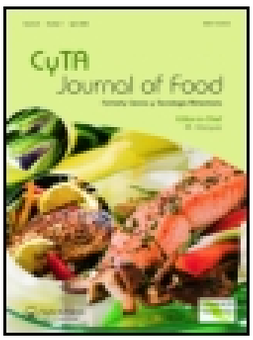

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# Multifactorial analysis of the effects of pre and postharvest treatments on the quality of stored tomato

# Análisis multifactorial de los efectos de tratamientos previos y posteriores a la recogida en la calidad del tomate en conserva

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This study attempted to explain the effect of combined pre and postharvest treatments [preharvest treatment (PHT) with a natural catalyst (*ComCat*®), disinfection and packaging (DP) and storage environment (SE)] on some quality parameters of stored tomato, using multifactorial statistics. The application of Wilk's lambda ($\lambda$) test statistic to the data showed the existence of a highly significant ($p < 0.001$) three-way interactive effect of treatments on some of the quality outputs. The similarity map of the response variables was defined by two significant principal components (PCs), PC1 and PC2, accounting for 30.9% and 21.89%, respectively, of the total variances. DP had a highly significant effect on PC1 ($p \leq 0.001$) and PC2 ($p \leq 0.01$) and were responsible for the largest proportion of their variances (30.9% and 5.5%, respectively). Response surface plots showed that PHT with *ComCat*®, disinfection with chlorinated water and packaging and cold storage were the consistent treatment combination for the optimal maintenance of the quality of stored tomato.

**Keywords:** tomato; treatments; multifactorial statistics; natural catalysts; response surface; quality

En este estudio se propuso explicar los efectos de la combinación de tratamientos previos y posteriores a la recogida [tratamiento previo a la recogida con un catalizador natural (*ComCat*®), desinfección, envase y entorno del almacenamiento] en algunos de los parámetros de calidad del tomate en conserva, utilizando la estadística multifactorial. La aplicación del test estadístico de Wilk Lambda (λ) a los datos mostró la existencia de tres efectos interactivos diferentes altamente significativos ($p < 0{,}001$) de los tratamientos en algunos de los resultados cualitativos. El mapa de similitudes de las variables de respuesta se definió por dos componentes principales significativos, PC1 y PC2, con valores de 30,9 y 21,89%, respectivamente, sobre el total de varianzas. La desinfección y el envase tuvieron un efecto altamente significativo en PC1 ($p \leq 0{,}001$) y PC2 ($p \leq 0{,}01$), además fueron responsables del mayor número de sus varianzas (30,9 y 5,5%, respectivamente). Los gráficos de superficie de respuesta mostraron que el tratamiento previo a la recogida con *ComCat*®, la desinfección con agua clorada y el envase, además del almacenamiento en frío resultaron la combinación de tratamiento más consistente para la conserva óptima de la calidad del tomate en conserva.

**Palabras claves:** tomate; tratamientos; estadística multifactorial; catalizador natural; superficie de respuesta; calidad



## Introduction

Tomato (*Lycopersicon esculentum*) continues to be one of the most widely consumed vegetables due to its global prominence and an array of constituents with human health benefits (Willett, 2010). A number of research efforts have been undertaken to maximise the potential of this important vegetable (Arvanitoyannis & Vaitsi, 2007; Gragera, Rodríguez, & Cuartero, 2002; Lee & Kader, 2000). Different multivariate statistics have been used to explain some of the findings of these studies. Also, effects of different pre and postharvest treatments on the quality and storage stability of tomato have been widely reported (Giovanelli, Lavelli, Peri, & Nobili, 1999; Javanmardi & Kubota, 2006). Combinatorial treatment approaches are being increasingly employed to achieve the desired quality objectives (Beckles, 2012). However, reports on the statistical explanations of the effect of treatments on the quality of stored tomato focused mainly on the main effect of individual treatment on the quality parameters.

The manifestation of the treatments on the final quality is a result of a string of interactions between the treatments (Alimi, Shittu, & Sanni, 2014). Analysis of multiple factors, using combined univariate and multivariate statistics, could be helpful to understand these interactions and the magnitude of their effects on the quality parameters of stored tomato, which may not be visible from the result of each individual treatment (Beckles, 2012). It could also assist to accurately predict the combination of factors for a desired quality output, without going through the difficult process of genotype modification. Multivariate statistics are especially useful because of their capability to standardise multiple layers of information of a set of characteristics (Podani & Schmera, 2006).

This study, therefore, employed combined univariate and multivariate statistics to explain the multifactorial effect of successive pre and postharvest integrated treatments on the quality of tomato during storage.

## Materials and methods

### *Tomato production and preharvest treatments (PHTs)*

Tomato (*L. esculentum*, var. Marglobe) was grown during the autumn season. *ComCat*® (brand name for a natural biocatalyst extracted from the seeds of plants. It consists of amino acids,

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gibberellins, kitenins, auxins (indole-3-acetic acid), brassinosteroids, natural metabolites, pathogenesis-related proteins with defence reactions, terpenoids, flavonoids, vitamins, inhibitors, other signal molecules, biocatalysts and cofactors. *ComCat*® acts by inducing resistance through activation of plant defence mechanisms against pathogens) was applied for PHT at the rate of 10 g $ha^{-1}$ in 350L (PHT1), and 0 g $ha^{-1}$ as control (PHT2). It was applied twice by spraying the foliar. The first spraying was performed prior to transplanting of the seedlings, while the second spraying was at the start of flowering. The fruits were harvested manually at the green-mature stage and delivered to the laboratory immediately after harvest.

### *Disinfection and packaging (DP)*

DP was performed on the day of harvest. After washing, a batch of tomatoes was subdivided into four groups. Each group was subjected to chlorinated water (DP1), anolyte water (DP2) and tap water (DP3) dipping treatments, packed and sealed immediately in 1 kg sample batches in commercial micro-perforated bags (Xtend® Film, Patent No. 6190710, StePac L.A., Ltd., Israel), specifically designed for tomato packaging. The last group was dipped in tap water and also subdivided into 1 kg sample batches and placed in open perforated plastic bags (DP4).

### *Modified atmosphere packaging*

Tomatoes were stored at a temperature of 13°C (storage environment 1 (SE1)), and at room temperature of 16.9–25.2°C (SE2). The relative humidity for the two storage conditions was not controlled and allowed to be governed by the dictate of environmental conditions. It ranged from 34% to 76%. Fresh packages of tomatoes (1 kg each) were randomly taken from each treatment for quality assay after 8, 16, 24 and 32 days.

### *Composition analyses*

The total soluble solid content (TSS) was determined using a handheld refractometer (Atago N1). Soluble sugars (sucrose, glucose and fructose) were determined by the method reported by Riaz and Bushway (1996). A 50 g tomato sample was homogenised for 2 minutes. Sugars were extracted by placing a 10 g aliquot in a 100 ml beaker and stirring for 1 minute with 35 ml of 95% ethanol. The samples were shaken 20 times and kept at room temperature overnight. The samples were transferred to a 50-ml volumetric flask and made to volume with 80% ethanol. After filtration, aliquots of 5 ml were placed in vials and centrifuged for 5 minutes at 3000 × *g* (Beckman, Microfuge E) before analysis by high-performance liquid chromatography (HPLC). HPLC was carried out on a Waters system (501 pump) and a Biorad Aminex column (7.8 × 300 mm) with a differential refractive index detector (R401) operated at 42ºC and a mobile phase of deionised water at a flow speed of 0.6 mL $min^{-1}$and a temperature of 85ºC. Concentrations of hexoses (glucose and fructose) were mathematically converted to sucrose equivalents by multiplying the concentrations with correction factors (0.74 and 1.73, respectively). The sum of their values was considered to be the sucrose equivalent. The sucrose–hexose ratio was calculated by dividing the sucrose content with the total sum of fructose and glucose (Maul et al., 2000). Ascorbic acid content was determined by titration with 2,6-dichloro-phenolindophenol, as described in AOAC (1990).

### *Microbiological analyses*

Microbial populations were estimated following the standard protocol described by Workneh, Osthoff, Pretorius, and Hugo (2003). The total aerobic bacteria (TAB) counts, *Escherichia coli* and coliform population, and fungi counts were determined as described in the protocol.

### *Experimental design*

A factorial experiment, with two PHTs, four disinfecting and packaging (DP) treatments, two storage temperatures (STs) and three replications, was performed in the study. The experimental design was arranged in a factorial type of randomised complete block design (RCBD), with three samples from each treatment combination. Microbial analyses were done in duplicate.

### *Data analyses*

A statistical analysis was undertaken, using the statistical package for social sciences (SPSS) 22.0 software (SPSS Inc). The results obtained using all the factors were subjected to *F*-statistic tests to check for the normality and homogeneity of the variances before univariate and multivariate analyses of the variance procedure. Descriptive statistics with combined one-way and multivariate analysis of variance (ANOVA and MANOVA) were employed. Significance of multi-factor interactions on quality outputs was tested using Wilks' lambda ($\lambda$) test statistics.

Principal component (PC) analysis was used to evaluate the relationship between the studied quality outputs. Varimax rotation was used to extract PCs. The extraction was based on eigen values greater than 1. The explained variances are calculated using the eigen values of the correlation matrix. The extraction was followed by application of univariate factorial ANOVA in each extracted component score.

Surface plots were generated using the EREGRESS (essential regression) package, which is a Microsoft Excel add-in software, for statistically significant interactive linear regression model outputs using central composite design. Standard error, which is a measure deviation of observed values from the regression line, was used to check the quality of the model.

## Results and discussion

Four statistical multivariate models 'data analyses' are usually employed to test for the significance of interactions among factors on test outputs. They are Pillai's trace, Wilks' lambda ($\lambda$), Hoteling's trace and Roy's largest root. Wilks' $\lambda$ is more commonly used when the independent variable has more than two groups (Johnson & Wichren, 2002). In this study, one of the independent variables (DP) has more than two categories. Hence, Wilks' lambda is applied for our testing. The significance ($p < 0.001$) of the three-way interaction test result indicated the possible existence of significant interactions of the factors on some, or all, of the dependent variables. Therefore, it is necessary to perform further tests to determine the significance of interaction on each dependent variable.

### *Total soluble solid*

The interactions of PHT, DP and SE had a highly significant effect ($p \leq 0.001$) on the total soluble solid (TSS) of stored tomato (Table 1). Of the two-way interaction terms tested, only

Table 1. The main and interactive effect of independent variables on some tomato quality attributes.

Tabla 1. El efecto principal e interactivo de las variables independientes en algunos de los atributos cualitativos del tomate.

| Variables | Total soluble solid | | Glucose | | Fructose | | Sugar–hexose ratio | | Ascorbic acid | | Total Coliform count | | Total aerobic bacteria | | Fungi | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square | *p*-value | Partial eta square |
| PHT | 0.023 | 0.023 | 0.008 | 0.031 | 0.017 | 0.025 | 0.030 | 0.021 | 0.285 | 0.005 | 0.000 | 0.135 | 0.000 | 0.165 | 0.001 | 0.044 |
| DP | 0.012 | 0.047 | 0.001 | 0.075 | 0.002 | 0.064 | 0.065 | 0.032 | 0.00 | 0.147 | 0.000 | 0.346 | 0.000 | 0.405 | 0.000 | 0.316 |
| SE | 0.206 | 0.007 | 0.000 | 0.139 | 0.011 | 0.028 | 0.113 | 0.011 | 0.003 | 0.039 | 0.000 | 0.166 | 0.000 | 0.197 | 0.000 | 0.115 |
| PHT*DP | 0.006 | 0.053 | 0.907 | 0.002 | 0.963 | 0.001 | 0.977 | 0.001 | 0.189 | 0.021 | 0.425 | 0.012 | 0.868 | 0.003 | 0.317 | 0.016 |
| PHT*SE | 0.058 | 0.016 | 0.006 | 0.033 | 0.046 | 0.018 | 0.301 | 0.005 | 0.511 | 0.002 | 0.059 | 0.016 | 0.047 | 0.018 | 0.167 | 0.009 |
| DP*SE | 0.066 | 0.032 | 0.724 | 0.006 | 0.409 | 0.013 | 0.922 | 0.002 | 0.002 | 0.063 | 0.205 | 0.020 | 0.045 | 0.035 | 0.239 | 0.019 |
| PHT*DP*SE | 0.000 | 0.097 | 0.072 | 0.031 | 0.810 | 0.004 | 0.376 | 0.014 | 0.239 | 0.019 | 0.182 | 0.021 | 0.829 | 0.004 | 0.727 | 0.006 |

Note: PHT: preharvest treatment; DP: disinfection and packaging; SE: storage environment.

Nota: PHT: tratamiento previo a la recogida; DP: desinfección y envase; SE: entorno de almacenamiento.

PHT by DP had a significant ($p \leq 0.01$) effect on TSS. In addition, a significant ($p < 0.05$) main effect was found for factors PHT and DP. Similar to the observation by Javanmardi and Kubota (2006), data of the present study show that SE as a factor had no effect on TSS. However, the three-way interaction of the factors caused a significant change in the level of TSS. This finding corroborates the earlier warning of Beckles (2012) on the reports of Javanmardi and Kubota (2006) and Luengwilai and Beckles (2010). He warned that the notion that TSS remains unchanged during cold storage of tomatoes must be viewed with great caution because of some factors that were not taken into consideration before arriving at that conclusion. This study, through the application of multiple factor analysis, had shown that the TSS content changes during cold storage and re-conditioning.

In effect size factorial analysis, eta-squared (magnitude of variability in the dependent variable that is associated with, or accounted for, by an independent variable) was computed to be 0.097 and 0.053, respectively, for the three-way interaction of PHT, DP and SE and the two-way interaction of PHT and DP (Table 1). This shows that the three-way interaction was responsible for much greater proportion of variances (approximately 9.7%) in TSS.

Application of the response surface methodology in predicting TSS yields from different treatment combinations, shown with response plots in Figure 1, revealed that the combined effect of PHT of tomato with ComCat® (PHT1), disinfecting the harvested tomato with either chlorinated water or anolyte before packaging (DP1 or DP2, respectively) and cold storage would yield the highest TSS.

### *Glucose and fructose*

In his review, Beckles (2012) stressed the importance of monitoring changes in individual sugar content (glucose and fructose are important sugars in tomatoes) as a measure of the quality index during the storage of tomatoes, rather than relying on changes in the total soluble solid content. In the present study, the three-way interaction did not have a significant effect on either glucose or fructose content of tomatoes during storage (Table 1). So, further analysis between subject effects is not needed. In the two-way interaction, only PHT by SE had a significant effect on glucose ($p \leq 0.01$) and fructose ($p < 0.05$), and was responsible for approximately 3.30% and 1.80% of their variances, respectively. All the three main factors had a significant ($0.001 \leq p < 0.05$) effect on both glucose and fructose levels. SE had the most significant ($p < 0.001$) effect on glucose and accounted for the largest proportion of variances (13.90%), while DP had the most significant ($p < 0.01$) effect on fructose and was responsible for the highest proportion (6.4%) of its variances.

Surface plots' predicting effect of interaction of PHT and SE at different DP on glucose during storage of tomatoes is shown in Figure 2(a–d). Obviously, the combination of PHT1, SE1 and DP1 favours higher glucose retention. The effect of SE on glucose retention found in this study was in contrast to the report of Kader, Morris, Stevens, and Holton (1978) that the glucose level reduced with cold temperature storage. The higher reducing sugar content obtained in this study at lower temperature could be due to the effect of interaction with other treatments employed in this study.

Increasing the reducing sugar content was reported as a way to enhance the flavour of tomatoes. Malundo, Shewfelt, and

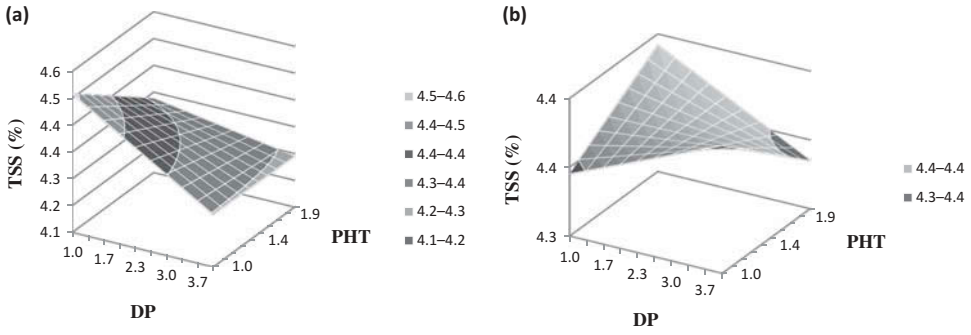


Figure 1. Surface plots showing the interactive effect of DP and PHT on TSS (a: SE1; b: SE2) [TSS: total soluble solid; PHT: preharvest treatment (PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® at 0 g/ha); DP: disinfection and packaging (DP1: chlorinated water + packaging; DP2: anolyte water + packaging; DP3: tap water + packaging; DP4: tap water without packaging); SE1: storage at 13°C and 34–76% relative humidity; SE2: storage under laboratory condition].

Figura 1. Gráficos de superficie mostrando los efectos interactivos de DP y PHT en TSS (a: SE1; b: SE2). [TSS: total de sólido soluble; PHT: tratamiento previo a la recogida (PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® a 0 g/ha); DP: desinfección y envase (DP1: agua clorada + envase; DP2: agua con Anolyte + envase; DP3: agua del grifo + envase; DP4: agua del grifo sin envasar); SE1: almacenamiento a 13°C y 34–76% de humedad relativa; SE2: almacenamiento bajo condiciones de laboratorio].



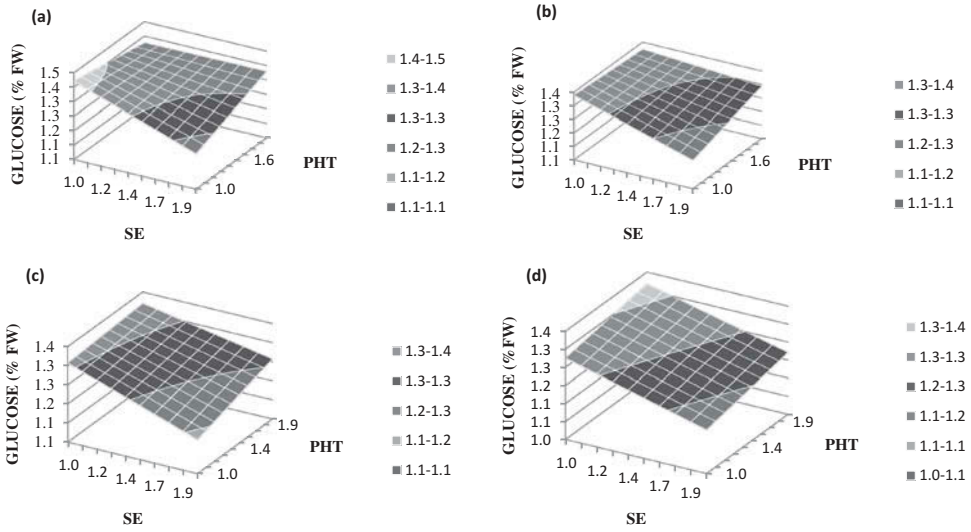


Figure 2. Surface plots showing the interactive effect of SE and PHT on glucose (a: DP1; b: DP2; c: DP3; d: DP4) [PHT: preharvest treatment (PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® at 0 g/ha); SE: storage environment (SE1: storage at 13°C and 34–76% relative humidity; SE2: storage under laboratory conditions); DP1: chlorinated water + packaging; DP2: anolyte water + packaging; DP3: tap water + packaging; DP4: tap water without packaging].

Figura 2. Gráficos de superficie mostrando los efectos interactivos de SE y PHT en glucosa (a: DP1; b: DP2; c: DP3; d: DP4). [PHT: tratamiento previo a la recogida (PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® a 0 g/ha); SE: entorno de almacenamiento (SE1: almacenamiento a 13°C y 34–76% de humedad relativa; SE2: almacenamiento bajo condiciones de laboratorio); DP1: agua clorada + envase; DP2: agua con Anolyte + envase; DP3: agua del grifo + envase; DP4: agua del grifo sin envasar].

Scott (1995) established a significant relationship between increased sugar content and the overall flavour intensity perception by trained sensory judges. Therefore, increasing the sugar content through the control of treatment combination could be a way to increase tomato appeal to the consumers and could eventually enhance its marketability.

### *Sugar–hexose ratio*

Hydrolysis of sucrose to its hexose units is a continuous process in matured tomato fruits. However, it has been established that sucrose is a better medium of sugar storage because of the osmotic effect (Schaffer et al., 1999). Therefore, it is important to monitor the rate of conversion of sucrose to hexose units during storage. Three-way and all the two-way interactions of factors did not have a significant effect on the sugar–hexose ratio. PHT was the only main factor that had a statistically significant ($p < 0.05$) effect on the sugar–hexose ratio and accounted for 2.1% of its variances (Table 1).

### *Ascorbic acid*

The three-way interaction did not have a significant effect on the ascorbic acid content of tomatoes during storage (Table 1). In the

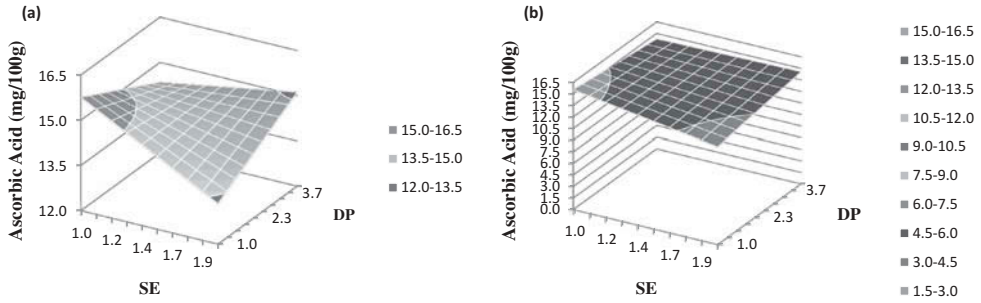


Figure 3. Surface plots showing the interactive effect of DP and SE on ascorbic acid (a: PHT1; b: PHT2) (DP: disinfection and packaging; SE: storage environment; PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® at 0 g/ha).

Figura 3. Gráficos de superficie mostrando los efectos interactivos de DP y SE en ácido ascórbico (a: PHT1; b: PHT2). (DP: desinfección y envase; SE: entorno de almacenamiento; PHT1: *ComCat*® 10 g/ha; PHT2: *ComCat*® a 0 g/ha).



two-way interactions, only DP by SE significantly affected ($p \leq 0.01$) ascorbic acid content and accounted for 6.3% of its variances. DP and SE had a significant effect on ascorbic acid ($p \leq 0.001$ and $p \leq 0.01$, respectively) and accounted for approximately 14.7% and 3.9%, of its variances, respectively. A significant effect of SE on ascorbic acid was similar to the report of Javanmardi and Kubota (2006). Figure 3(a) and (b) showed that optimum ascorbic acid content was obtained with the combination of DP1, SE1 and PHT1.

Proper retention of ascorbic acid has been linked to proper retention of other micro-nutrients and was therefore considered to be the index of nutrient quality of foods (Marfil, Santos, & Telis, 2008). The information available in the literature on the ascorbic acid content in tomatoes was mostly limited to its study as a component of antioxidants (Giovanelli et al., 1999), as well as its degradation kinetics during the drying of tomatoes (Marfil et al., 2008). There has been no report on the effect of interaction of treatment factors on ascorbic acid content of tomatoes, hence, the importance of the results of the present study.

### *Coliform count, TAB and fungi*

Fresh products, like tomatoes, are susceptible to deterioration, due to the activities of microorganisms caused by their high moisture content and the relatively higher temperature of the environment. They are also a reflection of the hygiene of the agricultural practice and postharvest handling. Their presence in significant amounts indicates unwholesomeness of the food (Workneh et al., 2003) and, therefore, should be controlled.

All the main factors had a highly significant ($p \leq 0.001$) effect on the total coliform, TAB and fungi counts (Table 1). DP was responsible for the largest proportion of variances in coliform (34.6%), TAB (40.5%) and fungi (31.6%) counts. Interactions of PHT by SE, and DP by SE had a significant effect ($p < 0.05$) on TAB. From the surface plots in Figure 4(a–d), the combination of PHT1, DP1 and SE1 was most effective in controlling bacterial proliferation during the storage period.

### *Estimate of the regression models*

The effect of the factors and their interactions on the quality outputs can be appreciated by observing the magnitude of their contributions, standard error (significance) and signal (+ or −) in the regression models for each response (Marafon, Sumi, Alcantara, Tamime, & Nogueira de Oliveira, 2011). The magnitude and signal of the linear coefficient obtained for the responses showed the relative contribution of the components to the studied quality outputs (Table 2). The precision of the models is shown by the low standard errors obtained. Standard error which represents the average distance the observed values fall from the regression line provides reliable measure of how well the model fits the data (Frost, 2014). It is known that standard error must be less than or equal to 2.5 to produce a sufficiently narrow 95% prediction interval, that is, smaller values indicate that the observations are closer to the fitted line. Therefore, our regression model is precise for the prediction of all of the studied quality outputs of stored tomatoes except ascorbic acid.

### *PC analysis*

The test of appropriateness of component analysis using Kaiser Meyer Olkin (KMO) statistics showed that KMO has a value of 0.69 which was above 0.5 minimum requirements. Moreover, the approximated value chi-square for Bartlett's test is 845.34 with a *p*-value less than 0.0001. This corroborated the fact that there is a significant correlation and the data are appropriate for reduction.

Two PCs, PC1 and PC2, were extracted, accounting for the total of 59.19% of the variances (37.30% and 21.89%, respectively, for PC1 and PC2).

The reduction process by rotating components showed that four variables (total bacteria count, total coliform, fungi and total soluble solid) contributed more to PC1, while the sucrose–hexose ratio, glucose and fructose contributed more to PC2 (Table 3).

In multivariate statistics, it is understood that parameters that fall into the same component have very similar characteristics (Shittu, Sanni, Awonorin, Maziya-Dixon, & Dixon, 2007). TAB (87.6%), coliform (87.7%) and fungi (88.8%) have a very high loading effect on PC1, while the total soluble solid (−52.1%) has a high negative loading effect on PC1. This shows the negative relationship between microbiological population and the total soluble solid content of tomatoes. The increase in their population is synonymous with depletion of the total soluble content of tomatoes (Workneh et al., 2003). In addition, glucose (77.1%) and fructose (81.8%) have high positive loading in PC2 while the sucrose–hexose ratio has a negative loading (−60.3%). This is understood, since hexoses (glucose and sucrose) are products of the breakdown of sucrose.

A univariate factorial ANOVA was applied to study the effect of treatment factors on the two extracted components. This would assist in identifying the relative importance of treatment(s) to the individual component as a group of parameters

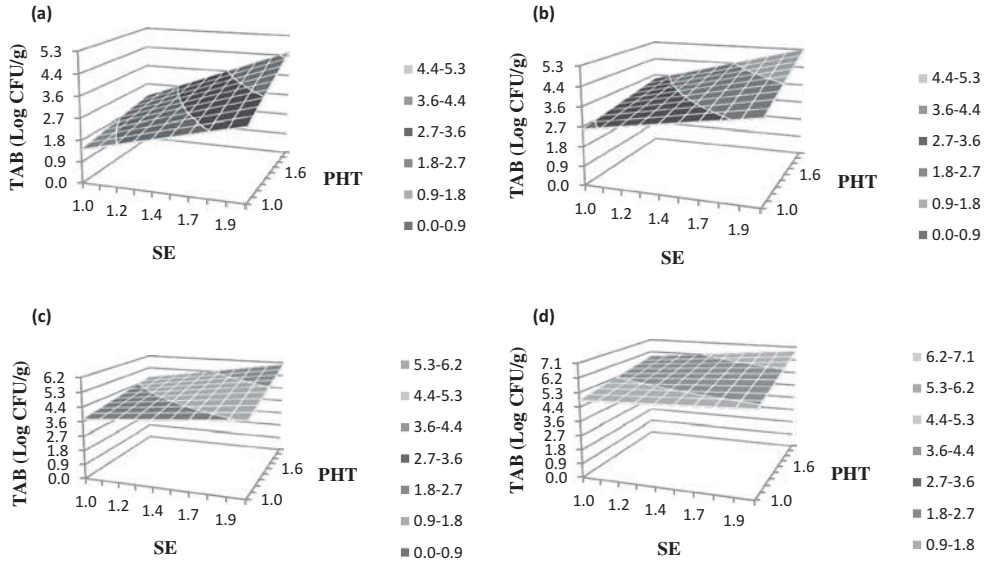


Figure 4. Surface plots showing the interactive effect of SE and PHT on the total aerobic bacteria count (a: DP1; b: DP2; c: DP3; d: DP4) (TAB: total aerobic bacteria count; PHT: preharvest treatment; SE: storage environment; DP1: chlorinated water + packaging; DP2: anolyte water + packaging; DP3: tap water + packaging; DP4: tap water without packaging).

Figura 4. Gráficos de superficie mostrando los efectos interactivos de SE y PHT en el recuento total de bacterias aeróbicas (a: DP1; b: DP2; c: DP3; d: DP4). (TAB: recuento total de bacterias aeróbicas; PHT: tratamiento previo a la recogida; SE: entorno de almacenamiento; DP1: agua clorada + envase; DP2: agua con Anolyte + envase; DP3: agua del grifo + envase; DP4: agua del grifo sin envasar).



Table 2. Regression parameters for the response variables.

Tabla 2. Parámetros de regresión para las variables de respuesta.

| Factors | Total soluble solid | Glucose | Fructose | Ascorbic acid | Total aerobic bacteria |
|---|---|---|---|---|---|
| Constant ($\beta_0$) | 5.679 | 2.048 | 1.566 | 19.61 | −1.243 |
| PHT ($\beta_1$) | −0.711 | −0.362 | −0.187 | 0.101 | −0.490 |
| DP ($\beta_2$) | −0.419 | −0.164 | −0.087 | −1.623 | 1.305 |
| SE ($\beta_3$) | −0.752 | −0.481 | −0.305 | −3.109 | 0.944 |
| PHT*DP ($\beta_4$) | 0.200 | 0.102 | 0.039 | 0.085 | 0.244 |
| PHT*SE ($\beta_5$) | 0.427 | 0.265 | 0.162 | −0.371 | 1.048 |
| DP*SE ($\beta_6$) | 0.254 | 0.083 | 0.036 | 1.09 | −0.274 |
| PHT*DP*SE ($\beta_7$) | −0.131 | −0.063 | −0.025 | −0.035 | −0.127 |
| Standard error | 0.215 | 0.102 | 0.180 | 2.819 | 1.291 |

Table 3. Factor loading of the rotated principal components.

Tabla 3. Factor de carga de los componentes principales rotativos.

| | Principal components | |
|---|---|---|
| Quality parameter | 1(37.3%) | 2 (21.89%) |
| Glucose | −0.315 | 0.771 |
| Fructose | −0.258 | 0.818 |
| Sucrose–hexose ratio | −0.340 | −0.603 |
| Ascorbic acid | −0.374 | −0.255 |
| Total aerobic bacteria | 0.876 | −0.149 |
| Coliform | 0.877 | −0.170 |
| Fungi | 0.888 | −0.061 |
| Total soluble solid | −0.521 | 0.060 |

and allow predicting the effect of treatments on a group rather than on individual quality parameters. None of the interactions had a significant effect on PC1 and PC2 (Table 4). While all the main factors had a highly significant effect ($p \leq 0.001$) on PC1, only DP ($p \leq 0.01$) and SE ($p \leq 0.05$) had a significant effect on PC2. DP was responsible for the largest proportion of variances in PC1 and PC2 (approximately 30.9% and 5.5%, respectively). This shows the importance of DP as a treatment factor on the quality of tomatoes during storage.

Table 4. Main and interactive effect of treatments on extracted components.

Tabla 4. Efecto principal e interactivo de los tratamientos sobre los componentes extraídos.

| | PC1 | | PC2 | |
|---|---|---|---|---|
| Factor | *p*-value | Partial eta squared | *p*-value | Partial eta squared |
| PHT | 0.000 | 0.080 | 0.110 | 0.011 |
| DP | 0.000 | 0.309 | 0.006 | 0.055 |
| SE | 0.000 | 0.151 | 0.028 | 0.021 |
| PHT*DP | 0.981 | 0.001 | 0.863 | 0.003 |
| PHT*SE | 0.430 | 0.003 | 0.085 | 0.013 |
| DP*SE | 0.117 | 0.026 | 0.844 | 0.004 |
| PHT*DP*SE | 0.860 | 0.003 | 0.183 | 0.021 |

Note: PHT: preharvest treatment; DP: disinfection and packaging; SE: storage environment.
Nota: PHT: tratamiento previo a la recogida; DP: desinfección y envase; SE: entorno de almacenamiento.

## Conclusions

This study investigated the effect of some pre and postharvest treatments on the quality of tomatoes during storage using multifactorial statistics. Some effects that were not discernible with one way analysis of variance were exposed and explained by multiple analysis of variance statistics. The significance of the interaction

and the magnitude of their effects help to understand the relative importance of the treatments on the quality of tomatoes during storage. DP as well as the SE were the important main factors that affected the quality of stored tomatoes. PHT with ComCat®, disinfection with chlorinated water and packaging and cold storage were the consistent treatment combination for optimum quality of tomatoes during the storage period. The findings of this study have obvious applications in selecting the appropriate treatment combinations to achieve specific objectives for a set of quality outputs.

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