and SB respectively. As seen, the coefficient of determination R^2 is close to 1 for all quality attributes indicating that the regression line perfectly fits the observed data. Values of the constant "k_L" were then determined which corresponds to the slope in each linear equation. For firmness and quality index, values of "k_L" were 3363.80 and 708.09, respectively whereas for weight and color, they were 0.04 and 0.12, respectively.

Substituting "k_L" values in equations 1 and 2, the quantity of loss was then found for all quality parameters in all 9 experiments used in the Taguchi design as demonstrated in Table 5 and illustrated in Figure 1. The results revealed that even at the very early stages after harvesting (test 1), the fresh cucumber had lost some of its quality, mainly in terms of firmness (loss = 13.68 units) and quality index (loss = 8.74 units). This loss continued to exponentially increase as long as the produce was exposed to undesirable environmental conditions during handling process. In theory, the only time when the loss is equal to zero is when the cucumber fruit is still attached to its mother plant and a minimum loss occurs when the produce is placed under its optimum conditions. According to Taguchi, loss increases as long as the distance of the population mean from the target increases (Wang et al. 2012). From the literature, the Taguchi approach provides an efficient way to determine the optimum conditions of a process that result in higher quality and minimum loss of a product (Oztop et al. 2007; Trabelsi et al. 2006). For this, another study was carried out by the authors, where Taguchi approach was applied to establish the optimum conditions of the postharvest storage of cucumber and the corresponding target values for each quality attribute obtained when the produce was stored under these conditions. Therefore, the target values of cucumbers were 16.95 N, 9 points, 0.57% and 0.71 for firmness, quality index, weight loss and color difference, respectively.

The Taguchi loss function was applied to cucumber quality characteristics where larger is better in the case of firmness and quality index, and smaller the better in case of weight loss and total color difference. As illustrated in the first 2 plots of Figure 1, in case of the LB target, only the left side of the curve was applicable, whereas in the other 2 plots, in case of the SB target, the right side of the curve was relevant. At firmness equal to 15.68 N, the loss was equivalent to 13.68 units. However, when the cucumber had lost its firmness by half (7.68 N), the loss value was increased by almost 4 times (56.98 units). In terms of quality index, it was noticed that even when the score was high (QI = 9 points), the produce had also lost 8.74 units of its quality. A plausible explanation of this was that in many cases quality index was assessed subjectively based on rating scales. However, in reality the produce had undergone some losses even though it was difficult to detect during the quality evaluation. This was a great indicator that the Taguchi approach can provide a robust and consistent method to measure the most unseen quality losses during postharvest handling of fresh fruits and vegetables. Moreover, the graph showed that when the quality index dropped to 1.67 points, the loss was increased by almost 30 times more (loss = 254.91 units). This indicated how large the extent of loss could be when the fresh cucumber was stored under undesirable conditions and was affected by undesirable environmental factors.

A similar scenario with a lower extent of loss was observed for weight and color attributes. As the percent weight loss and the total color difference increased, the loss increased too. A remarkable increase in loss was noticed at higher values of both quality attributes, which revealed for the second time the amount of damage caused to a produce's quality through a continuous increase in weight loss and color change. The Taguchi technique proved its validity one more time by consistently quantifying the quality loss of a fresh produce.

4.2 Percent influence

The environmental conditions under which fresh horticultural commodities are produced, transported and displayed have a significant effect on the keeping quality of the foods and the amount that is lost. Therefore, the quality retention or degradation of cucumber was directly related to the percent influence of extrinsic factors investigated in this study. As presented in Table 6.6, the factor "time" was the main driver causing quality loss of cucumber. Hence, the handling process duration for fresh fruits and vegetables should be kept at its minimum in order to maintain high quality (Kader et al., 2004). The firmness attribute was influenced at 77.5% by time followed by approximately 9.5% for both temperature and light. According to the results, the factor humidity had a negligible influence on firmness of fresh cucumber. In terms of the quality index parameter, 46.5% of loss was due to time, followed by 18% due to temperature. In this study, results also revealed that light and relative humidity had both almost an equal influence (~11.5%) on keeping quality of the produce. Besides, it is important to mention that around 12% of the quality index loss was due to other factors that happened during postharvest process. These factors could be handling practices or errors occurred during the experiments. Weight loss seemed to be affected mostly by time with 60.07%, followed by 29.10% due to humidity. Temperature and light were shown to have less influence on increasing the weight loss of the cucumber studied. On a different note, light appeared to have major influence on maintaining the color in cucumber, thus, continuous exposure of the crop to direct light was responsible of about 34% of increased color loss during storage. Time was the major factor causing color loss with 45% followed by 17% for temperature. Finally, the percent influence of environmental factors on quality loss differs between crops, geographies, growing conditions, and along the different segments in supply chain.

4.3 Quality prediction

Predicting food quality degradation is considered an important step for stakeholders to make better decisions regarding the control and reduction of postharvest quality loss of fresh produce. Using the Taguchi approach, it was possible to predict quality outcomes of different combinations of factors/levels and to generate the corresponding prediction expressions. Using ANOVA, it was possible to calculate a measure of goodness-of-fit of linear regression. Figure 2 illustrated the Taguchi predictions versus the measured values of combinations used in this study for each quality attribute. For all four plots, the values of R^2 were between 0.92 and 0.98, which provided a good measure of how well the observed data were fit to the statistical model. Consequently, the Taguchi method was able to predict the quality of cucumber at different storage conditions; therefore, it can be used effectively as a method for predicting the outcome in other storage and supply chain settings aimed at enhancing food quality and curtailing postharvest losses of fresh produce. Using the JMP statistical software, the prediction expressions were determined as follow:

$$Firmness = 10.87 + \begin{vmatrix} "1" \Rightarrow +1.31 \\ "2" \Rightarrow -0.39 \\ "3" \Rightarrow +0.91 \end{vmatrix} [Temperature\ level] + \begin{vmatrix} "1" \Rightarrow +4.29 \\ "2" \Rightarrow -2.48 \\ "3" \Rightarrow -1.81 \end{vmatrix} [Time\ level] + \begin{vmatrix} "1" \Rightarrow -0.11 \\ "2" \Rightarrow -0.27 \\ "3" \Rightarrow +0.38 \end{vmatrix} [Humidity\ level] + \begin{vmatrix} "1" \Rightarrow -0.69 \\ "2" \Rightarrow -0.60 \\ "3" \Rightarrow +1.30 \end{vmatrix} [Light\ level]$$

$$Quality\ Index = 5.18 + \begin{vmatrix} "1" \Rightarrow +0.92 \\ "2" \Rightarrow +0.26 \\ "3" \Rightarrow -1.18 \end{vmatrix} [Temperature\ level] + \begin{vmatrix} "1" \Rightarrow +2.59 \\ "2" \Rightarrow -0.85 \\ "3" \Rightarrow -1.74 \end{vmatrix} [Time\ level] + \begin{vmatrix} "1" \Rightarrow -0.63 \\ "2" \Rightarrow +0.15 \\ "3" \Rightarrow +0.48 \end{vmatrix} [Humidity\ level] + \begin{vmatrix} "1" \Rightarrow +0.92 \\ "2" \Rightarrow -0.07 \\ "3" \Rightarrow -0.85 \end{vmatrix} [Light\ level]$$

$$Total\ Color\ Difference = 5.38 + \begin{vmatrix} "1" \Rightarrow -1.44 \\ "2" \Rightarrow +1.44 \\ "3" \Rightarrow -0.01 \end{vmatrix} [Temperature\ level] + \begin{vmatrix} "1" \Rightarrow -2.62 \\ "2" \Rightarrow +2.39 \\ "3" \Rightarrow +0.22 \end{vmatrix} [Time\ level] + \begin{vmatrix} "1" \Rightarrow +1.47 \\ "2" \Rightarrow -1.01 \\ "3" \Rightarrow -0.46 \end{vmatrix} [Humidity\ level] + \begin{vmatrix} "1" \Rightarrow -2.06 \\ "2" \Rightarrow +2.06 \\ "3" \Rightarrow -0.54 \end{vmatrix} [Light\ level]$$

$$Weight\ Loss = 16.38 + \begin{vmatrix} "1" \Rightarrow -5.29 \\ "2" \Rightarrow -0.61 \\ "3" \Rightarrow +5.90 \end{vmatrix} [Temperature\ level] + \begin{vmatrix} "1" \Rightarrow -12.91 \\ "2" \Rightarrow +10.14 \\ "3" \Rightarrow +2.76 \end{vmatrix} [Time\ level] + \begin{vmatrix} "1" \Rightarrow +2.89 \\ "2" \Rightarrow -1.45 \\ "3" \Rightarrow -1.44 \end{vmatrix} [Humidity\ level] + \begin{vmatrix} "1" \Rightarrow -0.49 \\ "2" \Rightarrow +0.99 \\ "3" \Rightarrow -0.51 \end{vmatrix} [Light\ level]$$

Each predicted quality attribute was a function of all four studied factors including temperature, time, humidity and light. So by selecting the level for each factor in this research, it was possible to calculate the predicted quality of the stored cucumber. These models could also be used to predict the resulted quality for other combinations not used in Taguchi L-9 orthogonal arrays. As mentioned earlier, the full factorial design for this study is composed of 81 experiments, however, only 9 were recommended by the Taguchi design. Accordingly, using those prediction equations, the cucumber quality could be predicted for the remaining 72 different combinations. These results confirmed the ability of the Taguchi technique to predict postharvest quality loss of any other crop in response to different combinations of factors and their levels.

5. Conclusions

For the first time, the Taguchi approach was used as a new technique to quantify postharvest quality loss of cucumber during the handling process. This approach made it possible to quantify the loss for all combinations used in this experiment and to demonstrate how large the magnitude of loss could be when the fresh cucumber was stored under undesirable conditions of environmental factors. Using this approach, the percent influence of studied factors on each quality attribute was also determined permitting to pinpoint the main causes of produce's quality degradation. For the overall quality, 46.5% of loss was due to time, followed by 18% due to temperature and 11.5% due equally to light and humidity. Furthermore, the Taguchi method has proved its robustness for predicting the outcome quality of stored cucumber for any factor/level combinations used in this study. This work has provided an important tool that allows for the closing of major gaps in the knowledge of measuring postharvest losses of fresh produce and the prediction of the outcome of different storage and distribution conditions, aiming to increase fresh-market food availability and to enhance postharvest quality management. Additional studies are recommended to optimize postharvest handling practices as affected by other factors and levels such as: farm and farmer related factors, level of mechanization, distance to storage, quality of storage, processing plant related factors, quality of supply chain, use of standards and grading, firm and operator related factors, quality of packaging, transportation, retail outlet and manager related factors, quality of logistics and inventory control, and biological factors (respiration, transpiration, ethylene).

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Table 1. Selected factors and their levels recommended for this study

Factor	Level		
	1	2	3
A: Temperature (^{0}C)	10	20	30
B: Time (days)	1	5	10
C: Relative Humidity (%)	75	85	95
D: Light	No Light	12 hrs. Light / no Light	Light

Table 2. Different combinations according to Taguchi L-9 orthogonal array

Test	Combination				Factor			
					Temperature	Time	Humidity	Light
Test 1	1	1	1	1	10	1	75	No
Test 2	1	2	2	2	10	5	85	No/Yes
Test 3	1	3	3	3	10	10	95	Yes
Test 4	2	1	2	3	20	1	85	Yes
Test 5	2	2	3	1	20	5	95	No
Test 6	2	3	1	2	20	10	75	No/Yes
Test 7	3	1	3	2	30	1	95	No/Yes
Test 8	3	2	1	3	30	5	75	Yes
Test 9	3	3	2	1	30	10	85	No

Table 3. Full description of quality index scales of cucumber by Kader and Cantwell, (2010)

Quality Index	Quality	Description
9	Excellent	Bright green color; firm, crisp and turgid.
7	Good	Minor defects present but not objectionable. Drying of cut stem surface. Gives slightly in middle when compressed.
5	Average	No longer crisp and turgid; gives easily in middle when compressed. Water loss apparent on stem and blossom ends.
3	Poor	Soft, with slight shrivelling near ends. May show irregular yellowing or paleness of green color.
1	Unmarketable	Soft and flabby. Noticeable shrivelling at ends. May show irregular yellowing.

Table 4. Values of the proportionality constant "k_L" for each quality attribute

Quality attribute	Linear equation	R^2	k_L
Firmness	$L = 3363.8(1/y)^2 - 4.7779$*	0.99	3363.80
Quality Index	$L = 708.09(1/y)^2 + 2.0768$	0.87	708.09
Weight	$L = 0.0411(y)^2 + 1.0359$	0.99	0.04
Color	$L = 0.1243(y)^2 + 1.4372$	0.97	0.12

*L is the measured loss and y is the studied quality attribute

Table 5. Values of loss for observed quality attribute used in L-9 Taguchi tests

Test	Firmness (N)	Loss	Quality Index	Loss	Weight Loss (%)	Loss	Color Difference	Loss
1	15.68	13.68	9.00	8.74	0.60	0.01	0.74	0.07
2	8.82	43.27	5.33	24.89	20.78	17.75	7.93	7.81
3	12.06	23.12	4.00	44.26	11.91	5.83	3.16	1.24
4	15.79	13.49	7.33	13.17	0.90	0.03	2.66	0.88
5	7.68	56.98	6.00	19.67	23.99	23.65	6.70	5.57
6	7.95	53.27	3.00	78.68	22.44	20.70	11.13	15.39
7	14.03	17.08	7.00	14.45	2.60	0.28	4.89	2.98
8	8.66	44.82	1.67	254.91	34.82	49.84	8.71	9.42
9	7.17	65.37	3.33	63.73	23.12	21.96	2.53	0.80

Table 6. Percentage influence (P_i) and analysis of variance calculations of environmental factors for each quality attribute studied

Quality Attribute	Factor	Sum of Squares	Variance	F Ratio	Pi (%)
Firmness	Temperature	18.41	9.20	49.90	9.57
	Time	146.37	73.18	396.82	77.43
	Humidity	2.78	1.39	7.52	1.28
	Light	17.68	8.84	47.93	9.18
	Other/Error	3.32	0.18		2.54
Quality Index	Temperature	111.56	55.78	20.83	18.14
	Time	277.98	138.99	51.91	46.57
	Humidity	75.99	37.99	14.19	12.06
	Light	71.71	35.85	13.39	11.33
	Other/Error	48.20	2.68		11.89
Weight Loss	Temperature	424.10	212.05	14.91	7.32
	Time	3465.70	1732.85	121.88	60.07
	Humidity	1680.01	840.00	62.39	29.10
	Light	181.07	90.54	6.37	3.11
	Other/Error	15.77	0.88		0.39
Total Color Difference	Temperature	225.66	112.83	54.98	16.71
	Time	595.90	297.95	145.19	44.63
	Humidity	13.08	6.54	3.19	0.68
	Light	454.53	227.27	110.74	33.97
	Other/Error	36.94	2.05		4.02

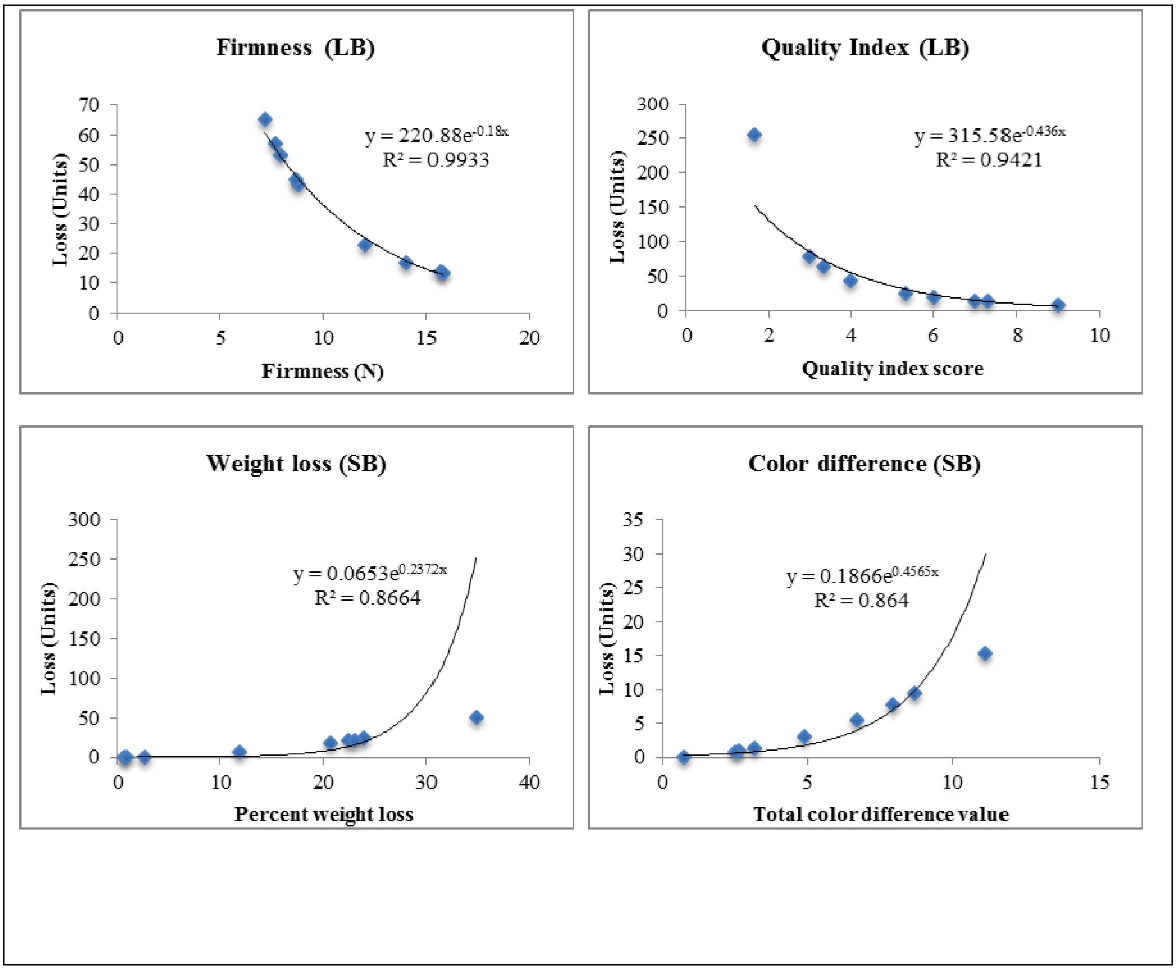

Figure 1. Taguchi quadratic loss functions obtained for all quality attributes. (LB=larger the better, SB=smaller the better)

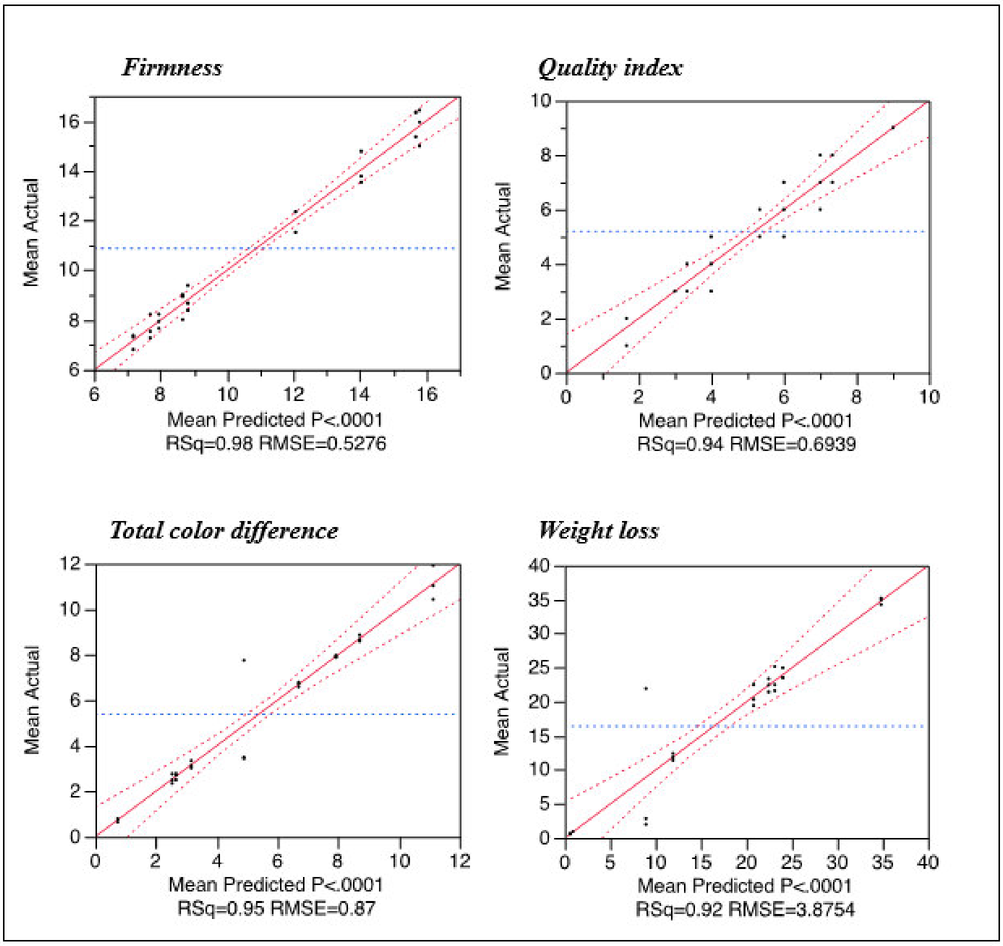

Figure 2. Plots of Taguchi predictions against actual (measured) values used in this analysis.