



## Research article

Packaging design proposal motivated by the identification of damages in Andean blackberry (*Rubus glaucus* Benth)María Cristina García Muñoz<sup>\*</sup>, William Andrés Cardona, Ana María Calvo Salamanca, John Javier Espitia Gonzalez, Martha Marina Bolaños Benavides

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## ABSTRACT

Andean blackberry is a fruit recognized by its health benefits associated with its high content of bioactive compounds. However, it is also one of the most perishable fruits because it does not have a protective cuticle, and it shows high respiration and ethylene production rates. Furthermore, it is susceptible to microbiological attacks. During harvest and commercialization, the highest percentage of losses is caused by factors such as the maturity stage, harvest practices and containers, and marketing packages. The current work aims at studying the effect of the package on fruit quality, for which the harvested fruits were placed in clamshells, traditional wooden and plastic crates with a capacity of 7 kg. The quality of the fruit was evaluated by counting *in situ*, damage by bruising, cuts, deformations, microbiological attacks, missing of the peduncle, and non-uniform pollination. Damage analysis included the evaluation of different regression models considering information criteria and significant parameters ( $P \leq 0.05$ ). The use of traditional packages led to higher damage from cuts and bruises. Although in clamshells there was a higher probability of finding healthy fruits, a proposal for its redesign is proposed to guarantee a better quality and shelf life of the Andean blackberry fruits.

## 1. Introduction

Trends in food consumption show more demanding consumers in terms of food quality and safety, as well as in products that provide health benefits beyond the basic nutrients. Andean blackberry responds very well to these trends, given the high content of bioactive compounds it comprises (García and Vaillant, 2014; Alarcón-Barrera et al., 2018; Vasco et al., 2009). Further, clinical studies have demonstrated their functionality in diseases such as breast, colon and prostate cancers, and vascular diseases (Larrosa et al., 2006, 2010; Larrosa et al., 2006; Larrosa et al., 2010), thanks to the generation of secondary metabolites called urolithins (García et al., 2014; Tulipani et al., 2012; Bialonska et al., 2009). However, improper practices during cultivation, harvest, and postharvest are reducing the quality and safety of the fruit, leading to high postharvest losses, and reducing the possibility to take advantage of these invaluable functional characteristics.

Among the different factors that should be considered to reduce losses and extend the shelf life of this fruit, the maturity stage, the type of harvesting containers and marketing packages, as well as fruit handling,

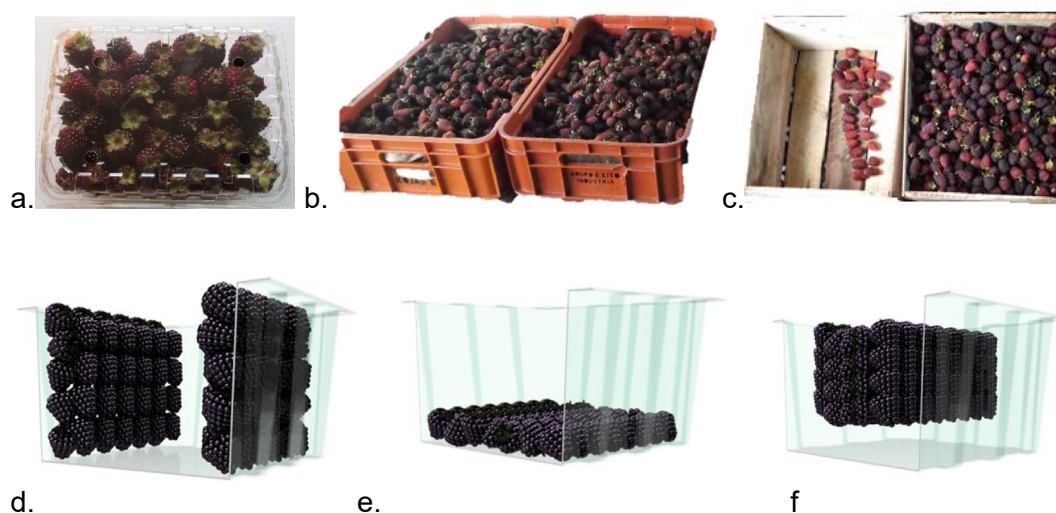
and the temperature throughout the commercialization process are highlighted.

Fruits and vegetables are an important source of vitamins and micronutrients in the diet. However, the high postharvest losses of these types of products have placed food security at risk (Singh et al., 2014) by limiting food access to a large part of the population. In this sense, around 800 million people suffer from hunger (ONU, 2018). This is inconceivable if we consider that about 1/3 of the food produced is lost (FAO, 2014).

The exact causes of food losses vary around the world. According to FAO (2017a), in Asian countries, losses of 20% in mandarin, 29% in banana, 38% in mango, and values of up to 52% in vegetables as cauliflower have been reported. In the case of more perishable fruits, such as Andean blackberry, losses of up to 60%–70% have been registered in Colombia (Ayala et al., 2013; Sora et al., 2006). Among the causes of quality loss, inefficient planning, refrigeration, storage, and transport, as well as poor packaging are emphasized (Gustavsson et al., 2011; Singh et al., 2014). On the other hand, a study carried out by FAO (2017b, 2018) showed that the improper use of packaging is the main cause of deterioration of fruits and vegetables since they generate mechanical

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**Figure 1.** Types of packages assessed and sampling points: a. Clamshells of polyethylene terephthalate (PET) package, b. Plastic crate of high-Density Polyethylene, c. Wooden crate (control); d. Wall sampling point, e. Base sampling point, and f. Center sampling point. Own source.

damage due to compression and abrasion, which, in turn, facilitates the development of pests and diseases. Packaging also plays an important role in moisture losses that deteriorate the appearance of the product and reduces its weight (Hadadinejad et al., 2018; Peano et al., 2014). According to Seglina et al. (2010), proper packaging can prolong the shelf life of fruits, protect these from damage, and prevent secondary contamination. Some studies have quantified the damages due to packaging in some food products (Anyasi et al., 2016; Affognon et al., 2015; Zewter et al., 2012), while others have focused on the effect of packaging on the reduction of product deterioration rate by controlling the physiological processes of fruit respiration and transpiration through the generation of modified and controlled atmospheres (Hadadinejad et al., 2018; Peano et al., 2014). Nonetheless, little has been investigated in the use of packages and its relation to mechanical damage. In Colombia and Costa Rica, blackberry is mainly sold in plastic bags (Castro-Herrera, 2012) that do not meet the basic packaging requirements, such as protection against mechanical damage (i.e., impact, compression, and vibration) during handling and distribution (Castro and Cerdas, 2005). Accordingly, the aim of this study is to identify the relationship between the type of package and the different kinds of damage suffered by Andean blackberry fruits to establish package design parameters that lead to the reduction of postharvest losses and improve fruit quality.

## 2. Material and methods

### 2.1. Material

The fruits used in this study were obtained from an Andean blackberry with thorns or *Mora de Castilla* plantation located in the municipality of Sylvania, department of Cundinamarca, Colombia, located at 4°27.723' N and 74°19.493' W, at an altitude of 2,408 m.a.s.l. The fruit was harvested at the maturity stages 4 (MS4), 5 (MS5), and 6 (MS6), according to NTC 4106 (Icontec, 1997), eliminating all fruits that did not meet the standards for good quality fruit.

### 2.2. Packaging

The fruit harvested was placed in several types of packages as follows. In polyethylene terephthalate (PET) clamshells of 125 g (C125), 250 g (C250), and 500 g (C500), respectively, with four holes in the lid and base, and non-hermetic closure for ventilation. In a plastic crate (PC) of high-density polyethylene (HDPE) of 7 kg capacity and with ventilation slots, and in a wooden crate of 7 kg capacity, which was taken as a

control, as it is the most common package used by Andean blackberry farmers in the country. In Figure 1 (a-c), the different types of packages evaluated are observed, and in Figure 1 (d), the three sampling points for the identification, quantification, and categorization of fruit damages are shown. These will be used to establish package design parameters to reduce fruit deterioration causes and extend its shelf life.

### 2.3. Harvest

Andean blackberry fruits were harvested directly by the producers in their respective PET clamshells, which were subsequently arranged in plastic HDPE crates for easy transport. In the case of packaging using wooden (WC) and plastic (PC) crates, the fruit was first harvested in containers used to collect coffee beans and then transferred to the WC and PC until reaching a weight of 7 kg. Subsequently, all the fruit harvested on one day was transported in the back of a non-refrigerated vehicle with wooden stakes that were covered with a tent to the wholesale food distribution center in Bogotá, department of Cundinamarca, Colombia. The fruit was collected at 18:00 h on the farm and delivered to the wholesale plant at 01:00 h, where three crates of WC, PC, and C500, and six clamshells of C125 and C250 were taken at random for inspection. These packages were immediately transported to the analytical chemistry laboratory of Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA) in the research center C.I. Tibaitatá for physicochemical analysis.

### 2.4. Inspection

The fruits of each package and section (location within the package) were arranged in different groups for their respective inspection. Initially, each group was subdivided according to their maturity stage, and subsequently, the fruit was classified as healthy and damaged through a visual inspection and by direct count. Then, the damaged fruit was separated in fruits with bruises, without sepals and peduncle, with non-uniform pollination, with cuts or deformations, and with microbiological damage (fruits with symptoms caused by the fungi such as *Botrytis cinerea* and *Peronospora sparsa*: gray mold and watery rot). Variables related to fruit weight, equatorial diameter, color parameters, firmness, pH, total soluble solids (TSS) and titratable acidity (TA) were measured based on the methodology used by Monroy-Cárdenas et al. (2019). Additionally, the maturity index (MI) derived from the TSS/TA ratio was calculated.

**Table 1.** Packages characteristics evaluated.

Package type	Length (m)	Width (m)	Height (m)	Superficial area, SA (m <sup>2</sup> )	SA/Height	Fruit Location*
Plastic crates (PB) of 7.000 g	0.60	0.39	0.17	0.234	1.38	Base
						Center
						<b>Wall</b>
Wooden crates (WB) of 7.000 g	0.35	0.28	0.12	0.098	0.82	Base
						Center
						<b>Wall</b>
Clamshells 125 g (C125)	0.106	0.052	0.044	0.0055	0.125	Base
						Center
						Wall
Clamshells 250 g (C250)	0.106	0.052	0.073	0.0055	0.075	Base
						Center
						Wall
Clamshells 500 g (C500)	0.185	0.14	0.085	0.0259	0.304	Base
						Center
						<b>Wall</b>

Note: the maturity stage 4 (MS4) was found only in larger packages (wooden and plastic crates).

\* The fruit location inside the package highlighted in bold was taken as a reference for each regression model generated.

The variables associated with the damages found in the fruit and its maturity stage, as well as the physicochemical properties were evaluated under the effect of the type of package and the location inside the package, as observed in Table 1.

**2.5. Statistical analysis**

Considering that the variables associated with the damages found in fruits were recorded by counting (where excesses of zeros were evidenced), the data were analyzed using Poisson, Negative Binomial (NB), Zero-Inflate Poisson (ZIP) and Zero-Inflated Negative Binomial (ZINB) models, selecting the best for each type of damage by comparing Pearson's chi-square, the complete log-likelihood (CDL), and the information criteria (AIC: Akaike information criteria, AICC: AIC with a correction for finite sample size, and BIC: Bayesian information criteria) of each model. On the other hand, to assess the type of damage in each package concerning the location of the fruit within each container, the log-likelihood criteria, and the information criteria (AIC and SBC: Schwarz Bayesian

information criterion) were considered to choose the best regression model. The parameters were considered significant when they showed a  $P \leq 0.05$ . The statistical analysis was carried out using the procedures "proc countreg" and "proc genmod" of the SAS 9.4 software.

For the variables associated with chemical and physical parameters, a MANOVA was performed for the type of package and maturity stage. Subsequently, a univariate analysis (ANOVA) was carried out for each of the variables associated with chemical parameters and firmness. For the physical parameters (non-normal and without transformation possibilities), a principal component analysis with the different types of packages used and the maturity stage of the fruits was performed. Finally, another ANOVA was carried out for the variables associated with each of the selected components. Differences between means were selected based on the t-test ( $P \leq 0.05$ ). The normality assumptions pointed out that the firmness variable needed to be transformed using Log+1. Further, TSS and MI were transformed by  $X^2$ , and the acidity was transformed by its multiplicative inverse. These analyses were performed using the SAS 9.4 software.

**Table 2.** Model chosen to explain the effect of the type of package on the reduction of the different types of damages in Andean blackberry fruits during its commercialization.

Type of damage	Model	Package type	% damage reduction compared to the WC (control)	Pr > ChiSq
Cuts	ZIP	C125	95.6	<0.0001
		C500	84.54	<0.0005
		PC	-150	<0.0221
Bruises	NB	C125	86.5	<0.0001
		C250	70.39	<0.0001
		C500	47.06	<0.0017
Deformations	ZIP	C125	78.68	<0.0001
		C250	70.94	<0.0289
		C500	48.94	<0.0351
Microbiological	ZINB	C125	90.34	<0.0001
		C250	85.46	<0.0002
Without sepals and peduncle	NB	C125	35.45	<0.0173
		PC	-200	<0.0001
Non-uniform pollination	NB	C125	88.89	0.0056
		C250	92.59	0.0155
		PC	91.67	0.0216

ZIP: Zero-Inflated Poisson, NB: Negative Binomial, ZINB: Zero-Inflated Negative Binomial, WC: Wooden crates, PC: Plastic crates.

**Table 3.** Type and grade of damage found in Andean blackberry fruits compared to fruit located against the wall of the plastic and wooden crates.

Type of damage	Model	Location in the package	Ratio of damage of fruit in the wall to fruit in other locations	Pr > ChiSq
<b>Plastic crater</b>				
Cuts	Poisson	Base	2.9	<0.0216
Bruises	Poisson	Base	3.9	<0.0001
		Center	1.8	<0.0092
Deformations	Poisson	Base	7.6	<0.0001
Microbiological	Poisson	Base	3.6	<0.0031
		Center	2.4	<0.0358
Without sepals and peduncle	Poisson	Base	4.0	<0.0001
		Center	1.9	<0.023
Healthy fruits	Poisson	Base	1.4	0.0283
		Center	1.6	0.0002
<b>Wooden Crates</b>				
Cuts	ZIP	Base	-96.71%	<0.0015
Bruises	NB	Center	-70.44%	<0.0001
Microbiological	Poisson	Base	4.2	<0.0187
Without sepals and peduncle	Poisson	Base	32.3%	<0.05
		Center	67.1%	<0.0002

ZIP: Zero-Inflated Poisson, NB: Negative Binomial.

### 3. Results

All the Data found for every one of the variables and factors evaluated are presented in the Supplementary material. Table S1 describes information concerning fruit damages, Table S2 shows results for physical parameters; Table S3 firmness data and Table S4 summarize the results for chemical parameters.

#### 3.1. Type of damage per package

Table 2, shows the regression model that adjusted best to each type of damage. The same table shows the effect of the type of package on damage reduction to the fruit, taking as a reference the wooden crate (control). The models were selected by comparison of Pearson's chi-square (closer to 1) and the lowest values in the complete log-likelihood criteria, AIC, AICC, and BIC. As an illustration, to estimate the damage from bruises, the best regression model that explains this type of damage was the Negative Binomial. This model indicates an 86.5% reduction in damage due to bruising with the use of the C125 package, but also a 150% increase in this type of damage if the plastic crate is used, compared to the wooden crate ( $P < 0.05$ ) as seen in Table 2.

#### 3.2. Effects of the package and fruit location inside the package on fruit quality

The type of damage suffered by the fruit is described below. Also, the relationship between these and the location of fruit in the package, taking as reference or point for comparison, the fruits located against the wall of the package.

##### 3.2.1. C125 clamshell

The ZIP model was the best fit to explain the relationship between this package and the presence of healthy fruits and fruits with non-uniform pollination damage. The damages associated with cuts, deformed fruits, or microbiological damages were not significant in any of the regression models generated. Concerning the location of the fruit in the package and the type of damage, the possibility of finding fruits without sepals and peduncle was 3.2 times higher in the fruit located in contact with the walls and the center of the box compared to the fruit located in the base of the package. Similarly, fruits located in contact with the wall

of the container showed 68.62% ( $P < 0.0364$ ) less healthy fruits compared to the base.

##### 3.2.2. C250 clamshell

The Poisson model showed the best values in selection criteria for the damages associated with bruises, fruits without sepals and peduncle and healthy fruits. Meanwhile, the damages associated with cuts, fruits with non-uniform pollination, or microbiological damage were not significant in any of the regression models generated. In this package, the fruits located in contact with the walls presented 63.2% fewer fruits with bruise damage compared to those located at the base ( $P < 0.0239$ ). Finally, the fruits located against the walls of the container and in the center of the same showed 2.7 times more fruits without sepals and peduncle compared with the fruits located in the base ( $P < 0.0073$ ). In general terms, 2.7 times healthier fruits were found in the center of the container compared to the ones located at the base ( $P < 0.0023$ ).

##### 3.2.3. C500 clamshell

The Zero-Inflated Poisson (ZIP) model showed the best values in selection criteria for damage associated with bruising, microbiological damage and healthy fruits. Meanwhile, the damages associated with cuts, fruits with non-uniform pollination, without sepals and peduncle, or deformed, were not significant in any of the regression models generated. The results showed that the fruits located in the center of the container are 9.5% and 4.9% more likely to be damaged by bruising and suffer microbiological damage, respectively, compared to those located at the base. On the other hand, there are 5.56% more possibilities of finding healthy fruits in the center area compared to those located at the base of the package.

##### 3.2.4. Plastic crate (PC)

The Poisson model showed the best values in selection criteria for the damages associated with cuts, bruises and deformed fruits, as well as microbiological damages, fruits without sepals and peduncle and healthy fruits. On the other hand, the damage associated with non-uniform pollination was not significant in any of the regression models generated. Table 3 summarizes the results found per type of damage and its relationship with the location of the fruit in the plastic crate and wooden crate. According to this table, in the base of the package, there is 3.9 times more fruit with damage by bruising compared to those located in contact with the wall ( $P < 0.0001$ ).



**Table 4.** Means of variables associated with chemical parameters and the type of package.

Variable	Package type	Mean	P*	Variable	Package type	Mean	P*
TSS	C500	7.77	A	TA	C250	3.933	a
	PC	7.76	ab		C125	3.727	ab
	C250	7.58	ab		WC	3.660	ab
	C125	7.13	bc		PC	3.647	bc
	WC	6.94	c		C500	3.871	c
pH	PC	2.873	a	MI	C500	2.41	a
	C125	2.854	ab		PC	2.28	a
	C250	2.810	bc		C125	1.98	b
	WC	2.799	c		C250	1.97	b
	C500	2.778	c		WC	1.94	b

PC: Plastic crates, WC: Wooden crates, TSS: Total soluble solids, TA: Titratable acidity, MI: Maturity index.

\* Different letters indicate significant differences at  $P \leq 0.05$ .

### 3.2.5. Wooden crate

The damages associated with bruises, deformations and healthy fruits adjusted best to the negative binomial (NB) model, while the fruits affected by microbiological damage and those without peduncle and sepals adjusted best to the Poisson model. According to Table 3, the damages due to cuts were 96.7% less frequent in fruits located at the base of the wooden crate compared to the fruits located in contact with the walls of this container.

## 3.3. Physical parameters

### 3.3.1. Firmness

Firmness, was the only physical parameter that registered a significant effect concerning the type of package and fruit location within the package. The fruits in packages C125 and C250 showed a firmness of 1.22 and 1.09 kgf, respectively, compared to 0.85 and 0.84 kgf reported in fruits in packages C500 and WC, respectively.

In the PC, a significant effect ( $P \leq 0.05$ ) of the fruit location on its firmness was found. The fruits located in contact with the wall and the center of the container had values of 1.29 and 1.02 kgf, respectively, in contrast to the fruit in the base that reported values of 0.74 kgf. The maturity stage did not make a significant difference in fruit firmness.

### 3.3.2. Principal component analysis and physical parameters

Considering that the other physical parameters were not adjusted to a normal distribution, a principal component analysis (PCA) was performed by transformation to assess the effect of different packages on these parameters. Three components with eigenvalue  $\geq 1$  were chosen, which explained 74.0% of the variability observed. In component 1 (PC1) the variables associated with fruit growth were represented. In component 2 (PC2) the variables associated with L and Chroma were included, and in component 3 (PC3). The Hue variable was represented. The multivariate analysis (MANOVA) showed significant differences ( $P \leq 0.05$ ) for the type of package and the fruit maturity stage. According to this analysis, the fruits packed in the PC had a higher average weight (7.31 g) ( $P < 0.05$ ) compared to the fruits in the C250 (6.02 g), C125 (5.96 g) and WC (5.89 g) packages. Further, the maturity stage showed no relationship with weight. On the contrary, the equatorial diameter showed an inverse relationship with the maturity stage ( $P < 0.05$ ), finding values of 19.43 mm for Andean blackberry fruits in maturity stage MS4, 18.82 mm in MS5 and 18.1 mm in MS6. Finally, in terms of color, significant differences due to the maturity stage were found for L, (luminosity parameter), which showed the highest values for MS5 (18.29) ( $P < 0.05$ ) compared to the luminosity for MS6 (17.97).

### 3.3.3. Packages and physical parameters

The principal components selected represented between 60% and 80% of the variability. The first component (PC1) included variables

related to fruit size and weight, while PC2 and PC3 included variables related to color (L, Chroma, and °Hue), except for WC. For this package, PC1 represented color variables and PC2 included size and weight variables.

The multivariate analysis (MANOVA) reported significant differences ( $P \leq 0.01$ ) for the type of package and the maturity stage for packages C125, C250, PC, and WC. The fruits located in contact with the wall of package C125 showed higher weight compared to those located in the center. Regarding the maturity stage, fruits in MS6 reported higher color intensity. Similarly, the fruits in the C250 box in MS5 registered the highest weight (6.55 g) and Chroma (19.2) compared to the fruits in MS6 (5.43 g and 18.5, respectively). In the plastic crate, the multivariate analysis showed significant differences ( $P \leq 0.01$ ) due to the location of the fruits in the package and the maturity stage. The fruits located in contact with the wall showed higher weight compared to those located in the center and at the base of the container. These results are contrary to the luminosity results, which were higher in the fruits located in the base of the container. On the other hand, fruits in MS4 showed a higher weight, diameter and luminosity (7.88 g, 19.5 mm, and 16.98, respectively) compared to fruits in MS6 (7.14 g, 18.14 mm and 16.34, respectively). Finally, in the wooden crate, the fruits located at the base of the package have a higher weight (7.52 g) compared to those located in contact with the wall (6.54 g) ( $P \leq 0.01$ ), while the fruits against the wall, showed a larger diameter (19.92 mm) compared to those located at the base (16.2 mm) ( $P \leq 0.01$ ). Regarding the maturity stage, the fruits in MS4 showed higher weight and diameter (7.6 g and 19.32 mm, respectively) compared to the fruits in MS6 (6.83 g and 17.19 mm, respectively) ( $P \leq 0.01$ ). The color parameters showed no significant differences. In the C500 box, the MANOVA analysis did not identify significant differences ( $P \leq 0.05$ ).

## 3.4. Chemical parameters

The maturity stage did not show significant differences in the chemical variables evaluated. The TSS ranged between 7.27 and 7.33° Brix, and acidity between 3.758 and 3.751% in MS5 and MS6, respectively. The pH was the only chemical parameter that showed a significant difference between MS6 (2.845) and MS5 (2.793). The type of package indicated significant differences according to the multivariate analysis ( $P \leq 0.05$ ) for all the variables considered, as can be seen in Table 4. The fruit contained in the C500 package had a higher TSS content compared to the fruit in packages C125 and WC. The pH was higher in the PC and C125 packages compared to the WC and C500. On the other hand, fruit acidity was higher in the C250 container compared to fruits contained in the PC and C500 packages. Finally, the maturity index reported higher values for the fruit contained in the C500 and PC packages compared to all the others.

Although a relationship between the chemical parameters and the type of package was not expected, the best characteristics showed by the fruits were found in the C500 package, mainly due to the lower acid content that favors a higher pH and MI values.

## 4. Discussion

### 4.1. Effect of the type of package on fruit damage

The results showed that PET clamshells of 125, 250, and 500 g capacities are a good option for the commercialization of Andean blackberry since the damages in these types of packages were significantly lower compared to those presented in the other types of packages (Table 2). This can be explained because of the low capacity of these packages, which significantly reduces the weight borne by the fruits located at the bottom of the container. Further, these packages have non-rough surfaces, reducing abrasion damage. As these packages are not reused, such as the PC or WC, they always have adequate physical and hygienic conditions. Finally, by having a low capacity and being transparent, fruit selection and handling activities carried out by the personnel in charge are more careful.

Among these PET clamshells, C125 showed better results, possibly due to its lower capacity. The container of 250 g is higher and has a smaller base area, so the fruit located in the base may have a greater chance of being damaged by bruising and cuts, among others. According to Cerdas (1995) and Aranguren (2006), PET clamshells provide an excellent commercial presentation to the product, increasing its value. However, it cannot improve the sanitary condition or the physicochemical characteristics of the harvested fruits. Moreover, it will not be able to correct the damages caused before being packed due to a bad harvest and postharvest product handling (Gil et al., 2015).

### 4.2. Location of the fruit in the package and different types of damage

Regarding the location of the fruit within each package and the damages these fruits show, the highest damage percentage of fruits showing no sepals and peduncle is found in those located in contact with the wall. The design of the PET clamshell explains this result, as these containers have a fixed and a mobile part, so the peduncle can get imprisoned in this space, causing its abscission. In the WC and PC packages where this type of damage was higher in fruits located at the base compared to the ones in contact with the wall, this can occur due to the imprisonment of the peduncle between the same fruits, which added to the higher weight that they bear and the vibration during transport, can facilitate its detachment.

The higher presence of fruits with damage by bruises located in contact with the walls of the PET clamshell is explained in the relief design that these packages have on their walls, while their base is flat without relief, reducing this type of damage (Figure 1). In the PC, the highest percentage of damage due to bruises presented by the fruit located at the base of the container can be explained by the weight that the fruit column exerts on the fruits located in this position. In the case of the WC, the highest presence of fruits with damage due to bruises in the fruits located in contact with the walls is explained by the material of the container, since the wood is rough, so the fruits in contact with it can suffer abrasion due to the vibration generated during transport.

In the PC, the most serious damage due to cuts suffered by the fruits located at the base of the package is explained by the presence of slots in the container at the base, and the pressure these fruits bear from the weight of the fruit on top, cutting the fruit. In the WC, the higher presence of fruits with damage in contact with the walls could be explained by the presence of splinters, imperfections of the material, presence of nails or pins used to join the walls, i.e., factors that can increase the possibilities of cutting the fruits.

The higher presence of microbiological damage at the base and center of the PC package can be a consequence of the greater damage caused by

bruises and cuts that the fruit showed in this location. These wounds or damages are the gateways for pathogenic microorganisms that only look for the right conditions for their development and fruits with damages provide these. In the case of the WC package, both the material and the marketing logistics favor microbiological attacks, since the wood makes cleaning and disinfection difficult as it is an absorbent material as well as difficult to dry. Furthermore, and as is well known, humidity favors the development of fungi in such a way that when these containers are reused, they contaminate the fruit transported in these.

Non-uniform pollination damage is not caused by the type of package, but it is affected by the most demanding selection made during harvest.

The results found in this study can be used to design a more suitable container for the commercialization of Andean blackberry, and these are the points we highlight:

- The container should have smooth, polished and non-rough surfaces to prevent the fruit from being damaged by abrasion.
- The design of the container should not include relief to avoid bruises, cuts or malformations to the fruit, which later facilitates microbiological development.
- If the container has a lid, it must fit perfectly to avoid having a space between the two parts (base and lid) that generates borders or cutting edges that cause cuts or bruises to the fruit.
- The container should be made in a material that does not interact with the fruit and does not retain moisture.
- Transparent containers facilitate visual inspection of the fruit and reduce damages by handling.
- Slots in fruit packages should be redesigned to maintain ventilation without causing mechanical damage to the fruit. These slots could be located at the wall package, keeping the number and size, as they are enough to avoid accumulation of heat and respiration gases concentration.
- The container should be sufficiently resistant to protect the fruit throughout its distribution and marketing.

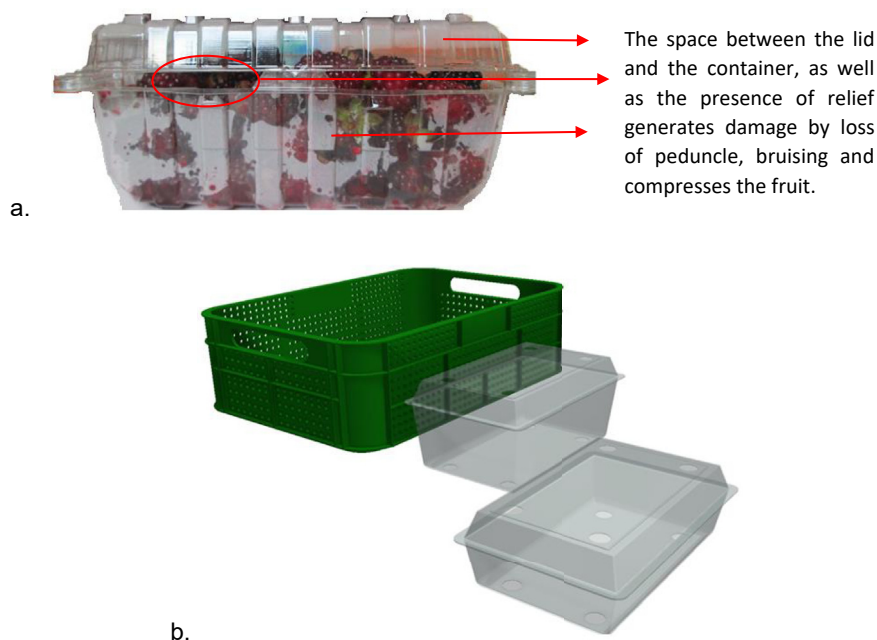
Regarding harvesting and transport practices, the results obtained allow us to make some recommendations, as follows:

- A rigorous selection of the fruit must be carried out to avoid harvesting and marketing fruit with damage.
- Reduce to the maximum the movement of the fruit in the packages to decrease damages by abrasion, bruises, and cuts.
- Take advantage of the low capacity of the PET clamshells to select and classify fruits during harvest to reduce handling.

According to our results, PET clamshells can be a good alternative for the commercialization of fruit, especially fruit highly susceptible to damage, but their surfaces must be smooth, without any relief, and it must close precisely, to leave no spaces that generate borders or cutting edges. The surface area/height ratio should be high to reduce the damage due to the weight of the fruit column and facilitate visual inspection.

Under these considerations and according to the dimensions of the packages shown in Table 1, the container C125 has an adequate surface area/height ratio considering its capacity. Container C250 is too high in relation to its base area, so we recommend modifying its dimensions to 0.106 m \* 0.07 m \* 0.06 m (height), to improve its surface area/height relation to resemble the one of C125 without affecting its capacity. Finally, although C500 has a good surface area/height ratio, its structure is not strong enough for the capacity it bears and to withstand the commercialization process. Therefore, we recommend increasing the thickness of the PET film when fabricated. In contrast, the PC and WC packages have a good surface area/height ratio and are structurally strong enough to withstand handling throughout the marketing process.

Regarding ventilation, all PET clamshells, although they have a lid, they also have ventilation holes, which reduce the accumulation of heat and condensation inside the container. The PC and WC containers are not



**Figure 2.** a. Current clamshells with the shortcomings identified in its design for the commercialization of Andean blackberry. b. Proposed models for high capacity plastic crates and clamshells with suggested changes in their design for the adequate commercialization of Andean blackberry. Own Source.

closed, which facilitates ventilation. However, in the case of the PC, the slots that it has, both in walls as well as in its base are very large. These slots carve the fruit, causing damage by bruising and cuts. In this case, a redesign of these slots is required. These slots should be narrower, or their shape should not be longitudinal but circular and smaller, among other alternatives that should be evaluated. In Figure 2, recommended changes are presented for both the PET clamshells as well as for the high capacity of the plastic crate.

#### 4.3. Physical parameters

##### 4.3.1. Firmness

The fruit in the C125 and C250 PET clamshells reported the highest firmness values, which agrees with the results of less damage due to bruises and cuts found in these packages, as these containers have a lower capacity and depth, the fruits do not withstand the high fruit column weight that the fruits bear in the other packages. Therefore, these fruits remained firmer compared to the high capacity packages, but particularly, compared to those of higher depth. In contrast to what Monroy-Cárdenas et al. (2019) and Ayala et al. (2013) found, in this study, no significant relationship was found between the maturity stage and the firmness values in fruits.

##### 4.3.2. Principal component analysis and physical parameters

The principal component analysis for the evaluation of other variables showed similar results to those reported by Ayala et al. (2013), who affirmed that the weight of the fruit shows an ascending behavior with an increase of 10% from maturity state MS4 to MS5, and 2% from MS5 to MS6, similar to the results found in the current study, i.e., 7.5% increase by weight from MS4 to MS5 and 2.8% from MS5 to MS6. Regarding color, these results confirm what was found by Monroy-Cárdenas et al. (2019) and Horvitz et al. (2017), where less mature fruits have a higher luminosity compared to fruits in more advanced maturity stages, indicating a loss of brightness of the fruit associated with senescence.

#### 4.4. Chemical parameters

During fruit maturity, the increase in pH is explained by the conversion of starches into sugars, the dilution and metabolization of acids

during ripening and respiration processes (Kader, 1999. Wills et al., 1998; Gallo, 1996), and the decrease in the concentration of H<sup>+</sup> ions at the vacuolar level in the later maturation stages (Montalvo, 2010; Ayala et al., 2013; Monroy-Cárdenas et al., 2019). Considering both the physical and chemical parameters, we recommend that Andean blackberry fruit should be harvested in maturity stage 4 (MS4), considering that in this stage, higher weight, size, and brightness are found. Although in the current study no differences in firmness were found, in other studies higher values are reported for this maturity stage compared to MS6 (Monroy-Cárdenas et al., 2019). Furthermore, although the MI of fruits in MS6 are higher than those found in MS4 (Carvalho and Betancur, 2015), the short shelf life of fruits in MS6 prevents their harvest and commercialization.

It is important to note that the monitoring of the physicochemical parameters allowed us to observe that these are not affected by the type of package, the location of the fruit in the package or the type of damage suffered by the fruit. This is possibly because of the short evaluation time that does not allow these damages to be reflected in the properties assessed since the tests were carried out in less than 24 h (including harvest, packaging, transport, and delivery to the wholesale dealer). On the other hand, this period was enough to observe the damage that the type of package can cause to the fruit. Firmness was the only physicochemical property that was clearly affected by the type of package.

## 5. Conclusions

The use of packages designed following the characteristics of the product to be contained can drastically reduce the causes of damage to the fruit during its postharvest management and commercialization.

PET clamshells have advantages over wood and plastic crates, such as having a smaller capacity, which reduces handling, facilitates inspection, and reduces damage from bruising. Nonetheless, it also forces handling personnel to be more demanding in the process of selecting the fruit to harvest.

PET clamshells can be improved to reduce postharvest damage, by designing them with smooth walls, without relief, with a higher surface area/height ratio (in the case of the C250 g container) and for the C500 g container, a stronger structure should be used to withstand firmly the capacity for which it is designed.

Regarding the harvest maturity stage, we recommend harvesting Andean blackberry fruits in the maturity stage 4 (MS4), given the higher firmness it shows, which gives it a longer shelf life with a minimum sacrifice of TSS accumulation, reflected in a lower MI compared to MS6.

## Declarations

### Author contribution statement

María Cristina García Muñoz: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

William Andrés Cardona: Analyzed and interpreted the data; Wrote the paper.

Ana María Calvo Salamanca, John Javier Espitia Gonzalez: Performed the experiments; Wrote the paper.

Martha Marina Bolaños Benavides: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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### Competing interest statement

The authors declare no conflict of interest.

### Additional information

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## References

- Affognon, H., Mutungi, C., Sangina, P., Borgemeister, C., 2015. Unpacking postharvest losses in Sub-Saharan Africa: a meta-analysis. *World Dev.* 66, 49–68.
- Alarcón-Barrera, K., Armijos-Montesinos, D.S., García-Tenesaca, M., Iturralde, G., Jaramilo-Vivanco, T., Granda-Albuja, M.G., Alvarez-Suarez, J.M., 2018. Wild Andean blackberry (*Rubus glaucus* Benth.) and Andean blueberry (*Vaccinium floribundum* Kunth) from the Highlands of Ecuador: nutritional composition and protective effect on human dermal fibroblasts against cytotoxic oxidative damage. *J. Berry Res.* 8 (3), 223–236.
- Anyasi, T.A., Aworh, C.O., Jideani, A.I., 2016. Effect of packaging and chemical treatment on storage life and physicochemical attributes of tomato (*Lycopersicon esculentum* Mill cv. Roma). *Afr. J. Biotechnol.* 15, 1913–1919.
- Aranguren, I., 2006. Desarrollo de un producto fresco cortado, utilizando piña dorada. Universidad de Costa Rica, San José, Costa Rica, p. 139.
- Ayala, S.L., Valenzuela, R.C., Bohórquez, P.Y., 2013. Variables determinantes de la madurez comercial en la mora de Castilla (*Rubus glaucus* Benth.). *Revista Scientia Agroalimentaria* 1, 39–44. <http://revistas.ut.edu.co/index.php/scientiaagro/article/view/29/>.
- Bialonska, D., Kasimsetty, S.G., Khan, S.I., Ferreira, D., 2009. Urolithins, intestinal microbial metabolites of pomegranate ellagitannins, exhibit potent antioxidant activity in a cell-based assay. *J. Agric. Food Chem.* 57 (21), 10181–10186.
- Carvalho, C.P., Betancur, J.A., 2015. Quality characterization of Andean blackberry fruits (*Rubus glaucus* Benth.) in different maturity stages in Antioquia, Colombia. *Agron. Colomb.* 33 (1), 74–83.
- Castro-Herrera, C., 2012. Evaluación del efecto del período de almacenamiento y tipo de empaque sobre la calidad poscosecha y nutricional de la mora vino (*Rubus adenotrichus* Schltdl.). Tesis presentada para optar al grado de licenciado en ingeniería agronómica con énfasis en fitotecnia. Facultad de ciencias agroalimentarias, Universidad de Costa Rica.
- Castro, J., Cerdas, M., 2005. Mora (*Rubus* spp.) Cultivo Y Manejo Poscosecha. Ministerio de Agricultura y Ganadería. Universidad de Costa Rica. Consejo Nacional de Producción, San José, Costa Rica.
- Cerdas, M.M., 1995. Evaluación de empaques para comercializar mora (*Rubus* sp.) en el mercado. Convenio Poscosecha CNP-UCR, San José, Costa Rica, p. 9.
- FAO, 2014. Save food -iniciativa global de reducción de pérdida y desperdicio de alimentos-. Evaluación de pérdida de alimentos: causas y soluciones. Casos de estudio en los subsectores agrícolas y pesqueros de pequeña escala. FAO.
- FAO, 2017a. Policy Measures for Managing Quality and Reducing post-harvest Losses in Fresh Produce Supply Chain in South Asian Countries. Save Food Global Initiative on Food Loss and Waste Reduction. FAO. <http://www.fao.org/3/a-i7954e.pdf>.
- FAO, 2017b. Food and Agriculture, Key to Achieving the 2030 Agenda for Sustainable Development. FAO.
- FAO, 2018. Food and Agriculture, SDG 12.3.1: Global Food Loss Index. FAO.
- Gallo, F., 1996. Manual de fisiología, patología post-cosecha y control de calidad de frutas y hortalizas. Convenio SENA - NRI, Armenia, pp. 10–41.
- García, C., Hernández, L., Vaillant, F., 2014. Diversity of urinary excretion patterns of main ellagitannins' colonic metabolites after ingestion of tropical highland blackberry (*Rubus adenotrichus*) juice. *Food Res. Int.* 55, 161–169.
- Gil, M.L., Selma, M.V., Suslow, T., Jaccsens, L., Uyttendaele, M., Allende, A., 2015. Pre- and postharvest preventive measures and intervention strategies to control microbial food safety hazards of fresh leafy vegetables. *Crit. Rev. Food Sci. Nutr.* 55 (4), 453–468.
- Gustavsson, J., Cederberg, C., Sonesson, U., 2011. Global Food Losses and Food Waste. SIK – the Swedish Institute for Food and Biotechnology. Save Food Congress, Düsseldorf, Germany.
- Hadadinejad, M., Ghasemi, K., Mohammadi, A., 2018. Effect of storage temperature and packaging material on shelf life of Thornless blackberry. *Int. J. Hortic. Sci. Technol.* 5 (2), 265–275.
- Horvitz, A., Chanaguano, D., Arozarena, I., 2017. Andean blackberries (*Rubus glaucus* Benth.) quality as affected by harvest maturity and storage conditions. *Sci. Hortic.* 226, 293.
- Icontec, 1997. Frutas frescas. Mora de Castilla – especificaciones. Norma Técnica Colombiana NTC 4106, Icontec. Bogotá, Colombia, p. 17.
- Kader, A.A., 1999. Fruit maturity, ripening and quality relationships. *Acta Hortic.* 585, 203–208.
- Larrosa, M., González-Sarriás, A., García-Conesa, M.T., Tomás-Barberán, F.A., Espín, J.C., 2006. Urolithins, ellagic acid-derived metabolites produced by human colonic microflora, exhibit estrogenic and antiestrogenic activities. *J. Agric. Food Chem.* 54 (5), 1611–1620.
- Larrosa, M., García-Conesa, M.T., Espín, J.C., Tomás-Barberán, F.A., 2010. Ellagitannins, ellagic acid and vascular health. *Mol. Aspect. Med.* 31 (6), 513–539.
- Monroy-Cárdenas, D., Cardona, W.A., García-Muñoz, M.C., Bolaños-Benavides, M.M., 2019. Relationship between variable doses of N, P, K and Ca and the physicochemical and proximal characteristics of Andean blackberry (*Rubus glaucus* Benth.). *Sci. Hortic.* 256.
- Montalvo, D.A., 2010. Evaluación de la calidad poscosecha de las accesiones seleccionadas de mora de castilla (*Rubus glaucus* Benth.) provenientes de las provincias de Tungurahua y Bolívar. Tesis de pregrado en Ingeniería Agroindustrial. Escuela Politécnica Nacional, Facultad de Ingeniería Química y Agroindustria. Quito, Ecuador, p. 174.
- ONU, 2018. The 2030 Agenda and the Sustainable Development Goals: an Opportunity for Latin America and the Caribbean. Goals, Targets and Global Indicators (LC/G.2681-P/Rev.3), Santiago.
- Peano, C., Girgenti, V., Giuggioli, N.R., 2014. Effect of different packaging materials on postharvest quality of cv. Envie2 strawberry. *Int. Food Res. J.* 21, 1129–1134.
- Seglina, D., Krasnova, I., Heidemane, G., Kampuse, S., Dukalska, L., Kampuss, K., 2010. Packaging technology influence on the shelf life extension of fresh raspberries. *Acta Hortic.* 877, 433–440.
- Singh, V., Zaman, P., Meher, J., 2014. Postharvest technology of fruits and vegetables: an overview. *J. Postharvest Technol.* 2, 124–135.
- Sora, A.D., Fischer, G., Flórez, R., 2006. Refrigerated storage of mora de Castilla (*Rubus glaucus* Benth.) fruits in modified atmosphere packaging (Almacenamiento refrigerado de frutos de mora de Castilla (*Rubus glaucus* Benth.) en empaques con atmósfera modificada). *Agron. Colomb.* 24 (2), 306–316.
- Tulipani, S., Urpi-Sarda, M., García-Villalba, R., Rabassa, M., López-Urriarte, P., Bulló, M., Jáuregui, O., Tomás-Barberán, F., Salas-Salvadó, J., Espín, J.C., Andrés-Lacueva, C., 2012. Urolithins are the main urinary microbial-derived phenolic metabolites discriminating a moderate consumption of nuts in Free-living subjects with diagnosed metabolic syndrome. *Agri. Food Chem.* 60 (36), 8930–8940.
- Vasco, C., Riihinen, K., Ruales, J., Eldin, K., 2009. Phenolic compounds in Rosaceae fruits from Ecuador. *J. Agric. Food Chem.* 57 (4), 1204–1212.
- Wills, R., McGlasson, B., Graham, D., Joyce, D., 1998. Postharvest: an Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals. CAB International, New York, p. 262.
- Zewter, A., Woldetsadik, K., Workneh, T., 2012. Effect of 1-methylcyclopropene, potassium permanganate and packaging on quality of banana. *Afr. J. Agric. Res.* 7, 2425–2437.