Title: **Comparison of three types of drying (air, freeze and supercritical CO_2) on the quality of packaged dried apple – Quality index approach**

Authors: Ilija Djekic[a], Nikola Tomic[a], Siméon Bourdoux[b], Sara Spilimbergo[c], Nada Smigic[a], Bozidar Udovicki[a], Gerard Hofland[d], Frank Devlieghere[b], Andreja Rajkovic[a,b]

Affiliation:

[a] Department of Food Safety and Quality Management, University of Belgrade - Faculty of Agriculture, Belgrade, Republic of Serbia

[b] Department of Food Safety and Food Quality, Food2Know, Faculty of Bioscience Engineering, Ghent University, Belgium

c Department of Industrial Engineering, University of Padova, Padova, Italy

[d] FeyeCon Carbon Dioxide Technologies, Weesp, The Netherlands

Corresponding author:

Name: Dr Ilija Djekic, associate professor

Address: Department of Food Safety and Quality Management

Faculty of Agriculture, University of Belgrade

Nemanjina 6, 11080 Belgrade, Republic of Serbia

Email: idjekic@agrif.bg.ac.rs

Abstract

The aim of this study was to examine the effects of different drying technologies on nine quality characteristics of dried apples during a six month storage period at ambient temperature. In order to assign weight factor to each quality parameters, the quality function deployment method was used. For the purpose of this study, based on the quality parameters, a single total quality index has been introduced. Apples were dried in supercritical CO_2, air-dried or freeze-dried, and subsequently packaged under different packaging conditions. At the beginning of the experiment, apples dried in $scCO_2$ had the best scores. After six months, samples dried in $scCO_2$ and freeze dried apples both packed in AluPE with 100% N_2 scored similar. The six months shelf-life research revealed that measurable changes occur during the second half of the shelf-life where it is possible to clearly distinguish differences in the overall index of different dried samples.

Key words: supercritical drying; air-drying; freeze-drying; total quality index; apples

1.0 Introduction

One of the oldest fresh fruit preservation techniques is air-drying (Mujumdar, 2014). Adequate understanding of heat/mass transfer mechanism and correlation with drying parameters such as temperature, velocity and relative humidity of drying air is required for ideal quality dried product (Unal & Sacilik, 2011). Dried foods should maintain quality, such as flavour, texture, convenience, and functionality, increasing the nutritional content (Rahman, 2005).

At the moment, the most widely used drying techniques are air-drying and freeze-drying. Use of elevated air-drying temperatures implies quality degradation of the fruit (Adiletta, Russo, Senadeera, & Di Matteo, 2016; Sette, Salvatori, & Schebor, 2016). Freeze-drying ensures high quality dehydration of fruit but can produce porous, brittle, amorphous and hygroscopic structures (de Santana, et al., 2015). Bonazzi and Dumoulin (2011) highlighted various aspects of dried product quality such as appearance in terms of colour and shape, taste as well as rehydration or dissolving rate, stability over time and type of packaging. Literature review shows that most research was performed in analysing different quality characteristics of dried fruit such as physical and mechanical properties (Sette, et al., 2016), colour (Ceballos, Giraldo, & Orrego, 2012) and texture profile analysis (Rizzolo, et al., 2014).

Supercritical drying process is a recently introduced process as an alternative to conventional drying techniques assisted by the use of supercritical fluids, usually $scCO_2$ (García-González, Camino-Rey, Alnaief, Zetzl, & Smirnova, 2012). In this process, supercritical CO_2 is used to dry the product but simultaneously an inactivation of micro-organisms is achieved due to the antimicrobial activity of the supercritical CO_2. This type of drying is considered as an attractive preservation technology meeting consumers' demands for a product with a high nutritional and sensory quality (Ferrentino, Balzan, & Spilimbergo, 2013). Its main advantage is the relatively low temperature which avoids the thermal effects of the traditional heat pasteurization, retaining the food freshness in combination with its decontaminating effect (Spilimbergo, Komes, Vojvodic, Levaj, & Ferrentino, 2013).

1.1 Food quality

Food quality is considered as a complex concept measured using objective indices (Araujo, et al., 2014). Constraints in developing a single total quality score are use of different units for measuring various quality parameters, and no consensus about the weight of each parameter (Finotti, Bersani, & Bersani, 2007). Various quality index methodologies were developed for different types of food such as extra-virgin olive oil (Finotti, et al., 2007), farmed tambaqui (*Colossoma macropomum*) (Araújo, De Lima, Joele, & Lourenço, 2017) and mushrooms (Djekic, et al., 2017b). Quality models for innovative drying technologies such as supercritical drying process have not been proposed.

Quality function deployment (QFD) is a tool developed to design quality aimed at satisfying the customer and transforming the customer's demands into quality targets (Akao, 1990; ReVelle, 2004). The very first step in applying QFD is to develop a house of quality (HOQ) and translate customer requirements to quality characteristics (Park, Ham, & Lee, 2012). Such a HOQ enables calculating weight importance of each quality characteristic. Literature review reveals use of QFD for chocolates (Viaene & Januszewska, 1999), extra virgin olive oil, (Bevilacqua, Ciarapica, & Marchetti, 2012), Bulgogi bovine meat, (Park, et al., 2012) and organic products (Cardoso, Casarotto Filho, & Cauchick Miguel, 2015). No QFD application on any food drying technology has been reported.

Led by the perspective of using $scCO_2$ drying for its outspoken microbial inactivation properties, the aim of this study was to examine the effect of three drying technologies (classical air drying, freeze drying and scCO2 drying) and the use of different MAP systems in order to evaluate quality characteristics of dried apples, stored for 6 months in ambient conditions. For the purpose of this study based on nine quality parameters, a mathematical model for calculating a single total quality index of dried apples packed in modified atmosphere during shelf-life has been introduced.

2.0 Material and methods

Two independent research trials were performed in order to develop the quality model. The first trial was designed for consumers to identify their preferences towards quality characteristics of dried apples. The second trial included the changes of selected quality characteristics of dried apple cuts during six months of modified atmosphere storage.

2.1 Field research

The survey on consumers' perception of quality of apples has been conducted during the end of 2016. Total of 85 respondents from Belgrade as the biggest and most developed food markets in Serbia were interviewed. The questionnaire consisted of two sections. The first section included general demographic information about the respondents. The second section gave the respondents the opportunity to rank eight sensory / quality characteristics of dried apples (apple skin colour, apple flesh colour, odour, overall flavour, sourness, sweetness, and crunchiness) from 1='the least important' to 8='the most important'. These characteristics were chosen in line with the research of Tomic, Radivojevic, Milivojevic, Djekic, and Smigic (2016) and Rahman (2005).

2.2 Dried apple samples

Granny Smith apples of the harvest 2016 with uniform size, firmness, colour, ripening and maturity, prior storage and without obvious sunburn, red blush, and pale green colour were cut into semi-circular slices and dried using three different drying methods: air drying in a stagnant belt dryer (temperature 60°C, drying time 8h), freeze drying (pressure: 0.2 mbar during sublimation and 0.05 mbar during desorption: temperature of sublimation was maintained at -25°C and gradually increased to 40°C during desorption; drying time 24h) and supercritical drying using CO_2 (pressure 125 bar; temperature 50^{o}C; drying time 16h). Before drying, all samples were prepared in the shape of semi-circular cuts with diameter 50-55mm and thickness 2.2 – 2.5mm (Defraeye, 2017).

Dried apples were packed under modified atmosphere using different packaging materials (Table 1) as follows: CO_2 dried packed in PE with air (C-α); CO_2 dried packed in EVOH-PE with 100% N_2 (C-β); CO_2 dried packed in AluPE with 100% N_2 (C-γ); Air dried packed in AluPE with 100% N_2 (A-γ); Freeze dried packed in AluPE with 100% N_2 (F-γ). Each package contained cca. 100g of dried fruit. Packed dried-apple samples were stored at ambient temperature (≈22◦C) during 6 months and were sampled for analysis after 0 months (within 15 days), 3 months and 6 months of storage.

2.3 Colour changes

Visual colour of 10 dried apples slices was measured on both cut surfaces of each slice using colour analyser (RGB-1002, Lutron Electronic). Data were further expressed in CIELAB coordinates (L*, a* and b*). Total colour difference (ΔE) was determined by using the equation 1 (Hunter & Harold, 1987):

$$\Delta E = \sqrt{(L^* - L_o^*)^2 + (a^* - a_o^*)^2 + (b^* - b_o^*)^2} \qquad /1/$$

Values for a_o, b_o, L_o were values obtained from the apples dried in supercritical CO_2 just after drying. Browning index (BI) of dried apples was calculated using equation 2 (Maskan, 2001; Oliveira, Sousa-Gallagher, Mahajan, & Teixeira, 2012).

$$BI = \frac{100(x - 0.31)}{0.17} \quad \text{where} \quad x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \qquad /2/$$

2.4 Texture profile analyses

Texture profile analysis of the dried apples was conducted using a texture analyser (Brookfield CT3 Texture analyser). Trigger was set at 10g. Dried apple slices were compressed with a sphere of 12.7mm in diameter setting the deformation of 1.0 mm. The speed of the probe was 0.1mm/s during the penetration. The left and right positions of each slice were used for measurements. Hardness, cohesiveness and springiness as quality parameters were recorded. Measurements were performed on eight dried apple slices in two replicates for each treatment.

2.5 Sensory analysis

Sensory quality rating was conducted by a trained 8-member panel consisted of researchers from the University of Belgrade who participated in the research. The analysis was performed using a 5-level quality scoring method as follows: excellent quality (quality score > 4.5); very good quality (3.5 < score ≤ 4.5); good quality (2.5 < score ≤ 3.5); poor/unsatisfactory quality (1.5 < score ≤ 2.5); very poor quality (score ≤ 1.5). Four initially selected characteristics were evaluated: appearance, odour, oral texture, and flavour. Each of the five integer quality scores (1-5) was divided into fourths, to obtain a category scale with 20 alternative responses. All of the samples (Table 1) were evaluated by the panel in two replications after 0 months (within 15 days), 3 months and 6 months of storage.

2.6 Statistical analysis

Colour and texture data were analysed by applying one-way and two-way ANOVA models (combining 'drying methods', 'storage time' and 'packaging' as fixed factors) followed by Tukey's HSD *post-hoc* test. Sensory data were first subjected to 3-way ANOVA with 'assessors' and 'replications' as random factors. Then, in order to assess the influence of drying methods, storage time, and packaging condition on sensory quality scores, two 4-way ANOVA models were applied (both with 'assessors' and 'replications' as random factors): one included only scCO_2-dried samples with 'storage time' and 'packaging' as fixed factors; the second one included only the γ samples (Table 1) with 'storage time' and 'drying methods' as fixed factors. Tukey's HSD test was used to separate the mean sensory scores.

The ranking data based on consumers' attitudes towards sensory quality characteristics of dried apples were analysed using Friedman's test followed by the least significant difference *post-hoc* test (ISO, 2006). The level of statistical significance was set at 0.05. Statistical processing was performed using Microsoft Excel 2010 and SPSS Statistics 17.0.

2.7 Quality function deployment

HOQ used in this paper (Figure 1) consists of three elements: A: demanded quality (WHATs); B: quality characteristics (HOWs); C: relationship matrix (WHAT vs. HOW). This HOQ was modified according to Chan and Wu (2005), Park, et al. (2012) and Djekic, et al. (2017a). Ranking of predetermined sensory attributes (apple skin colour, apple flesh colour, odour, overall flavour, sourness, sweetness, juiciness, crunchiness) from the field research was used as inputs for defining weight importance of defined quality characteristics. W_i is the weight importance of the 'i' demanded quality characteristics identified by the consumers. Relative weight is the percentage of the weight importance divided by the sum of all weight importance, equation 3.

$$= \frac{}{\sum} * 100\ [\%] \qquad /3/$$

The nine quality characteristics (HOWs) used in the matrix were the characteristics identified as colour parameters (ΔE and BI), sensory properties (appearance, odour, oral texture and flavour) and texture parameters (hardness, cohesiveness and springiness). Relationships between the WHATs and HOWs in order to identify weight importance were calculated using the following scale of relationships: '9' - very strong, '3' - strong, '1' - weak, and '0' no relationship (Cardoso, et al., 2015; Park, et al., 2012). Absolute weight importance was calculated using equation 4:

$$= \sum \quad * \qquad /4/$$

Where:

RW_i is the relative weight (WHATs) of 'i' demanded quality characteristic (n – number of demanded quality characteristics).

RS_{ij} is the relationship score (WHATs vs. HOWs) between demanded quality characteristic 'i' and product quality characteristics 'j' (m – number of product quality characteristics). Based on the absolute importance, the relative absolute weight importance (RAW) was finally calculated (Park, et al., 2012).

2.8 Total quality index

The quality parameters have been divided into three groups, in line with the work of Finotti, et al. (2007). Parameters of the first kind are the ones with a target value. The following rule applies - 'the nearer to the target values the parameter is, the better the quality is', equation 5:

$$= \frac{2 * (\quad - \quad)}{-} \qquad /5/$$

Where: QI – quality index for a parameter; x_i – measured value in the subset of values; T - target value; x_{max} – maximal value in the subset of values; x_{min} – minimal value in the subset of values. Four sensory attributes were included in this rule (target values = 5).

Parameters of the second kind have the following rule: 'the smaller the value is, the better the quality is'. For this type of parameters, QI is calculated based on equation 6:

$$= \frac{\quad}{\quad} \qquad /6/$$

Where:

QI – quality index for a specific quality parameter; x_i – measured value in the subset of values; x_{max} – maximal value in the subset of values. Colour parameters were included in this group (ΔE and BI).

Parameters of the third kind have the following rule: 'the higher its value, the better the quality is'. For this type of parameters, QI is calculated based on equation 7:

$$= \frac{\quad}{\quad} \qquad ; x_i \leq x_{max} \qquad /7/$$

Where:

QI – quality index for a specific quality parameter; x_i – measured value in the subset of values; x_{max} – maximal value in the subset of values. Texture quality parameters were included in this group.

Upon calculation of all QIs, we can assume that in the new Euclidean space R^m (m is the number of quality parameters) quality indexes are considered as vectors $QI = (QI_1, QI_2, . . . , QI_m) \epsilon R^m$ (Horn & Johnson, 1985). The Euclidean norm of the vector, whose components are the indexes QI, multiplied by weighting factors (RAW) will represent the overall total quality index (TQI) equation 8 (Finotti, et al., 2007).

$$= \quad * \qquad /8/$$

As a conclusion, the “rule of thumb” is that the further from the origin the vector, the worse its “TQI” is, and the nearer from the origin the vector, the better the “TQI” (Finotti, et al., 2007).

3.0 Results and discussion

3.1 Field research

Figure 2 presents the results of examining consumer attitudes towards sensory quality characteristics of dried apples showing that product flavour obtained the highest rank sum and is overall considered as the most important sensory / quality characteristic. Crispiness is the least important and the other characteristics are in between and equal but significantly different from flavour and crispiness. This information was included within demanded quality characteristics (WHATs) in QFD.

3.2 Colour changes

In this study, different drying technologies initially induced colour changes (Table 2). The colour of air dried and freeze dried apples were statistically different compared to the colour of apples dried in $scCO_2$ ($p<0.05$) in all three measurement periods. After six months, all samples (except A-γ) showed significant differences compared to the beginning of the experiment. Depending on the value of ΔE, when this value is below 2.0, trained observers may notice the difference while when this values is over 3.5 than a clear difference in colour is noticed even by average observers (Mokrzycki & Tatol, 2011). The largest colour differences were for A-γ samples. Colour changes may occur due to degradation of pigments or non-enzymatic Maillard browning (Dadali, Demirhan, & Özbek, 2007).

The browning index (BI) is used to characterize the overall changes in browning colour and is one of the most common indicators of browning in food products containing sugar (Quitão-Teixeira, Aguiló-Aguayo, Ramos, & Martín-Belloso, 2008). Browning of apples may results from both enzymatic or non-enzymatic reactions and may differ depending on the apple cultivar (Putnik, et al., 2017). The formation of browning in dried fruits is often associated with the Maillard reaction (Baini & Langrish, 2009) but Persic, Mikulic-Petkovsek, Slatnar, and Veberic (2017) confirmed that non-enzymatic browning is dominant in heat-processed products. Assessing the formation of browning in dried food helps in the selection of an appropriate drying technique, which minimizes the degradation of quality in terms of colour (Pathare, Opara, & Al-Said, 2013). Our results indicate that this index increases over time and was initially the largest for air dried samples compared to other samples ($p<0.05$). The colour changes in samples C-α, C-β and F-γ, reflected through browning index, were statistically significant ($p<0.05$) after six months of storage.

Two way ANOVA confirmed statistically significant interactions between different drying technologies and shelf-life on both colour differences and browning index ($p<0.05$).

3.3 Sensory analysis

The results of sensory quality judging are shown in Table 3. Different ANOVA models applied on the quality scores of the evaluated sensory characteristics showed significant changes in sensory quality as affected by 'drying method', 'storage time' and 'packaging'. The most affected were the samples packed in PE/Air (C-α) and EVOH-PE/N_2 (C-β), followed by the air-dried sample (A-γ). At the end of the observed period, the quality scores of C-α and C-β samples were within the ranges of 'poor' and 'very poor' quality, while A-γ sample retained its initial sensory quality to a greater extent than the former two. Air-drying of apple cuts led to the product characterized by pronounced shape deformation, well preserved skin colour, yellowish-brown colour of meat, as well as pronounced hardness, brittleness, and apple odour and flavour.

The effects of different types of packaging on sensory quality of dried apple were assessed by observing only the three scCO_2-dried samples (Table 1). The effect of supercritical CO_2 drying was reflected in partly deformed shape of the apple cuts, the appearance of reddish/pinkish discolorations in flesh originating from the skin colour, the appearance of cracks on the flesh surface, relatively intensive crispiness, good chewiness, and pleasant apple flavour. According to the ANOVA results, it seems that after relatively short period of storage for dry fruits (3 months) 'type of packaging' did not affect the evaluated sensory characteristics. Statistically significant decrease was found only in texture quality, when compared γ packaging with α and β (Table 1). Decrease in quality of practical significance was observed only in C-α and C-β samples after 6 months of storage (the scores within the ranges of 'poor' and 'very poor' quality). After six months of storage, C-α and C-β became darker yellow-brown to grayish-brown in colour, typical apple odour and flavour were lost and replaced by hay-like odour and empty dried-fruit flavour, crispiness had completely disappeared and they became soggy, more adhesive on first bite and chew, and also with increased chewiness. Traces of mould growth and musty flavour were also noticed in sample C-α, which resulted in lower score values as compared to C-β. The presence of moulds and musty sensory properties are probably correlated with each other.

Taking only γ samples into account (the samples packed in Alu-PE/N_2, Table 1), the results showed that 'drying method' significantly affected appearance and texture over the observed storage time. The best preserved sensory characteristics were found in the freeze-dried sample (F-γ). After six months of storage all of the evaluated characteristics of F-γ sample retained their initial level of sensory quality ('excellent' or 'very good'). The sample F-γ was characterized by apple-cuts of regular shape (not deformed), pale yellow colour of meat without red discolorations, typical apple flavour with pleasant sourness, crispiness (at certain level even after six months of storage), low hardness, and also good chewiness. In order to compare the effects of supercritical CO_2 drying and freeze-drying, the results showed no statistically significant differences in quality scores between C-γ and F-γ (with the exception of 'appearance') over the period of storage. All of the quality scores of C-γ sample are found in the range of 'very good' quality. Unlike F-γ, the sample C-γ was characterized by reddish/pinkish discolorations of meat, shape deformations of apple cuts (at low level), the presence of cracks on meat surface, as well as lower intensity of apple flavour. These results led us to the conclusion that the supercritical drying, as an emerging drying technology, can bring and retain for at least six months the same sensory quality level of dried apples as it can be obtained by freeze-drying, provided the product is packed in non-permeable and inert packaging (such as Alu-PE/ N_2).

3.4 Texture profile analysis

Hardness of dried apples showed a gradual decrease for all samples over the storage period, with the highest decrease level found in C-β and F-γ (Table 4). This is in accordance with the results of Kutyła-Olesiuk, Nowacka, Wesoły, and Ciosek (2013) showing that drying methods influence mechanical properties of dried apples. This is mainly since water content has an impact on the loss of the fragility of dried products (Labuza, et al., 2004).

Comparison of hardness of different dried samples during the same storage period showed no statistical difference ($p>0.05$). Taking the storage time as a factor, significant decrease in hardness was found in samples C-α, C-β and F-γ mainly after the period of six months. Two way ANOVA revealed that including different drying technologies and the storage time as factors, showed no statistically significant interaction between the factors ($p>0.05$) related to hardness.

Cohesiveness was the texture characteristic that showed significant changes in values ($p<0.05$) taking into account both the period of storage and drying methods. Also, a two way ANOVA confirmed that there was a statistically significant interaction between different drying technologies and storage time on cohesiveness ($p<0.05$).

Freeze-drying of apple cuts resulted in lower level of the product springiness ($p<0.05$) as compared to scCO2-drying and air-drying methods. However, at the end of the shelf-life samples showed no statistically significant differences ($p>0.05$). Results show that during the shelf life, samples C-γ and F-γ expressed statistically significant differences ($p<0.05$). Two way ANOVA confirmed that there was no statistically significant interaction ($p>0.05$) between different drying technologies and shelf-life on springiness.

3.5 Quality function deployment

Upon completion of the field research and laboratory testing of dried apples during the six-month period, the next step was to complete the HOQ and establish absolute and relative importance of each quality characteristic. Figure 3 reports the relative and absolute importance of the quality characteristics for dried apples packed in modified atmosphere. The three most important characteristics are flavour with 21.5% of RAW, followed by total colour difference (20.1%) and odour (15.8%).

3.6 Total quality index

Figure 4 shows the final TQI scores of the dried apples. At the beginning of the experiment, apples dried in scCO_2 (regardless of the packaging) had the best TQI scores. After three months similar results were obtained for samples dried in scCO2 and freeze dried apples (scores between 0.39 – 0.44). Only air dried samples had a worst score. However, after six months, samples C-α and C-β expressed the worst scores while C-γ and F-γ had similar scores.

This method of calculating a unique TQI is capable of comparing and evaluating apples dried in different drying technologies and packed in different MAPs in a quantitative way. It is sensitive to any displacement of QI from their optimal and/or target values (Finotti, et al., 2007). Also, this model can enable a large-scale comparison of various products packed in MAPs and was found reliable, precise, and simple tool for monitoring TQI during shelf-life (Djekic, et al., 2017b).

4.0 Conclusion

This research indicates potential of QFD and the case of a novel total quality index (TQI) in analysing the shelf-life of dried apples packaged and stored under modified atmosphere. QFD enabled merging consumer research of the most important sensory attributes, and made it possible to transfer these demanded quality characteristics to measurable product characteristics. As an outcome QFD calculated the importance of quality characteristics typical for dried apples packaged in modified atmosphere and identified the most important attributes that play a significant role in consumer preference. This study established a mathematical index of TQI in order to evaluate the total quality of dried apples packed in different types of packaging during shelf life. This model enables the evaluation and comparison of different types of packaging during the shelf-life.

Results revealed two phases in quality deterioration of dried apples during six months of shelf life. TQI showed that measurable changes occur during the second half of the shelf-life where it is possible to clearly distinguish differences in the overall TQI. Although at the end of shelf life samples C-γ and F-γ had similar scores, there is the additional advantage of fruit dried in $scCO_2$ by guaranteeing safety as an inactivation is obtained and these products are typically eaten raw.

Acknowledgement

The research leading to these results has received funding from the European Community's Horizon 2020, Call H2020-SFS-2014-2 - Faster Upcoming Technology Uptake Relevant for the Environment in FOOds Drying „FUTURE-FOOD".

References

Adiletta, G., Russo, P., Senadeera, W., & Di Matteo, M. (2016). Drying characteristics and quality of grape under physical pretreatment. *Journal of Food Engineering, 172*, 9-18.

Akao, Y. (1990). *Quality function deployment - Integrating customer requirements into product design* (1st ed.). New York, NY, USA: Productivity Press.

Araujo, Q. R., Fernandes, C. A., Ribeiro, D. O., Efraim, P., Steinmacher, D., Lieberei, R., Bastide, P., & Araujo, T. G. (2014). Cocoa Quality Index–A proposal. *Food Control, 46*, 49-54.

Araújo, W. S. C., De Lima, C. L. S., Joele, P., & Lourenço, L. D. F. H. (2017). Development and Application of the Quality Index Method (QIM) for Farmed Tambaqui (Colossoma macropomum) Stored Under Refrigeration. *Journal of Food Safety, 37*(1).

Baini, R., & Langrish, T. (2009). Assessment of colour development in dried bananas–measurements and implications for modelling. *Journal of Food Engineering, 93*(2), 177-182.

Bevilacqua, M., Ciarapica, F. E., & Marchetti, B. (2012). Development and test of a new fuzzy-QFD approach for characterizing customers rating of extra virgin olive oil. *Food Quality and Preference, 24*(1), 75-84.

Bonazzi, C., & Dumoulin, E. (2011). Quality changes in food materials as influenced by drying processes. *Modern Drying Technology, Volume 3: Product Quality and Formulation*, 1-20.

Cardoso, J. d. F., Casarotto Filho, N., & Cauchick Miguel, P. A. (2015). Application of Quality Function Deployment for the development of an organic product. *Food Quality and Preference, 40, Part A*, 180-190.

Ceballos, A. M., Giraldo, G. I., & Orrego, C. E. (2012). Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. *Journal of Food Engineering, 111*(2), 360-365.

Chan, L.-K., & Wu, M.-L. (2005). A systematic approach to quality function deployment with a full illustrative example. *Omega, 33*(2), 119-139.

Dadali, G., Demirhan, E., & Özbek, B. (2007). Color Change Kinetics of Spinach Undergoing Microwave Drying. *Drying Technology, 25*(10), 1713-1723.

de Santana, R. F., de Oliveira Neto, E. R., Santos, A. V., Soares, C. M. F., Lima, Á. S., & Cardoso, J. C. (2015). Water sorption isotherm and glass transition temperature of freeze-dried Syzygium cumini fruit (jambolan). *Journal of Thermal Analysis and Calorimetry, 120*(1), 519-524.

Defraeye, T. (2017). Impact of size and shape of fresh-cut fruit on the drying time and fruit quality. *Journal of Food Engineering, 210*, 35-41.

Djekic, I., Vunduk, J., Tomašević, I., Kozarski, M., Petrovic, P., Niksic, M., Pudja, P., & Klaus, A. (2017a). Application of quality function deployment on shelf-life analysis of Agaricus bisporus Portobello. *LWT - Food Science and Technology, 78*, 82-89.

Djekic, I., Vunduk, J., Tomašević, I., Kozarski, M., Petrovic, P., Niksic, M., Pudja, P., & Klaus, A. (2017b). Total quality index of Agaricus bisporus mushrooms packed in modified atmosphere. *Journal of the Science of Food and Agriculture, 97*(9), 3013-3021.

Ferrentino, G., Balzan, S., & Spilimbergo, S. (2013). Supercritical carbon dioxide processing of dry cured ham spiked with Listeria monocytogenes: inactivation kinetics, color, and sensory evaluations. *Food and Bioprocess Technology, 6*(5), 1164-1174.

Finotti, E., Bersani, A. M., & Bersani, E. (2007). Total quality indexes for extra-virgin olive oils. *Journal of Food Quality, 30*(6), 911-931.

García-González, C. A., Camino-Rey, M. C., Alnaief, M., Zetzl, C., & Smirnova, I. (2012). Supercritical drying of aerogels using CO2: Effect of extraction time on the end material textural properties. *The Journal of Supercritical Fluids, 66*, 297-306.

Horn, R. A., & Johnson, C. R. (1985). Matrix Analysis Cambridge University Press. *New York*.

Hunter, R. S., & Harold, R. W. (1987). *The measurement of appearance*: John Wiley & Sons.

ISO. (2006). ISO 8587:2006. Sensory analysis – Methodology – Ranking. In. Geneva, Switzerland: International Organization for Standardization.

Kutyła-Olesiuk, A., Nowacka, M., Wesoły, M., & Ciosek, P. (2013). Evaluation of organoleptic and texture properties of dried apples by hybrid electronic tongue. *Sensors and Actuators B: Chemical, 187*, 234-240.

Labuza, T., Roe, K., Payne, C., Panda, F., Labuza, T. J., Labuza, P. S., & Krusch, L. (2004). Storage stability of dry food systems: influence of state changes during drying and storage. In *Proceedings of the 14th International Drying Symposium (IDS 2004), Sao Paulo, Brazil* (pp. 48-68).

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering, 48*(2), 169-175.

Mokrzycki, W. S., & Tatol, M. (2011). Color difference ΔE - a survey. *Machine Graphics and Vision, 20*(4), 383-411.

Mujumdar, A. S. (2014). *Handbook of industrial drying*: CRC press.

Oliveira, F., Sousa-Gallagher, M. J., Mahajan, P. V., & Teixeira, J. A. (2012). Development of shelf-life kinetic model for modified atmosphere packaging of fresh sliced mushrooms. *Journal of Food Engineering, 111*(2), 466-473.

Park, S. H., Ham, S., & Lee, M. A. (2012). How to improve the promotion of Korean beef barbecue, bulgogi, for international customers. An application of quality function deployment. *Appetite, 59*(2), 324-332.

Pathare, P. B., Opara, U. L., & Al-Said, F. A.-J. (2013). Colour measurement and analysis in fresh and processed foods: a review. *Food and Bioprocess Technology, 6*(1), 36-60.

Persic, M., Mikulic-Petkovsek, M., Slatnar, A., & Veberic, R. (2017). Chemical composition of apple fruit, juice and pomace and the correlation between phenolic content, enzymatic activity and browning. *LWT - Food Science and Technology, 82*, 23-31.

Putnik, P., Roohinejad, S., Greiner, R., Granato, D., Bekhit, A. E.-D. A., & Bursać Kovačević, D. (2017). Prediction and modeling of microbial growth in minimally processed fresh-cut apples packaged in a modified atmosphere: A review. *Food Control, 80*, 411-419.

Quitão-Teixeira, L. J., Aguiló-Aguayo, I., Ramos, A. M., & Martín-Belloso, O. (2008). Inactivation of oxidative enzymes by high-intensity pulsed electric field for retention of color in carrot juice. *Food and Bioprocess Technology, 1*(4), 364.

Rahman, M. S. (2005). Dried food properties: challenges ahead. *Drying Technology, 23*(4), 695-715.

ReVelle, J. B. (2004). *Quality Essentials: A Reference Guide from A to Z* (1st ed.). Milwaukee, Wisconsin: American Society for Quality, Quality Press.

Rizzolo, A., Vanoli, M., Cortellino, G., Spinelli, L., Contini, D., Herremans, E., Bongaers, E., Nemeth, A., Leitner, M., Verboven, P., Nicolaï, B. M., & Torricelli, A. (2014). Characterizing the tissue of apple air-dried and osmo-air-dried rings by X-CT and OCT and relationship with ring crispness and fruit maturity at harvest measured by TRS. *Innovative Food Science & Emerging Technologies, 24*, 121-130.

Sette, P., Salvatori, D., & Schebor, C. (2016). Physical and mechanical properties of raspberries subjected to osmotic dehydration and further dehydration by air- and freeze-drying. *Food and Bioproducts Processing, 100*, 156-171.

Spilimbergo, S., Komes, D., Vojvodic, A., Levaj, B., & Ferrentino, G. (2013). High pressure carbon dioxide pasteurization of fresh-cut carrot. *The Journal of Supercritical Fluids, 79*, 92-100.

Tomic, N., Radivojevic, D., Milivojevic, J., Djekic, I., & Smigic, N. (2016). Effects of 1-methylcyclopropene and diphenylamine on changes in sensory properties of 'Granny Smith' apples during postharvest storage. *Postharvest Biology and Technology, 112*, 233-240.

Unal, H. G., & Sacilik, K. (2011). Drying characteristics of Hawthorn fruits in a convective hot-air dryer *Journal of Food Processing and Preservation, 35*(2), 272-279.

Viaene, J., & Januszewska, R. (1999). Quality function deployment in the chocolate industry. *Food Quality and Preference, 10*(4–5), 377-385.

Table 1. Packaging material and atmosphere used for packing dried apple samples

Drying method	Packaging material[1]	Atmosphere	Sample abbreviation
	PE	Air	C-α
$scCO_2$-drying	EVOH-PE	Nitrogen (N_2)	C-β
	Alu-PE	Nitrogen (N_2)	C-γ
Air-drying	Alu-PE	Nitrogen (N2)	A-γ
Freeze-drying	Alu-PE	Nitrogen (N2)	F-γ

[1] PE=polyethylene; EVOH-PE=ethylene vinyl alcohol/polyethylene copolymer; Alu-PE = polyethylene coated aluminium.

Table 2. The effects of different atmospheres and storage time on the color properties of dried apples

	Dried apple samples[1, 2]				
	C-α	C-β	C-γ	A-γ	F-γ
Total color difference (ΔE)					
"0" months	4.17 ± 2.08$^{a, A}$	5.94 ± 3.17$^{a, A}$	4.06 ± 1.55$^{a, A}$	21.11 ± 9.09$^{a, C}$	11.37 ± 1.23$^{a, B}$
"3" months	7.76 ± 5.70$^{ab, A}$	11.04 ± 8.85$^{a, A}$	7.83 ± 6.16$^{a, A}$	24.37 ± 7.16$^{a, B}$	8.39 ± 2.01$^{a, A}$
"6" months	12.65 ± 7.37$^{b, A}$	17.30 ± 5.60$^{b, AB}$	14.88 ± 9.13$^{b, A}$	28.02 ± 9.24$^{a, C}$	22.53 ± 6.51$^{b, BC}$
Browning index (BI)					
"0" months	34.31 ± 4.27$^{a, A}$	39.13 ± 12.55$^{a, A}$	33.44 ± 6.53$^{a, A}$	77.94 ± 18.19$^{a, B}$	35.55 ± 5.49$^{ab, A}$
"3" months	36.18 ± 6.03$^{a, A}$	39.22 ± 6.92$^{a, A}$	35.15 ± 6.32$^{a, A}$	76.84 ± 13.73$^{a, B}$	31.96 ± 2.81$^{a, A}$
"6" months	50.78 ± 17.66$^{b, A}$	48.37 ± 5.22$^{b, AB}$	36.42 ± 4.72$^{a, C}$	82.47 ± 17.78$^{a, D}$	38.27 ± 7.42$^{b, BC}$

[1] Sample abbreviations are given in Table 1.
[2] Values are the arithmetic mean ± standard deviation (N = 10 samples on both cut surfaces). Values marked with the same small letter within the same column are not stat. different (α = 0.05). Values marked with the same capital letter within the same row are not stat. different (α = 0.05).

Table 3. Effects of different storage conditions on changes in sensory quality characteristics of dried apples during six months of storage.

	Dried apple samples[1, 2]				
	C-α	C-β	C-γ	A-γ	F-γ
Appearance					
"0" months	3.9±0.6$^{a, B}$	4.1±0.5$^{a, B}$	4.1±0.7$^{a, B}$	3.0±0.8$^{a, C}$	4.8±0.2$^{a, A}$
"3" months	4.3±0.5$^{a, B}$	4.3±0.5$^{a, B}$	4.2±0.6$^{a, B}$	3.2±1.1$^{a, C}$	4.9±0.2$^{a, A}$
"6" months	1.3±1.3$^{b, D}$	1.7±1.2$^{b, CD}$	3.5±0.7$^{b, B}$	2.1±1.2$^{b, C}$	4.6±0.4$^{b, A}$
Odor					
"0" months	3.8±0.6$^{a, A}$	4.0±0.5$^{a, A}$	4.0±0.6$^{a, A}$	4.3±0.8$^{a, A}$	4.1±0.7$^{a, A}$
"3" months	3.9±0.8$^{a, A}$	4.3±0.7$^{a, A}$	3.8±1.0$^{a, A}$	4.1±1.0$^{a, A}$	4.5±0.4$^{a, A}$
"6" months	2.0±1.0$^{b, B}$	2.3±0.9$^{b, B}$	3.6±0.9$^{a, A}$	3.4±1.1$^{a, A}$	3.6±0.9$^{b, A}$
Texture					
"0" months	4.1±0.5$^{a, A}$	4.1±0.6$^{a, A}$	4.5±0.5$^{a, A}$	4.4±0.6$^{a, A}$	4.5±0.4$^{b, A}$
"3" months	3.8±0.6$^{a, C}$	4.0±0.5$^{a, C}$	4.7±0.4$^{a, AB}$	4.4±0.6$^{a, B}$	4.8±0.3$^{a, A}$
"6" months	1.2±0.6$^{b, C}$	1.6±1.0$^{b, C}$	4.1±0.7$^{b, A}$	3.3±1.2$^{b, B}$	4.1±0.6$^{c, A}$
Flavor					
"0" months	4.4±0.4$^{a, A}$	4.5±0.4$^{a, A}$	4.4±0.4$^{a, A}$	4.6±0.4$^{a, A}$	4.7±0.3$^{a, A}$
"3" months	4.2±0.8$^{a, A}$	4.2±0.8$^{a, A}$	4.4±0.5$^{a, A}$	4.7±0.4$^{a, A}$	4.6±0.5$^{a, A}$
"6" months	0.9±0.9$^{b, C}$	2.3±1.1$^{b, B}$	3.9±0.9$^{b, A}$	4.1±1.3$^{b, A}$	4.0±0.8$^{b, A}$

[1] Sample abbreviations are given in Table 1.
[2] Values are the arithmetic mean ± standard deviation (N = 16 = 8 assessors x 2 replications). Values marked with the same small letter within the same column are not stat. different (α = 0.05). Values marked with the same capital letter within the same row are not stat. different (α = 0.05).

Table 4. The effects of different atmospheres and storage time on the textural properties of dried apples

	Dried apple samples[1, 2]				
	C-α	C-β	C-γ	A-γ	F-γ
Hardness [g]					
"0" months	302.4 ± 98.8$^{a, A}$	270.9 ± 77.5$^{a, A}$	266.6 ± 267.5$^{a, A}$	264.2 ± 138.3$^{a, A}$	175.8 ± 70.0$^{a, A}$
"3" months	208.7 ± 35.2$^{ab, A}$	172.8 ± 64.7$^{b, A}$	177.5 ± 221.6$^{a, A}$	239.3 ± 196.8$^{a, A}$	174.8 ± 75.2$^{a, A}$
"6" months	165.1 ± 166.4$^{b, A}$	80.1 ± 88.5$^{c, A}$	158.5 ± 183.3$^{a, A}$	178.7 ± 153.3$^{a, A}$	96.6 ± 48.3$^{b, A}$
Cohesiveness					
"0" months	0.63 ± 0.15$^{ab, B}$	0.70 ± 0.13$^{a, A}$	0.62 ± 0.15$^{a, AB}$	0.59 ± 0.23$^{a, AB}$	0.47 ± 0.25$^{a, B}$
"3" months	0.78 ± 0.36$^{a, AB}$	0.62 ± 0.28$^{a, AB}$	0.77 ± 0.3$^{a, AB}$	0.49 ± 0.21$^{a, A}$	0.84 ± 0.04$^{b, B}$
"6" months	0.42 ± 0.05$^{b, A}$	0.62 ± 0.20$^{a, AB}$	0.80 ± 0.51$^{a, B}$	0.72 ± 0.21$^{a, AB}$	0.67 ± 0.45$^{ab, AB}$
Springiness [mm]					
"0" months	0.73 ± 0.04$^{a, A}$	0.78 ± 0.03$^{a, A}$	0.77 ± 0.04$^{a, A}$	0.73 ± 0.11$^{a, A}$	0.61 ± 0.04$^{ab, B}$
"3" months	0.74 ± 0.08$^{a, AB}$	0.77 ± 0.05$^{a, A}$	0.71 ± 0.05$^{b, ABC}$	0.57 ± 0.38$^{a, BC}$	0.54 ± 0.05$^{a, C}$
"6" months	0.75 ± 0.09$^{a, A}$	0.75 ± 0.17$^{a, A}$	0.76 ± 0.03$^{a, A}$	0.89 ± 0.39$^{a, A}$	0.69 ± 0.16$^{b, A}$

[1] Sample abbreviations are given in Table 1.
[2] Values are the arithmetic mean ± standard deviation (N = 8 samples in 2 replications). Values marked with the same small letter within the same column are not stat. different (α = 0.05). Values marked with the same capital letter within the same row are not stat. different (α = 0.05).

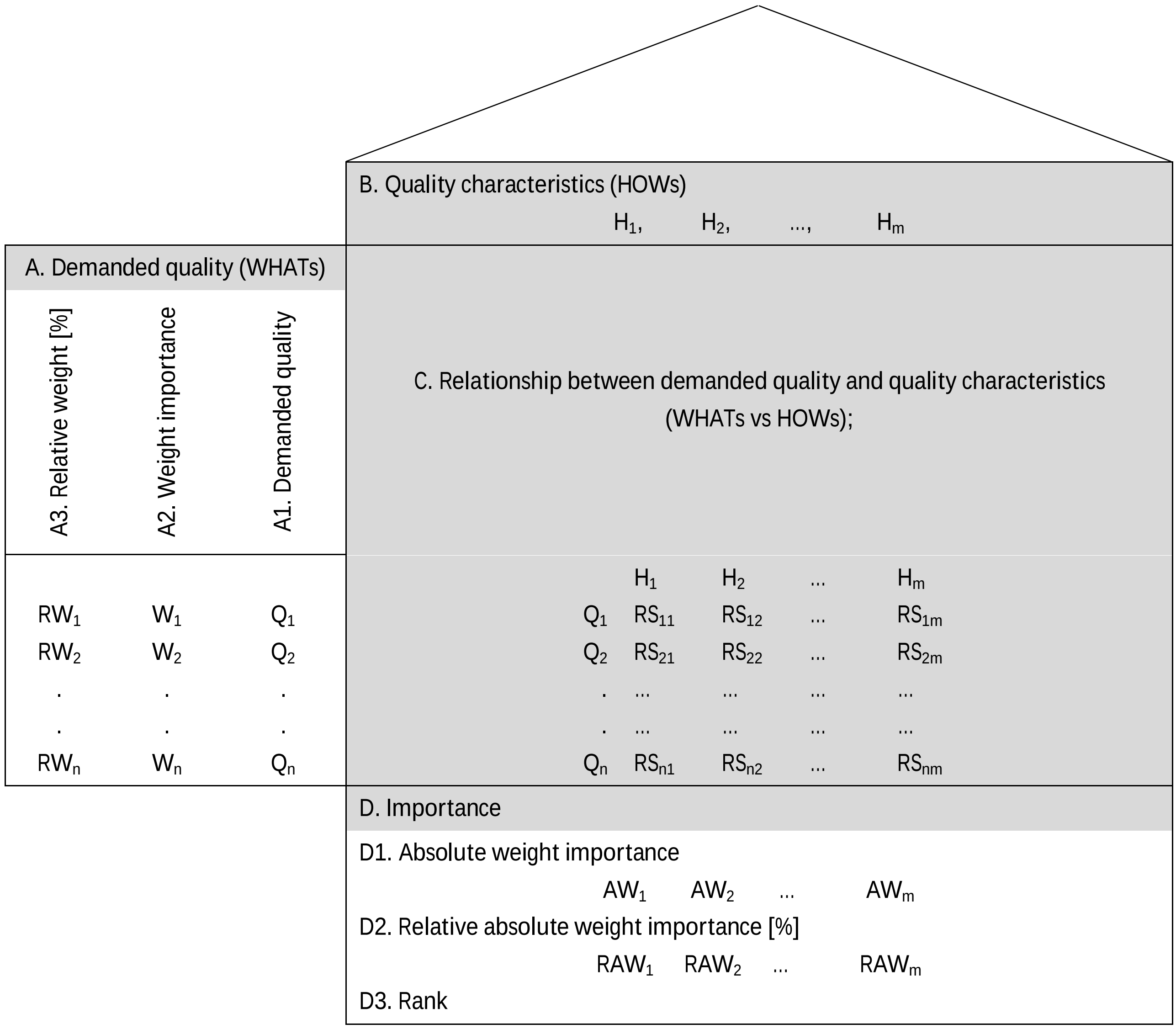

Figure 1. House of quality (HOQ)

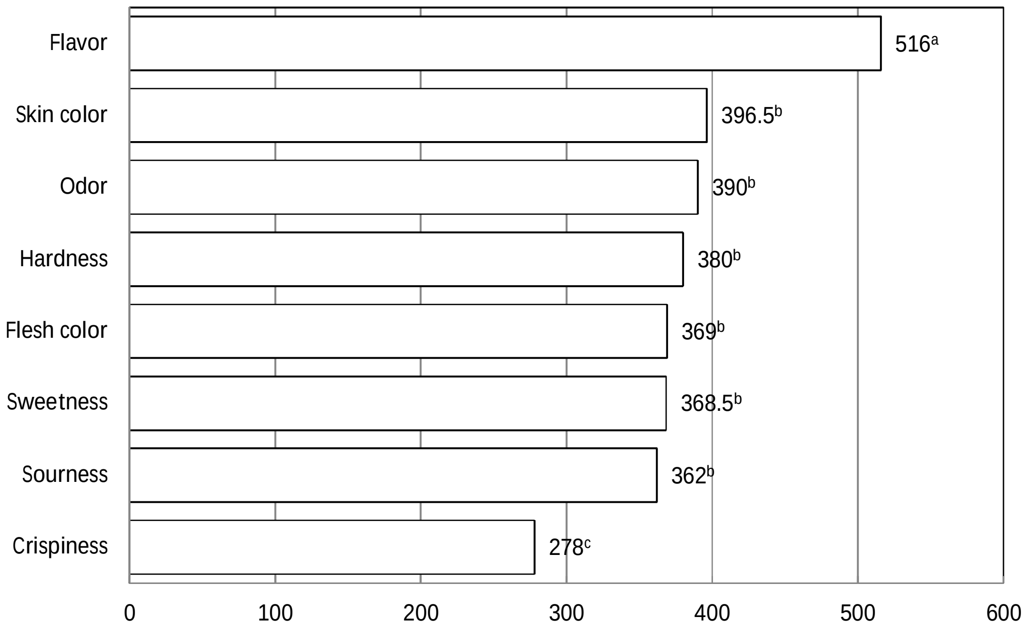

Figure 2. Consumer attitudes towards sensory quality characteristics of dried apples

Legend: Values are the rank sums (N = 85). The characteristics were ranked from 1='the least important' to 8='the most important'. Values marked with the same letter are not stat. different (α = 0.05).

Weight			Color		Sensory parameters				Other		
Relative weight [%]	Weight importance	Quality characteristics (HOWs) / Demanded quality (WHATs)	Total color difference (ΔE)	Browning Index	Appearance	Odor	Oral texture	Flavor	Hardness	Cohesiveness	Springiness
19.44%	**7**	Skin color	●	⭘	⭘						
11.11%	**4**	Flesh color	●	⭘	⭘						
16.67%	**6**	Odor				●		⭘			
22.22%	**8**	Flavor				⭘		●			
5.56%	**2**	Sourness						⭘			
8.33%	**3**	Sweetness						⭘			
13.89%	**5**	Hardness					●		●	⭘	⭘
2.78%	**1**	Crispiness					●	○	●	⭘	⭘
Absolute weight importance			2.75	0.92	0.92	2.17	1.50	2.94	1.50	0.50	0.50
Relative absolute weight importance [%]			20.1%	6.7%	6.7%	15.8%	11.0%	21.5%	11.0%	3.7%	3.7%

Figure 3. House of quality for dried apples packed in MAP

Legend: ● 'strong relationship' = 9, ⭘ 'moderate' = 3, ○ 'weak relationship' = 1 and blank = 'non-existent' or 'zero'

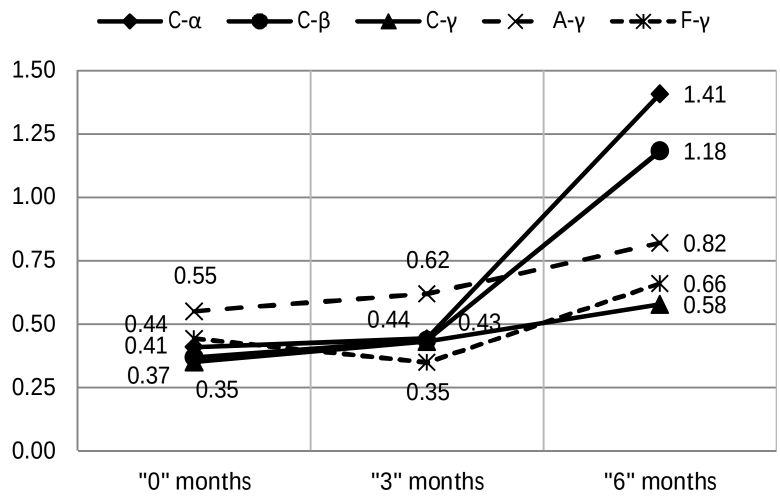

Figure 4 – Total quality index of dried apples packed in modified atmosphere during shelf-life

Legend: CO_2 dried packed in PE with air (C-α); CO_2 dried packed in EVOH-PE with 100% N_2 (C-β); CO_2 dried packed in AluPE with 100% N_2 (C-γ); Air dried packed in AluPE with 100% N_2 (A-γ); Freeze dried packed in AluPE with 100% N_2 (F-γ)

Rule of the thumb: the lower the value, the better the total quality index