Total soluble solids and dry matter of cucumber as indicators of shelf life

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A B S T R A C T

The objective of the present study was to show the relationship between total soluble solids (TSS) and dry matter content (DMC) at harvest and of shelf life of cucumber (*Cucumis sativus* L.) cultivars. Two groups of cultivars with different production cycles were studied during two agricultural seasons. Sample cucumbers were stored for 28 d in the dark, at 10 °C, and 85–95 % relative humidity. The DMC, TSS, and commercial quality were determined every seven days. The crop cycle, harvest month, type of cultivar, and storage time affected cucumber DMC and TSS. The TSS content showed a linear relationship with DMC, which was maintained from harvest to senescence. In addition, the values of these two parameters decreased progressively during storage. The DMC and TSS at the time of collection may influence the shelf life of cucumbers, the higher their contents at harvest, the longer the shelf life. Therefore, the TSS and DMC of cucumbers measured at harvest can be used as indicators of cucumber shelf life.

1. Introduction

Cucumber (*Cucumis sativus* L.) for fresh consumption is one of the most popular vegetables worldwide and a rich source of vitamins, minerals, and antioxidants (Patel and Panigrahi, 2019). The volume of cucumber production in the world in 2018 was 75.22 million tonnes, 7.9 % of which was produced in Europe (Faostat, 2020). In 2019, production in Europe was 2.44 million tonnes, with 30.3 % produced in Spain (Eurostat, 2020). However, it is estimated that one-third of the global production is lost or wasted (FAO, 2013; 2018). These losses occur throughout the value chain, from production and collection, transport and storage, to marketing and distribution to the consumer (Prusky, 2011; HLPE, 2014).

More than 40 % of fruit and vegetable losses occur during post-harvest and distribution. These losses are similar in both developing and industrialised countries, although with differences in the moment of the value chain in which they occur. In industrialised countries, the losses occur in retail sales and consumption, whereas in developing countries, they occur during the postharvest and processing stages (Gustavsson et al., 2011). In addition, the greater the time elapsed from harvest to consumption, the greater the losses (Kader, 2008).

Marketability depends on cucumber quality factors, such as size (diameter and length), shape, colour, freshness, turgidity, maturity, and appearance defects (i.e. rots, cuts, bruises, scars, or insect damage) (Kingston and Pike, 1975; Kader, 1983, 2002). Cucumber losses, waste, and poor quality may occur during the postharvest period. The post-harvest deformation of fresh cucumbers (wilting) is caused by changes in water and polysaccharide content that degrade the cell wall (Nishizawa et al., 2018). Moreover, healthy cucumbers can suffer rotting, peel yellowing (chlorophyll loss), cold burning, bruising, and other me-chanical injuries (Snowdon, 1992; Tonetto de Freitas and Pareek, 2019).

To meet the world demand for food in the coming years, it is necessary to increase the supply and reduce losses and waste (López-Barrera and Hertel, 2020). In this context, many studies have attempted to increase the postharvest time of cucumbers. Some studies included wax coatings (Bhansawi and Khater, 2012), edible coatings (Mohammadi et al., 2016; Patel and Panigrahi, 2019), and different storage conditions (Lufu et al., 2020) to prolong shelf life. Other authors have studied short treatments with hot water at the beginning of the postharvest period to control decomposition, reduce cold damage, and maintain their quality (McCollum et al., 1995; Nasef, 2018). The use of modified atmospheres (Manjunatha and Anurag, 2012; Glowacz et al., 2015) and chemical treatments such as nitric oxide (Yang et al., 2011; Dong et al., 2012) are also alternatives.

In addition to the conditions and treatments applied during storage to prolong shelf life, the type of cultivar is a key source of biological variation in the postharvest longevity of cucumbers (Schouten et al., 2004). Therefore, the genetic improvement of cultivars with prolonged postharvest longevity is presented as one of the best alternatives for increasing cucumber shelf life (Díaz-Pérez et al., 2019a). To facilitate and improve this process, easily applicable indicators that allow the selection of high-quality phenotypes with great potential for prolonged shelf life during the varietal selection process are needed.

Postharvest quality of cucumbers is also affected by agronomic and climatic conditions, crop age, and cucumber load (Marcelis, 1993; Gómez-López et al., 2006). Moreover, one of the main problems during the supply chain originates in the quality heterogeneity of the marketed batches of cucumbers. This heterogeneity is usually due to a mixture of cucumbers from different origins (i.e. producers or fields), cultivars, or maturity at harvest. Cucumbers of the same appearance, shape, and colour at harvest can present great differences in shelf life. Therefore, quality control at the time of harvest is essential (Schouten et al., 1997, 2002; 2004).

Finally, various studies have modelled the influence of various factors on biomass allocation and crop-yield (Marcelis, 1993; Gajc-Wolska et al., 2010). Other studies have revealed that total soluble solids (TSS) decreased during the postharvest period (Nasef, 2018; Kahramanoğlu and Usanmaz, 2019), and the linear relationship between dry matter content (DMC) and TSS of cucumbers (Davies and Kempton, 1976; Verheul et al., 2013). Conversely, there are no studies that specifically relate the influence of DMC and TSS of cucumbers with longevity of postharvest life. The use of DMC and TSS as indicators of quality and shelf life has already been shown in mangoes (Nordey et al., 2017, 2019), apples (Palmer et al., 2010), kiwis (McGlone et al., 2002), to-matoes (Pedro and Ferreira, 2007), and pickled cucumbers (Kavdir et al., 2007). However, the use of these indicators to assess shelf life of cucumbers for fresh consumption has not been shown yet. Therefore, the objective of this study was to demonstrate that TSS and DMC can be effective indicators of the probability of marketability of cucumbers.

2. Materials and methods

2.1. Plant material

The study was conducted in greenhouses in different production areas of Almería (Spain). "LET" (long European type) cucumbers were used, grown by commercial farmers who market their products in different European countries. LET cucumbers are elongated, with slightly grooved or smooth skin, and the weight and length can range between 350 and 500 g and 25 and 40 cm, respectively.

Two independent studies were conducted during two crop cycles (2018–2019 and 2019–2020). One of the studies was conducted using cucumbers of local cultivars 'Levantino' (cv1.1), 'Litoral' (cv1.2), and 'Montano' (cv1.3), with a typical harvest period from October to January on plants transplanted from August 20 to September 15 (this cycle is known as "mid-autumn-winter cycle" in the Spanish southeast). The other study was conducted using cucumbers of the cultivars 'Bra-ganza' (cv2.1) and 'Valle' (cv2.2), whose transplantation is usually from September 25 to October 25, and the harvest is usually between December and February (i.e. "mid-winter cycle"). For each study, sample cucumbers of the specific cultivars (study 1: cv1.1, cv1.2, and cv1.3; study 2: cv2.1 and cv2.2) were collected monthly during the corresponding harvest periods in the two crop years. The cucumbers were selected from plants grown under the standard conditions of the production area and were collected in a state of optimal commercial maturity and quality for exportation.

2.2. Experimental design

For both studies, a complete factorial design was performed, consisting of four factors (design 2^4; Montgomery, 2017) formed by the two crop cycles, different months of study (October–January in one study; and December–February in the other study), days of storage, and different cucumber cultivars. The sample size for each cultivar and month evaluated included 125 cucumbers. The samples were labelled and transported to the Laboratory 1160 of the University of Almería (Almería, Spain). Each sample was divided into 5 subsamples of 25 cucumber to evaluate the commercial quality every seven days; that is, at 0, 7, 14, 21, and 28 d. Samples were kept in the dark at 85–95 % relative humidity and 10 °C, which resemble the standard conditions during the transport, storage, and distribution of cucumbers (Cantwell and Kasmire, 2002; Thompson, 2002).

The parameters measured included loss of commercial value, TSS (%), and DMC (%). Loss of commercial value was evaluated using the parameters described by Kader (1983, 2002) and Valero and Serrano (2010): damage by cold, ageing, wilting, loss of colour (yellowing), and damage by fungi or bacteria, which are the common causes along the distribution chain (Díaz-Pérez et al., 2019a). Based on these parameters, each cucumber was classified as commercial or non-commercial (1 or 0, respectively).

To determine TSS and DMC contents, each whole cucumber was ground using a Taurus Supreme mixer (Taurus Group, Oliana, Spain) until a homogeneous mixture was obtained. From the resulting mixture, a subsample of approximately 45 g was extracted and centrifuged at 1700 × *g* for 20 min; the supernatant was then collected to measure TSS using an digital refractometer (PR-101α, ATAGO Co. Ltd., Tokyo, Japan), with a measurement interval between 0% and 85 % and an accuracy of 0.1 %. DMC was determined following the official method AOAC 920.151 (AOAC, 1999). Briefly, another 45 g subsample of the mixture was dried at 70 °C until the oscillations between two consecu-tive weight measurements (performed at 2-h intervals) were < 0.1 %.

2.3. Statistical analysis

The data were subjected to analysis of variance (ANOVA), simple linear regression, and multiple binary logistic regression. For the different statistical analyses performed, Statgraphics Centurion XVII-X64 (Statgraphics Technologies, Inc., The Plains, VA, USA) and SPSS Statistics v.23 (IBM, Armonk, NY, USA) were used.

2.3.1. ANOVA

The data were subjected to ANOVA according to the additive linear model described in the Eq. (1):

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \tau_k + \gamma_l + (\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\alpha\gamma)_{il} + (\beta\tau)_{jk} + (\beta\gamma)_{jl} + (\tau\gamma)_{kl} + \varepsilon_{ijkl}, \quad (1)$$

where Y_{ij} is the ij-th observation, μ is the global mean, α_i is the effect of the i-th cultivar (first study: cv1.1, cv1.2, and cv1.3; second study: cv2.1 and cv2.2), βj the effect of the j-th crop cycle (2018–2019 and 2019–2020), τ_k the effect of the k-th study month (first study Octo-ber–January; second study, December–February), γ_l the effect of the l-th storage day (0, 7, 14, 21, and 28 d); while the different effects include $(\alpha\beta)_{ij}$ between cultivar and crop cycle, $(\alpha\tau)_{ik}$ between cultivar and month of study, $(\alpha\gamma)_{il}$ between cultivar and days of storage, $(\beta\tau)_{jk}$ be-tween crop cycle and month of study, $(\beta\gamma)_{jl}$ between crop cycle and days of storage, $(\tau\gamma)_{kl}$ between month of study and days of storage; and ε_{ijkl} is the experimental error. The interaction order two was considered to avoid the interaction confusion between factors (Montgomery, 2017).

Conversely, to compare the TSS and DMC of the cucumbers at the time of collection for the cultivars cv1.1, cv1.2, and cv1.3, a simple ANOVA was performed according to the model $Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$, where Y_{ij} is the ij-th observation, μ the global mean, α_i is the effect of the i-th cultivar, and ε_{ij} is the experimental error. Regarding the study of cv2.1 and cv2.2, as it was a comparison between two cultivars, the analysis was performed using the Student's *t*-test for independent samples. This statistical analysis is the most appropriate to determine whether there are significant differences when two independent samples (Mont-gomery, 2017).

Finally, the hypotheses of normality and homoscedasticity were verified in all analyses. The comparison between the means of each treatment was performed using the least significant difference (LSD) test.

2.3.2. Simple linear model

The relationship between TSS and DMC was verified using simple linear regression analysis. The estimation of the model parameters was obtained by the least-squares method, which consists of calculating those estimators of the model coefficients that minimise the sum of the squares of the residuals. In addition, the significance of the model was calculated using ANOVA for the regression contrast. Finally, the goodness of fit of the linear models was verified using the correlation coefficient (r) of the sample by the independent variable x_i ($y_i = \alpha + \beta_1 x_i$); the determination coefficient (R^2), which corresponds to the proportion of the variability explained by the independent variable x_i ($y_i = \alpha + \beta_1 x_i$); and the fulfilment of the hypotheses of linearity, absence of autocorrelation of the studentised residuals, normality of the standardised residuals, and homoscedasticity. For this analysis, the Goldfeld–Quandt test was used.

2.3.3. Binary logistic regression

Binary logistic regression models are very appropriate when the dependent variable is dichotomous. These models allow to explain the factors that influence the response variable to belong to a certain group, such as whether a cucumber is commercial or not after a period of storage. The factors decreasing the shelf life of cucumbers are usually complex, and because single independent variables may not explain postharvest quality, it is advisable to evaluate any changes using models with multiple indicators. In our study, the multiple binary logistic regression model was applied according to Eq. (2) (Agresti, 1996; Hosmer et al., 2013) and following the methodology described by Día-z-Pérez et al. (2018; 2019a; 2019b).

$$\pi(x) = \frac{e^{\alpha + \sum_{i=1}^{n} \beta_i x_i}}{1 + e^{\alpha + \sum_{i=1}^{n} \beta_i x_i}} \tag{2}$$

where π(x) is the probability of marketability of the cucumbers, and x_1, x_2… x_i are the independent variables (i.e. storage time, cultivar, TSS, and DMC) of the cucumbers.

The estimation of the α and βi parameters of the multiple model was performed using the maximum likelihood method (Kleinbaum and Klein, 2010). To verify if the β_i coefficient was different from 0, the Wald test was applied; statistics are shown in the Eq. (3) (Agresti, 1996).

$$Z_{wald} = \widehat{\beta}/SE_{\widehat{(\beta)}} \tag{3}$$

where β is the estimation of the parameter β using the maximum likelihood method, and $SE_{\widehat{(\beta)}}$ is the standard error of $\widehat{\beta}$ The statistic Z_{wald} is distributed according to χ^2; therefore, all the coefficients that have a $Z_{wald} > 4$ are considered significant.

To help interpret the logistic regression coefficients, the odds ratios were calculated according to Eq. (4). The odds ratio "θ" is the association between the occurrence of an event [π(x)] and [1 - π(x)], shows the relationship and strength of association between variables, and allows quantification of their strength of association (Agresti, 1996; Rudas, 1998).

$$\theta = \frac{odds_1}{odds_2} = \frac{\frac{\pi(1)}{1-\pi(1)}}{\frac{\pi(2)}{1-\pi(2)}} \tag{4}$$

Finally, the goodness of fit of the models was studied by calculating different indicators used in binary logistic regression based on the Hosmer–Lemeshow goodness-of-fit statistic (Hosmer et al., 2013). This contrast evaluates how well the model fits the observations by constructing a contingency table to which a χ^2 contrast is applied. This evaluation is performed by calculating the deciles of the estimated probabilities and dividing the observed data into 10 given categories. The null hypothesis of the contrast is that there are no differences between the observed and predicted values compared with the alternative of the presence of such difference. It is considered that the model is not well adjusted when $p < 0.05$ (the null hypothesis is rejected). In addi-tion, the omnibus test was performed to determine whether the general model was significant. This test examines χ^2 statistics to determine whether the model and its predictors are significantly greater than the constant alone (Maroof, 2012). Other tests of goodness of the estimated models that were used are Cox and Snell R^2 and Nagelkerke R^2 tests. The Cox and Snell R^2 is a generalised coefficient of determination used to estimate the proportion of variance of the dependent variable explained by the predictors (independent variables). Its estimation is based on the comparison of the logarithm of the likelihood for the complete model with the logarithm of the likelihood for a baseline model (Cox and Snell, 1989). The Nagelkerke R^2 is an improved version of the Cox and Snell R^2 test with values oscillating between 0 and 1, however it covers the entire range, and the closer it is to 1, the better the model is (Nagelkerke, 1991).

Table 1
Total soluble solids (TSS) and dry matter (DMC) of cucumbers obtained in different crop cycles (2018–19 and 2019–20), harvest months, storage time, and cultivars.

	TSS (%)	DMC (%)		TSS (%)	DMC (%)
A: Cultivar			A: Cultivar		
cv1.1	3.3b	4.07b	cv2.1	3.7a	4.55a
cv1.2	3.1c	3.87c	cv2.2	3.5b	4.25b
cv1.3	3.5a	4.32a			
Significance	***	***	Significance	***	***
B: Cycle			B: Cycle		
2018–19	3.2b	4.12b	2018–19	3.7a	4.60a
2019–20	3.4a	4.22a	2019–20	3.5b	4.29b
Significance	***	***	Significance	***	***
C: Month(i)			C: Month(ii)		
October	3.5ab	4.16b	December	3.4b	4.15b
November	3.2bc	3.85c	January	4.0a	4.90a
December	3.1c	4.02c	February	3.5b	4.30b
January	3.6a	4.43a			
Significance	***	***	Significance	***	***
D: Storage time (d)			D: Storage time (d)		
0	3.6a	4.44a	0	3.8a	4.65a
7	3.5b	4.29b	7	3.7b	4.50b
14	3.3c	4.10c	14	3.5c	4.29c
21	3.2d	3.96d	21	3.5c	4.24cd
28	3.0e	3.74e	28	3.4d	4.07d
Significance	***	***	Significance	***	***
A × B	***	***	A × B	***	***
A × C	ns	ns	A × C	ns	ns
A × D	***	***	A × D	**	*
B × C	***	***	B × C	***	***
B × D	***	***	B × D	*	*
C × D	ns	ns	C × D	ns	ns

Analysis of variance according to the model $Y_{ijkl}=\mu+\alpha_i+\beta j+\tau_k+\gamma_l+(\alpha\beta)_{ij}+(\alpha\tau)_{ik}+(\alpha\gamma)_{il}+(\beta\tau)_{jk}+(\beta\gamma)_{jl}+(\tau\gamma)_{kl}+\varepsilon_{ijkl}$. ns: not significant, significant for *p ≤ 0.05, **0.01, and ***0.001. Numerical values followed by different letters denote statistical significance for p < 0.05 according to the LSD test.

(i) Crop cycle in which harvest goes from October to January.

(ii) Crop cycle in which harvest goes from December to February.

3. Results

3.1. Behaviour of TSS and DMC in cucumbers

The individual effects of the crop cycle, month, cultivar, and storage time factors were analysed with the effect of their interactions. Table 1

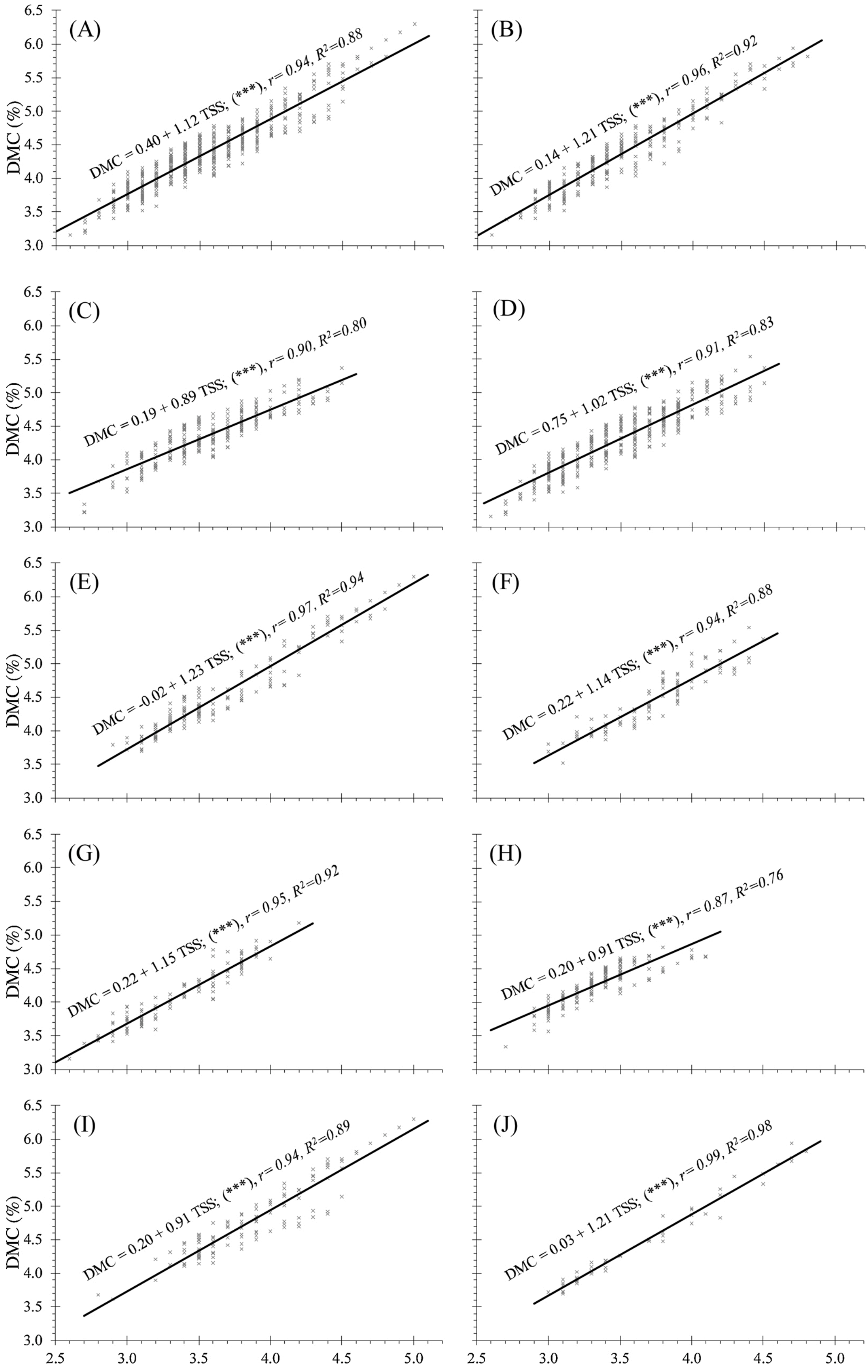

Fig. 1. Relationship between total soluble solids (TSS) and dry matter (DMC) of cucumbers: at the time of collection (0 d; A); collected in crop cycle 2018–2019 (B) and 2019–2020 (C); for cultivars cv1.1, cv1.2, and cv1.3 (D) and cv2.1 and cv2.2 (E); in October (F), November (G), December (H), January (I), and February (J). r, correlation coefficient; R^2, determination coefficient. Ns, not significant, significant at $p \leq 0.05$, **0.01, and ***0.001.

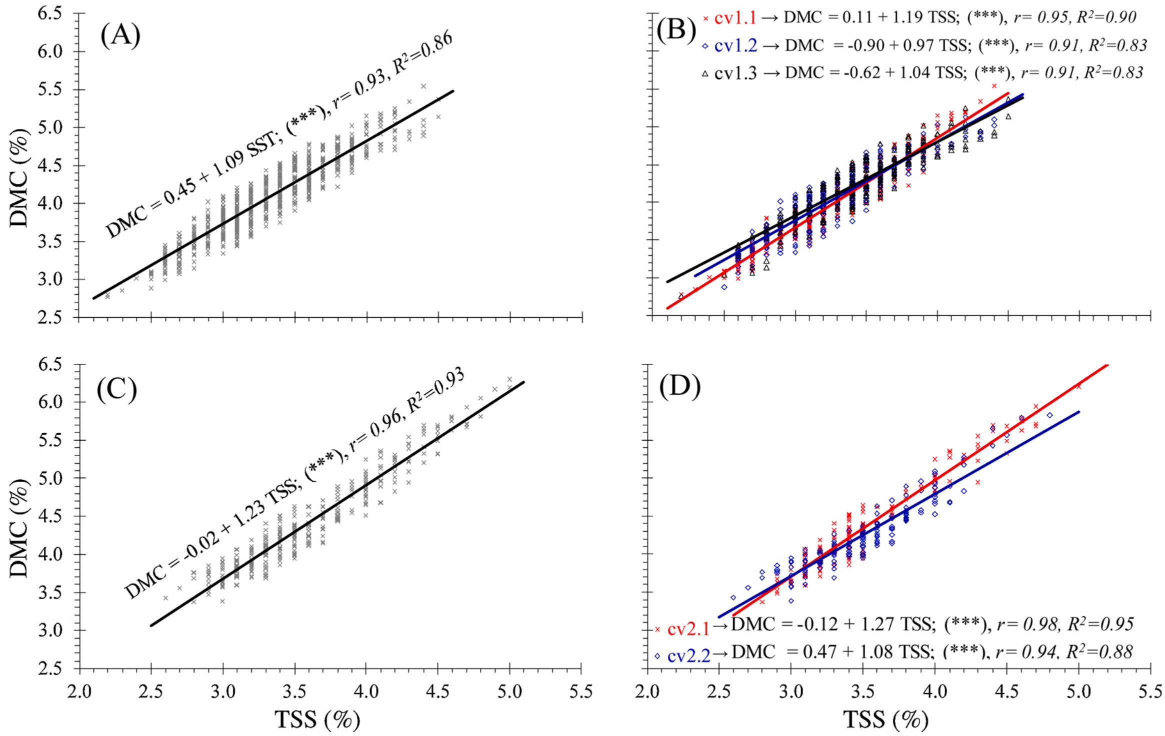

Fig. 2. Relationship between TSS and DMC for cucumbers during 28 days of storage from October to January (A) and from December to February (C). Linear regression models for cultivars cv1.1, cv1.2, and cv1.3 (B) and cv2.1 and cv2.2 (D). Models (A) and (C) are of cucumbers of all cultivars evaluated in each study during 28 days of storage. Models (B) and (D) are of each cultivar evaluated in each study during 28 days of storage. r, correlation coefficient; R^2, determination coefficient. ns, not significant, significant for $*p \leq 0.05$, **0.01, and ***0.001, respectively.

shows that the TSS and DMC of cucumbers were affected by the type of cultivar, cultivation cycle, month of measurement, and storage time in the two studies. In addition, for the same variables, interactions occurred in both studies between the cultivar factors (cycle and cultivar) × storage time, and between cycle (month of study and cycle) × storage time. The fact that there was a significant interaction shows that the factors do not act independently; therefore, the main effects should be studied in combination with their interactions. The interactions between factors showed that the TSS and DMC among the cultivars, month, and storage time behaved differently in the two cultivation cycles studied. In addition, the TSS and DMC during the storage time did not show the same behaviour in the evaluated cultivars. Conversely, there was no interaction between the cultivar × month of study and month of study × storage time factors. Therefore, cultivars and storage time presented similar behaviour during the months of study.

In the second study (cv2.1 and cv2.2), the evaluated cultivars produced higher TSS and DMC values than those in the first study. In addition, January was the month in which the highest values of TSS and DMC were obtained in both studies. Regarding the postharvest evolution, the highest values of TSS and DMC were obtained at the time of collection (0 d of storage), and progressively decreased (with significant differences) with the increase in storage time (7, 14, 21, and 28 d). In the study 1, the TSS and DMC after 28 d of storage decreases 16.7 % and 15.8 %, respectively, compared with the TSS and DMC at the beginning of the storage; this means a daily decrease of 0.6 % in both parameters. In the study 2, the decrease of TSS and DMC from 0 d to 28 d of storage is 10.5 % and 12.5 %, respectively, which means a daily decrease of 0.4 % (Table 1).

3.2. Relationship between TSS and DMC in cucumbers

Table 1 shows a direct proportionality among the studied factors (cultivar, cultivation cycle, month, and storage time) with TSS and DMC. The cv1.3 and cv2.1 are the cultivars with the highest TSS and DMC (3.5 % and 3.7 %; 4.32 % and 4.55 %, respectively). Similarly, cultivars with low TSS values also produced low DMC (Table 1).

The relationship between TSS and DMC is linear, and was calculated on all freshly collected cucumbers (Fig. 1A). This same analysis was also performed for the crop cycles 2018–2019 (Fig. 1B) and 2019–2020 (Fig. 1C), for cultivars cv1.1, cv1.2, and cv1.3 (Fig. 1D) and cv2.1 and cv2.2 (Fig. 1E), for October (Fig. 1F), November (Fig. 1G), December (Fig. 1H), January (Fig. 1I), and February (Fig. 1J). In all cases, the linear model was significant and presented Pearson correlation co-efficients close to 1 ($r \geq 0.87$), which shows good fit. In addition, the coefficients of determination were also close to 1 ($R^2 \geq 0.76$), which shows that, in the worst scenario, 76 % of the variability of the DMC was explained by TSS.

The linear regression model was calculated for the studies performed from October to January (Fig. 2A) and from December to February (Fig. 2C). The models show a statistically significant linear relationship when evaluated at 0, 7, 14, 21, and 28 d of storage, with $r \geq 0.91$ and $R^2 \geq 0.83$. This same analysis was performed independently for cultivars cv1.1, cv1.2, and cv 1.3 (Fig. 2B), and cv2.1 and cv2.2 (Fig. 2D); a significant linear fit is also obtained, with $r \geq 0.91$ and $R^2 \geq 0.83$.

3.3. Probability of marketability as a function of the DMC of cucumbers at harvest

Multiple binary logistic regression analyses were performed considering the storage time and DMC of the cucumbers at the time of harvest (% DMC at 0 d). The DMC values at the time of collection were grouped into discrete continuous variables of 3.5 %, 4.0 %, 4.5 %, 5.0 %, and 5.5 % to simplify the DMC study as a determinant. To determine the evo-lution of the probability of marketability during the storage time in each level of DMC, the regression model was applied in each of the studies independently (Fig. 3A and B). Moreover, to determine this same behaviour in a general way for the entire study, this same analysis was performed considering all the cultivars (Table 2 and Fig. 3C). In all cases,

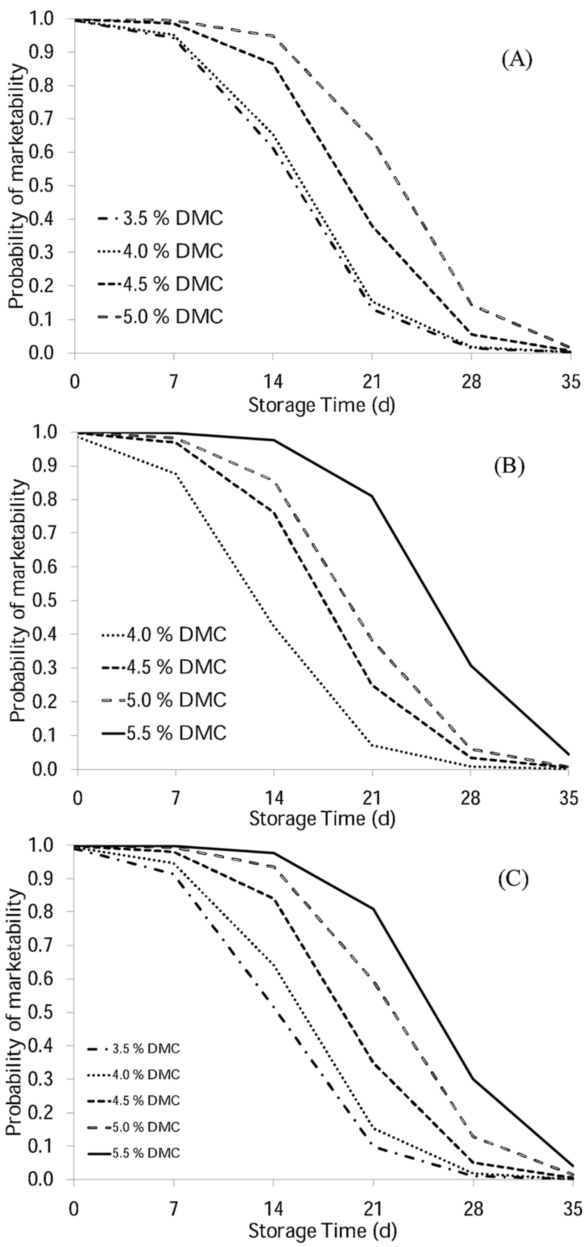

Fig. 3. Evolution of the probability of marketability of cucumbers as a function of DMC from collection. The study was conducted from October to January (A), and December to February (B), considering all the cultivars from the two studies (C).

a good fit of the logistic models is achieved (Hosmer–Lemeshow, omnibus, Nagelkerke R^2, and Cox and Snell R^2 tests). In addition, the α and β coefficients of the models show a significant fit for the storage time and DMC (Wald statistic, $p < 0.001$). This result shows that the explanatory variables (storage time and DMC at collection time) influenced and explained the behaviour in the response variable (probability of marketability); therefore, β≠0 and Exp (β)≠1 in the entire confidence interval for Exp (β). Regarding the β coefficients of the postharvest period studied, the values were negative (β < 0), which shows that the probability of marketability decreased as the storage time of cucumbers increased (Table 2 and Fig. 3).

Regarding the storage time, the odds-ratios was 0.721, which means that one day of storage reduced the probability of marketability by 27.9 %. However, if a fixed storage time and 5.5 % DMC are considered as the reference value, the β coefficients of the other DMC are negative and directly proportional to the DMC values. This means that, as the DMC of a cucumber at harvest decreases, its probability of marketability also decreases. Therefore, increasing the DMC from 3.5 % of a cucumber at harvest to 4.0 %, the probability of marketability has a 1.7-fold increase. Alternatively, the increase in harvest DMC from 4.0%–4.5%, 4.5%–5.0% or 5.0%–5.5% has a 4.9-fold, 2.7- or 2.9-fold increase in probability of marketability. Therefore, increasing the DMC of cucumbers 0.5 % during harvest can increase 3-fold (on average) the fruit probability of marketability (Table 2).

Table 2
Estimation of multiple logistic regression parameters for storage time (d) and dry matter content of cucumbers at collection (% DMC at 0 d) as factors influencing the probability of marketability of cucumbers (considering all the cultivars from the two studies).

Variables	Coefficients (α, β)	Wald χ^2	p	Odds ratio [Exp (β)]	95 % CI for [Exp (β)] Lower	Upper
Constant	8.313	916.449	<0.000			
Storage Time (d)	−0.327	1287.436	<0.000	0.721	0.708	0.734
MSC (%) at 0 d						
3.5	−3.672	321.981	<0.000	0.025	0.017	0.038
4.0	−3.159	191.648	<0.000	0.042	0.027	0.066
4.5	−2.076	126.936	<0.000	0.125	0.087	0.180
5.0	−1.071	27.060	<0.000	0.343	0.229	0.513
5.5		Reference				

CI: Confidence interval.
Hosmer and Lemeshow test (p = 0.091), Likelihood ratio test (omnibus; p < 0.000), Cox and Snell R^2: 0.520, Nagelkerke R^2: 0.720.

3.4. *DMC and TSS as indicators of shelf life in cucumbers*

The cultivars and storage time have a similar behaviour during the months of study as a consequence of the absence of interaction between the cultivar–month factors (Table 1). Therefore, cultivars are the main indicators of shelf life when studying TSS and DMC. The TSS and DMC of the cucumbers at harvest showed significant differences among the cultivars, except between cv1.1 and cv1.3. The highest values of TSS and DMC of each study were obtained for cultivars cv1.3 and cv2.1, and the lowest, for cv1.2 and cv2.2 (Fig. A1).

In Table A1, parameters are shown for the multiple model when considering the cultivars and storage time as factors influencing the probability of marketability of cucumbers. The quality of fit of the models obtained is good, as shown by the indicators of the goodness of fit studied (Hosmer–Lemeshow test, $p > 0.05$; omnibus, $p < 0.05$; and high Cox and Snell R^2 and Nagelkerke R^2 values). The β coefficients for the cultivars were significant ($p < 0.05$) in all cases (except cv1.1 when cv1.3 was the reference cultivar, and vice versa), which shows that the probability of marketability was significantly different between these cultivars; therefore, their β≠0, and Exp (β) ≠1. Conversely, this probability was equal between the cultivars cv1.1 and cv1.3 [$p > 0.05$, β=0, and Exp (β)=1] and significantly higher than the probability of marketability of cv1.2. Odds ratios between cultivars, when combined with the storage time as influencing factors, show a relationship between the probability of marketability of a cultivar and the storage time. For example, cv1.1 and cv1.3 show 1.3- and 1.5-fold more probability of marketability than that of cv1.2 (Table A1).

The differences in the probability of marketability between the cultivars are consistent with the differences found in the TSS and DMC at harvest. For example, TSS and DMC at the time of collection of cv2.1 are significantly higher than those of cv2.2 (Fig. A1), and the probability of marketability of cv2.1 is 1.8-fold greater than that of cv2.2 (Table A1). This proportion between TSS and DMC with respect to the probability of marketability is verified among cultivars cv1.1, cv1.2, and cv2.1 (Fig. A1 and Table A1). Finally, the β coefficients for the storage time are

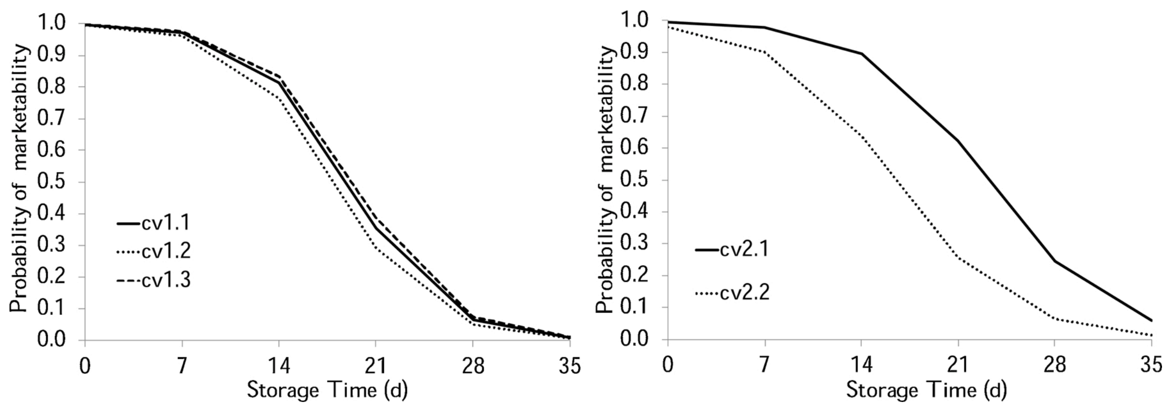

Fig. 4. Temporal evolution of the probability of marketability of cucumber cultivars (study 1: cv1.1, cv1.2, and cv1.3; study 2: cv2.1 and cv2.2).

Table 3
Estimation of multiple logistic regression parameters for DMC, TSS, and cultivars as influencing factors on the probability of marketability of cucumbers (considering all the values of DMC and TSS at 0, 7, 14, 21, and 28 d of storage).

	Coefficients			Odds ratio	95 % CI for [Exp (β)]	
Variables	(α, β)	Wald χ^2	p	[Exp (β)]	Lower	Upper
Constant	−10.940	150.480	<0.000			
MS (%)	2.571	154.042	<0.000	13.079	8.715	19.629
Cultivar[(i)]						
cv1.1	0.211	1.203	0.273	1.235	0.847	1.801
cv1.2	0.700	11.989	0.001	2.013	1.355	2.992
cv1.3		Reference				
Constant	−5.375	38.119	<0.000			
MS (%)	1.267	39.209	<0.000	3.551	2.388	5.279
Cultivar[(ii)]						
cv2.1	−0.558	5.678	0.017	0.572	0.362	0.906
cv2.2		Reference				
Constant	−8.503	125.515	<0.000			
SST (%)	2.475	128.243	<0.000	11.888	7.745	18.246
Cultivar[(iii)]						
cv1.1	0.098	0.273	0.601	1.103	0.764	1.593
cv1.2	0.384	4.123	0.042	1.468	1.013	2.127
cv1.3		Reference				
Constant	−3.965	22.812	<0.000			
SST (%)	1.133	23.672	<0.000	3.105	1.967	4.901
Cultivar[(iv)]						
cv2.1	−0.364	4.056	0.048	0.695	0.449	0.977
cv2.2		Reference				

CI: Confidence interval.
[(i)] Hosmer–Lemeshow test (p = 0.291), Likelihood ratio test (omnibus; p < 0.000), Cox and Snell R^2: 0.530, Nagelkerke R^2: 0.734.

[(ii)] Hosmer–Lemeshow test (p = 0.120), Likelihood ratio test (omnibus; p < 0.000), Cox and Snell R^2: 0.492, Nagelkerke R^2: 0.680.

[(iii)] Hosmer–Lemeshow test (p = 0.097), Likelihood ratio test (omnibus; p < 0.000), Cox and Snell R^2: 0.428, Nagelkerke R^2: 0.591.

[(iv)] Hosmer–Lemeshow test (p = 0.059), Likelihood ratio test (omnibus; p < 0.000), Cox and Snell R^2: 0.467, Nagelkerke R^2: 0.646.

negative (β < 0), which indicates that the possibility of marketability decreases over time, as can be observed in Fig. 4.

The DMC and TSS are linearly related and have a strong influence on the probability of marketability of cucumbers (Fig. 1, Fig. 3, and Table 2). In addition, the values of these parameters decrease along the postharvest period (Table 1). Similarly, differences between the culti-vars are also verified (Table 1 and Fig. A1). Therefore, to further our understanding about these aspects, the probability of marketability of cultivars based on cucumber TSS and DMC was studied. Conversely, the combined effect of the DMC or TSS of the cucumbers and cultivars on the probability of marketability was analysed (Table 3 and Fig. 5).

The quality of the fit of the regression parameters obtained was suitable, as Hosmer and Lemeshow, omnibus, Cox and Snell R^2, and Nagelkerke R^2 tests showed. The β coefficients for the DMC and TSS are significant and >0, which shows that the probability of marketability increases when the TSS and DMC of cucumbers increase, as shown in Fig. 5. In the case of the β coefficients for the cultivars, they are significant, except for cv1.1 when cv1.3 is the reference cultivar and vice versa. This implies that the DMC and TSS of the cucumbers influence the shelf life of the different cultivars, although cv1.1 and cv1.3 show a similar behaviour (Table 3 and Fig. 5).

The odds ratio between cultivars when combined with TSS and DMC as influencing factors shows a relationship between the probability of marketability of a cultivar and the contents of TSS and DMC in a cu-cumber increases or decreases. As shown in Fig. 6, the odds ratio of the different cultivars is related to the average of their TSS and DMC values at the time of collection. The cv1.2 and cv2.2 are considered references because they show the lowest odds ratio with respect to the other

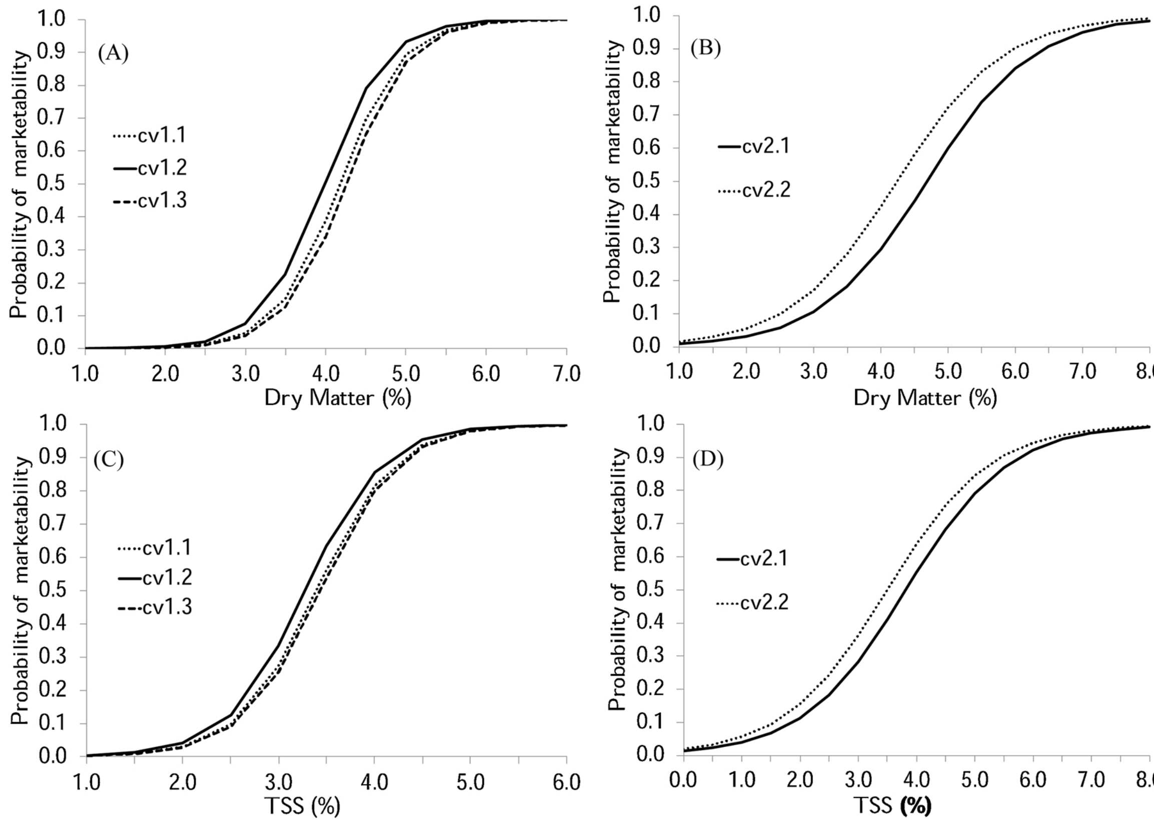

Fig. 5. Effect of probability of marketability as a function of TSS and DMC of cucumber during its storage and affected by cultivars (study 1: cv1.1, cv1.2, and cv1.3; study 2: cv2.1 and cv2.2).

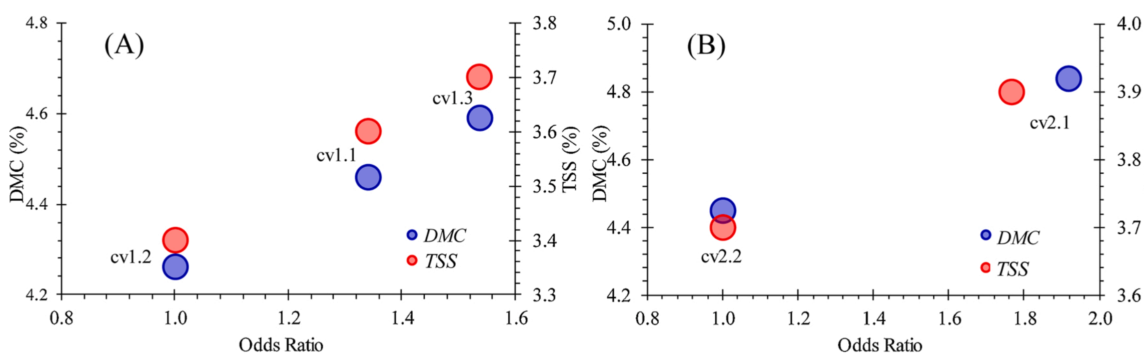

Fig. 6. Relationship between odds ratio and DMC and TSS of cucumber at collection for cultivars cv1.1, cv1.2, and cv1.3 (A) and cv2.1 and cv2.2 (B). The multiple binary logistic regression model considered cultivar and storage time as factors influencing the probability of marketability of cucumbers. The cultivars cv1.2 and cv2.2 were considered as reference (odds ratio = 1) in their corresponding studies.

cultivars. The cultivar cv2.1 produced an increase of 8.8 % DMC and 5.4 % TSS compared with those of cv2.2. This result is related to cv2.1 showing a 1.8-fold higher probability of marketability than cv2.2. Moreover, cv1.1 show 4.7 % and 5.9 % higher DMC and TSS, respectively, than those of cv1.2, and this is associated with a 1.3-fold increase in the probability of marketability. In the case of cv1.3 and cv1.2 (reference cultivars), the increases in DMC and TSS are 7.7 % and 8.8 %, respectively, producing a 1.5-fold higher probability of marketability (Fig. 6). In general, the cultivars with lower TSS and DMC show the lowest odds ratio. As the TSS and DMC of cucumbers at harvest increase, the odds ratio increase linearly with the value of the reference cultivar. This shows that, for the cultivars studied, the higher the TSS and DMC of cucumbers at harvest, the greater the probability of cucumber market-ability (Fig. 6).

4. Discussion

The DMC and TSS of the cucumbers at harvest showed differences between the cycles and months of cultivation and between the cultivars evaluated and storage time. In the study 1, from December to February, more TSS and DMC were produced than in the study 2, from October to January. The results validate the study by Gajc-Wolska et al. (2010), who obtained higher DMC and concentration of total sugars in cucum-bers harvested in spring than in those collected in autumn. Similarly, Gómez et al. (2003) obtained higher DMC in cucumbers collected in spring compared with those harvested in winter.

In this study, once the cucumbers were collected, the TSS and DMC progressively decreased during storage. The daily rate of decrease in TSS and DMC in both studies was 0.5 %. These results are consistent with those reported by other authors. Kahramanoğlu and Usanmaz (2019) observed that the TSS of cucumbers showed a downward trend during 24 d of storage; Gómez-López et al. (2006) verified a significant decrease in TSS 14 d after harvest; and Nasef (2018) verified a decrease in TSS in cucumbers along the storage period.

The linear relationship between TSS and DMC has been described for different crops, including apples (Palmer et al., 2010), mangoes (Nordey et al., 2019), and kiwis (Harker et al., 2009). In contrast, this relation-ship in cucumbers for fresh consumption had not been explicitly studied. In the present study, the relationship between TSS and DMC of cu-cumbers was linear and maintained until senescence was reached. Therefore, when a cucumber had low TSS values, it also had low DMC and vice versa. These results are in line with those reported by other authors, although these studies failed to comprehensively evaluate the relationship between these variables. Davies and Kempton (1976) studied the changes in DMC, alcohol-insoluble solids and soluble solids during growth, ripening, and senescence of cucumbers grown in greenhouses and demonstrated a similar evolution for DMC and soluble solids. Verheul et al. (2013) studied the postharvest development of cucumbers of different origins, and the results of the DMC and TSS ob-tained showed a linear relationship. This was also verified by Colla et al. (2012, 2013) and Huang et al. (2009).

The longer the time elapsed from the time the cucumbers are harvested until they are consumed, the greater the losses and waste produced (Kader, 2008). In the present study, the DMC content at the time of collection and throughout the storage influenced and determined the shelf life of cucumbers. The longer the time from harvest to consump-tion, the lower the chances of marketing the cucumbers. In addition, the higher or lower the DMC at the time of collection determines the shelf life of cucumbers. This applies to TSS, owing to the high linear rela-tionship between TSS and DMC. On average, the results of the present study revealed that a 3-fold increase of marketability can be achieved if the DMC of the cucumbers at harvest increases by 0.5 %. Díaz-Pérez et al. (2019a) showed that multiple logistic regression is a useful tool to evaluate the shelf life of cucumbers. In their results, the storage time is one of the main factors influencing the probability of marketability, similar to the results in the present study. In addition, the influence of DMC and TSS on the longevity of the cucumber shelf life has been demonstrated.

The studied cultivars showed different values of TSS and DMC at the time of harvest. Other studies have also showed that the genetic po-tential between cultivars to produce DMC and TSS can be different (Gajc-Wolska et al., 2010; Gajc-Wolska et al., et al., 2010). In addition, high values of TSS and DMC of cucumbers at harvest were associated with a greater probability of marketability and vice versa.

The standard interpretation considers that the estimated probabilities of success between two groups are OR-times greater in group 1 than in group 2 (Bilder and Loughin, 2014). In our study, the odds ratio be-tween cultivars and storage time was calculated as these two factors influence the probability of marketability with respect to the reference during the storage. It was verified that cv1.1 and cv1.3 had 1.3- and 1.5-fold more probability of marketability than cv1.2. Similarly, cv2.1 had 1.8-fold more probability of marketability than cv2.2. Therefore, the quality of the cucumbers during storage was different between cul-tivars. This coincides with the results of Schouten et al. (2002), who obtained different shelf lives among the three cucumber cultivars. Conversely, the odds ratios between cultivars, combined with TSS and DMC showed the relationship of the probability of marketability of a cultivar with respect to the reference when the content of TSS and DMC increased or decreased in cucumbers. Our results show that, as the TSS and DMC at harvest increased, the odds ratio increased linearly with respect to the value of the reference cultivar; therefore, the probability of marketability of cucumbers increased. This coincides with Schouten et al. (2002), who verified longer shelf life in some of the cultivars they studied, although TSS and DMC was not considered as factors of influ-ence on shelf life.

5. Conclusions

The cycles and months of cultivation, type of cultivar, and storage time affect the DMC and TSS of cucumbers. Once the cucumbers are harvested, the content of TSS and DMC decrease progressively during storage; the longer the time from collection to consumption, the greater the decrease. In addition, the relationship between TSS and DMC is linear, and this relationship is maintained from collection to senescence.

The storage time and the content of TSS and DMC at the time of collection are factors that influence the probability of marketability of cucumbers during postharvest and under cold-storage conditions. Higher TSS and DMC contents at harvest indicate a longer shelf life.

The TSS and DMC of the cucumbers measured at harvest could be used as indicators to identify shelf life. These indicators (among others) may be used to manage the value chain and identification of cultivars with a potential longer shelf life. In addition, they may serve as a basis for the development of quality control and shelf life through non-destructive measurement methods. Lastly, the indicators may be utilised to decrease the amount of food wasted from harvesting until they are consumed.

Author contribution

All authors contributed equally to the conceptualisation, methodology, validation, acquisition of data, statistical analysis and interpretation, and writing of the original and revised versions.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.postharvbio.2021.111603.

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