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Influence of harvest method on the quality and storage of highbush blueberry

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ABSTRACT

Blueberry quality is one of the most important elements that needs to be evaluated when automatisation processes, such as harvest automation, occur along the supply chain. The aim of this work was to evaluate the suitability of two blueberry cultivars, of new introduction for the area of study, to the mechanical harvest. Particularly the influence of harvest method was evaluated on the quality of cv. Cargo® and Top Shelf® for a short storage time (max. 28 days) in normal atmosphere assuming so an immediate sale of blueberries. Samples mechanically harvested were compared in terms of qualitative performance with samples manually picked throught two activity carried on two years. In the activity 1 a preliminary laboratory test simulation of mechanical harvest was carried on to evaluate the attitude of both cultivars to the automatisation process and the berries were evaluated immediately after the harvest time. The activity 2 was aimed to evaluate the quality of berries mechanically harvested in field and after the storage process at 2 ± 1 °C and 90% RH in a cold room for 28 days under normal atmospheric conditions (NA). The higher percentage of shrivelled berries for the simulation of mechanical harvest samples (SEH) (activity 1) and berries harvested with the Easy Harvester machine® (EH samples) (activity 2) in the post-harvest period was probably due to the low % of pruin on berries skin content at the harvest time (0 days). All samples although achieved a quality assessment equivalent to still marketable berries after 28 days of storage. TSSC were significantly higher in the EH group for both years. TSSC and TA were higher in Cargo® than in Top Shelf®. In general the automatisation of the harvesting process did not significantly affect blueberry quality after storage.

1. Introduction

Blueberries have experienced considerable growth in terms of production and consumption worldwide in the last decade [1,2]. The global production of blueberries has increased significantly in recent years both in terms of cultivated area and harvested product due to emerging production areas in South America, Africa and Asia. The volume of blueberries exported doubled between 2015 and 2020. The exported volumes of five countries (Peru, Chile, Canada, Netherlands and Spain) amounted to over 2/3 of the total blueberry exports in 2020. The top importers for blueberries in the world are the U.S, the Netherlands, Germany, the United Kingdom and Canada [3]. To date, evidence has accumulated from different fields of science, including human medicine and nutrition, to support the important role of these berries in the prevention of many diseases [4,5]. The invested surfaces of blueberry show high potential for growth due to the opening of new markets and the reorganisation of existing markets with the introduction of new products and new technologies. Mechanisation and precision farming are key technologies for increasing the efficiency of field production and maintaining high competitiveness in the international market with low income of seasonal human labour. Among all the possible automated operations in the fruit crop industry, harvest and postharvest show the most relevant difficulties due to the size of the berries, their orientation in the bush and the state of their readiness to be picked, which can affect the quality of stored fruits using different techniques [6]. Among berry crops, blueberries have been of interest to many researchers regarding the possibility of introducing different automated processes (fertilisation of the plantation, pruning, harvesting, sorting and packing blueberries) into the supply chain [7–10]. In fact, fruit quality is one of the most important elements to be evaluated during the automatisation process and throughout the entire supply chain. The berries must maintain the same quality as those manually harvested being more susceptible bruise damage [11]. Focusing on the harvesting process, several studies have confirmed that mechanical harvesters affect fruit texture and do not pick

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only mature berries, thereby losing marketable fruit [7,8,12]. Bruising is one of the most frequently reported damages to blueberry tissue [13], and it is difficult to monitor externally due to the dark colour of the fruit's skin; however, its effect severely compromises both the post-storage and shelf life of fruit [14,15]. In addition to the damage that can result from the impacts to the fruit (bruising), mechanically harvested blueberries are more susceptible to deterioration caused by incorrect removal of the pedicel, which can cause greater weight loss and may represent a vehicle for fungal diseases [12]. Among the factors that affect the mechanisation of the harvest process for blueberry are the following:

- Detachment of the berry from the plant is a function of the abscission characteristics at the two breaking points (the peduncle–pedicel junction or the fruit–pedicel junction) [16].
- Berry ripeness is fundamental for good postharvest management. The selection of blueberries could be a function of the uniformity of colour and size.
- Susceptibility to plant damage is a function of the plant architecture. Olmstead and Finn [17] suggested that blueberry cultivars with short pedicels, large berry size and cluster ("tight") architecture are not amenable to harvesting machines.
- The use of new cultivars suitable for mechanized harvesting [8]

Recently, a study in the Italian context suggested interesting results in terms of harvesting efficiency, labour productivity and farm rentability for the planning of blueberry production and marketing [10]. The harvesting method is also suggested to drive the storage management of blueberries in normal atmosphere (NA) or modified atmosphere (MA) and as consequence the type of market sale [10].

At the light of previous consideration the aim of this work was to evaluate the suitability of two blueberry cultivars, of new introduction for the area of study, to the mechanical harvest. Particularly

The influence of harvest method was evaluated on the intrinsic and extrinsic berries quality of cv. Cargo® and Top Shelf® for a short storage time (max. 28 days) in normal atmosphere assuming so an immediate sale of blueberries. Furthermore, the research aimed to link the results obtained from a preliminary laboratory test and a field mechanical harvest test in order to discuss the two activities performed together.

2. Materials and methods

2.1. Plant material and experimental setup

For this study, two activity experiments were carried out as reported in Table 1. All activities were performed on cv. Cargo® and Top Shelf® that are new late and mid-early season cultivars suitable for their characteristics in the machine-harvesting process. These cultivars are of new introduction for the area of the study (Cuneo, Piedmont) and under evaluation for the *shelf life* attitude in the post storage field research. Both blueberries cultivars (*Vaccinium corymbosum* L.) were harvested from a commercial orchard (in 2018, 4 years old and in 2019, 5 years old) in Lagnasco, Cuneo, Piedmont, Italy (44°38′N 7°33′E). The experimental period lasted two years (2018–2019). Both cultivars were grown under homogenous conditions and planted in 3.00 m × 0.90 m plots (2875 plants*ha-^{1}) in loam soil with a drip irrigation system and under a net hail. In the activity 1 a preliminary laboratory test simulation to evaluate the attitude to the mechanical harvest of cv Cargo® berries and Top Shelf® berries was performed. Simulated mechanical harvesting was carried out in the laboratory of the Department of Agricultural, Forest and Food Sciences (DISAFA), University of Turin. For each cultivar, 300 berries were collected using a mechanical harvest simulation (SEH samples) for comparison with control berries [18]. Control berries (not fallen fruit) were harvested under field conditions and were traditionally manually harvested (MH samples). In the activity 2 field mechanical harvest with Easy Harvester® [10] machine and blueberries postharvest quality was performed. Cargo® and Top Shelf® cultivar harvested with the Easy Harvester machine® (EH samples) were compared with manually harvested blueberries (MH samples). Harvested fruit, from the second picking time on 600-plant plots, was manually preliminarily selected and classified by the quality operators of the Agrifrutta Soc. Agr. Coop. (Piedmont, Italy), which is one of the most important companies for the berries production and sale in Italy [10].

From the 600 plants measured production, the yield per hectare was estimated with the following calculation method:

1) Actual blueberries harvested (kg)/600 plants = blueberries harvested per plant (kg*plants^{-1})
2) Blueberries harvested per plant (kg*plants^{-1}) * 2875 plants*ha^{-1} = second picking time estimated production (kg*ha^{-1})

The percentage for each ripening stage class was calculated for both cultivars and for both harvest metods (EH e MH). Since the blueberry field used for the test was a homogeneous orchard, we assumed that the ripening class percentages measured on the 600 plants plot represent the percentage of unmarketable fruit per hectare.

Then only marketable blueberries were stored and evaluated for the postharvest quality. The postharvest quality evaluation of blueberries was performed for each activity (1 and 2) on blueberries packed in rigid ventilated polyethylene terephthalate (PET) baskets (INFIA s. r.l., Forlì, Italy). For each samples 0.250 kg of fruit were considered. Blueberries were stored at 2 ± 1 °C at 90% RH in Agrifrutta Soc. Agr. Coop cold storage for 28 days under normal atmospheric conditions (NA) [19]. Blueberry samples were analysed at the start (0 days) (only for the activity 1) and after 7, 14, 21 and 28 days of storage.

2.2. Qualitative evaluation on blueberries

All analysis on blueberries were reported in Table 1. To evaluate the impact of mechanical harvest on blueberries, a visual evaluation of external and internal aspects was performed according to Ref. [18], with some modifications (Fig. 1). For the external visual evaluation the blueberries surface was considered, counting the shrivelled berries (%), the presence of pruin on the skin (%), and a general quality assessment with a five-grade scale. For the internal aspects the bruising pulp was observed. The internal bruising of the pulp was scored on the sliced fruit on a 5-point scale, from 5 (unusable) to 1 (excellent). The proportion (%)

Table 1
Qualitative blueberries analysis for the activity 1 and 2.

	Visual external evaluation			Visual internal evaluation		Qualitative analysis		
	Shrivelled berries %	Pruin on skin%	General judgement	Bruising Index (BI) %%	Marketable fruits	Total soluble solid content (TSSC) °Brix	Titratable acidity (TA) meq/L	TSSC/TA
Activity 1	x	x	x	x				
Activity 2	x	x	x	x	x	x	x	x

Fig. 1. Blueberry score measurement for the internal visual evaluation (IB) [18].

of total blueberries presenting symptoms was considered as follows:

$$0\text{–}9\% = 1;\ 10\text{–}25\% = 2;\ 26\text{–}50\% = 3;\ 51\text{–}75\% = 4;\ 76\text{–}100\% = 5$$

Then, the bruising index (BI) was calculated as follows:

Bruising Index: $\sum$ (Fruit score × Number of blueberries with this score)/Number of sampled blueberries.

Categories were assigned based on the extent of bruised equatorial area: 1 (0–9%), 2 (10–25%), 3 (26–50%), 4 (51–75%), and 5 (>75%).

The general quality assessment was visually scored using a 5-point scale: 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = unusable. Fruit was rated visually [20] as follows:1 = 76–100% decay, severe to extreme decay; 2 = 51–75% decay, moderate to severe decay; 3 = 26–50% decay, slight to moderate decay.

4 = 1–25% decay, probable decay (brownish/greyish sunken minor spots); 5 = 0% decay.

Scores above 3 were considered marketable. 300 fruits for each cultivar and harvest method were considered for the visual evaluation of external and internal aspects.

The marketable fruits were evaluated as follows: the berries were grouped into three classes based on healthy fruit and the ripening stage [21] as follows:

- Marketable blueberries (bright blue colour)
- Green/immature blueberries
- Overripe (extremely dark; senescent/damaged blueberries)

As performed according to Ref. [19] the total soluble solid content (TSSC), the titratable acidity (TA) and their ratio (TSSC/TA) was measured. The TSSC was determined in the juice using a handheld Atago digital refractometer model PR-32 (Atago, Italia, Milan, Italy). The TA was measured using an automatic titrator (Titritino 702, Metrohm, Switzerland), and it was determined potentiometrically using 0.1 N NaOH to an end point of pH 8.1 in 10 mL of juice made up to volume with deionized water [22,23]. The results were expressed as meq/L. The TSSC/TA ratio is largely influenced by the cultivars, is reported as an indicator of overall sweetness [24]. The TSSC, TA and TSSC/TA results were expressed as an average of 3 replicates for each sample control quality day.

3. Statistical analysis

Analyses of the data were conducted when possible with IBM SPSS Statistics software (Version 25.0). The results are expressed as the mean ± SD. Two-way ANOVA and Fisher's least significant difference (LSD) test were used to investigate significant differences ($p < 0.05$).

4. Results

4.1. Activity 1

The highest percentage of shrivelled berries was observed for each storage day and for both cultivars for samples simulating mechanical harvest (SEH) (Fig. 2). The water loss is consistent with the % pruin on skin decrease observed in the same samples. The reduction in wax content was already visible at the start time (0 days) when compared with manually harvested berries, that showed a reduction after 21 days. This phenomenon was due to the berry surface mechanical abrasion during falling, and it didn't affect the general quality assessment up to 21 days; after this time, SEH samples showed lower score when compared with MH samples. At the end of the storage time (28 days), SEH samples were still considered marketable, with scores of 3 and 4 for Top Shelf® and Cargo®, respectively.

For both varieties, the SEH samples showed the highest BI values at all storage control days (Fig. 3). After 7 days of storage, the increase in bruising was 0.56 and 0.67 for Top Shelf® and Cargo® SEH samples, respectively, while it was +0.33 and + 0.16 for the Top Shelf® and Cargo® MH samples, respectively. The BI trend may be linked to the fact that after 7 days of storage, there was a greater manifestation of internal damage on fallen berries compared to that on the day of harvest. Cargo® showed lower IB values for the MH samples than for Top Shelf ®.

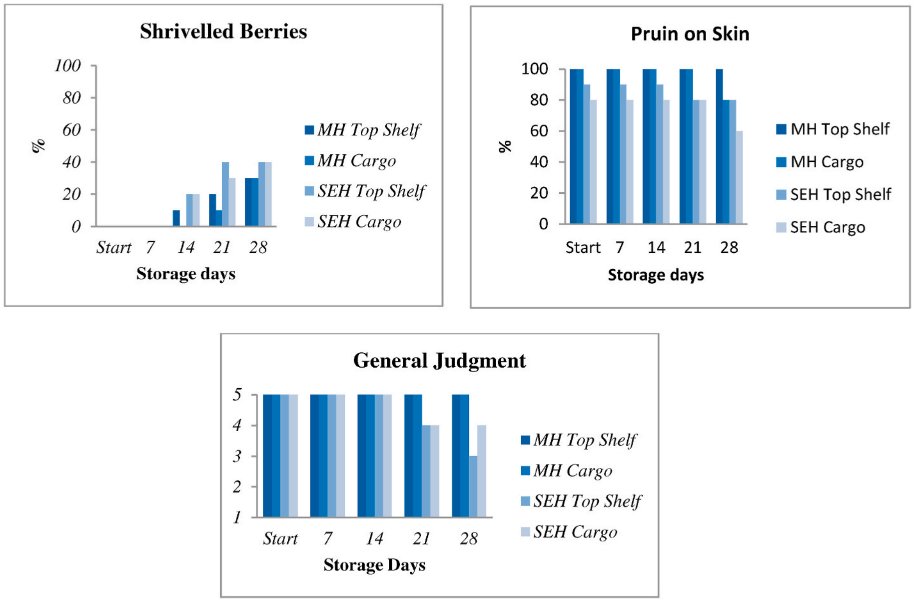

Fig. 2. Visual evaluation of external aspects (from 0 to 28 days) in postharvest storage for the Cargo and Top Shelf cultivars. Simulation of mechanical harvest (SEH) and manual harvest (MH) in 2018: % shrivelled berries (A), % pruin on skin (B) and general judgement (C). Number of blueberries samples = 300 for each variety and harvest method.

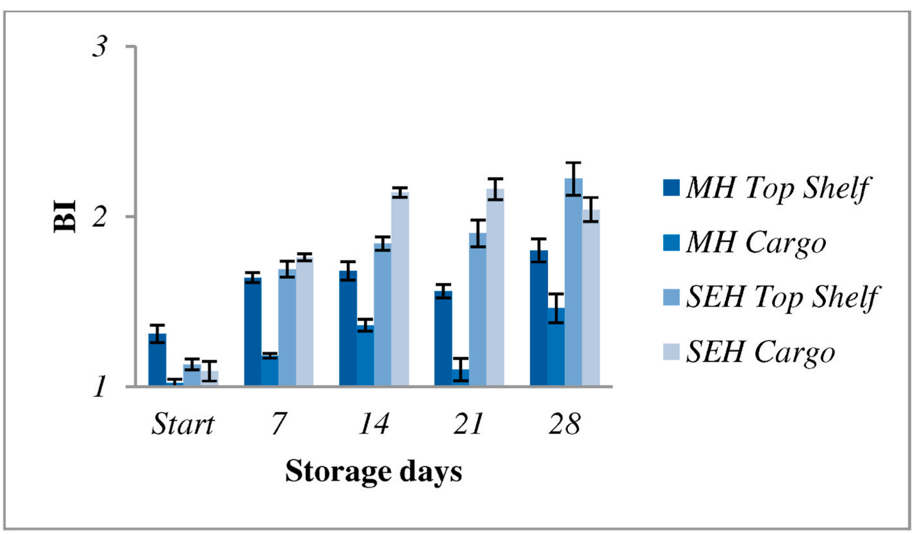

Fig. 3. Bruising index of berries in postharvest storage (from 0 to 28 days) for Cargo® and Top Shelf® after simulation of mechanical harvest (SEH) and manual harvest (MH) in 2018. Number of blueberries sampled = 300 for each variety and harvest method. BI categories: 1 (0–9%), 2 (10–25%), 3 (26–50%), 4 (51–75%), and 5 (>75%).

4.2. Activity 2

In both years of research, the blueberries yield per hectare at the second picking time was higher on Top Shelf for both types of harvest (Table 2). Cargo shows a −30% fruit harvest for MH and EH. This difference is explained by the winter pruning. The same number of productive buds was left on the two varieties but Top Shelf has an average fruit size larger than Cargo.

Table 2
Estimated production*ha^{-1} at second picking time (kg) based on the actual harvest data on 600-plant plots for the Cargo® and Top Shelf® cultivars. The two varieties were both harvested using Easy Harvest (mechanical harvest—EH) and manual harvest (MH) methods in 2018 and 2019.

Production*ha^{-1} (kg)		
	2018	2019
MH Top Shelf	661	2645
MH Cargo	403	1150
EH Top Shelf	575	2300
EH Cargo	374	1466

During both years of the research, the greatest product losses for both harvest methods were related to green and immature fruits detached from the bush during the harvest operation (Fig. 4). EH harvesting showed the greatest product losses in 2018 and 2019, both as green/immature and overripe/damaged, for both cultivars.

In the two year period, EH on Top Shelf® showed an annual marketable product average of 92.95%, which was −5.05% compared with MH, while Cargo® had an annual average of 95.67%, which was 2.90% less than the MH samples.

Considering the two cultivars and the two years of the experiment,

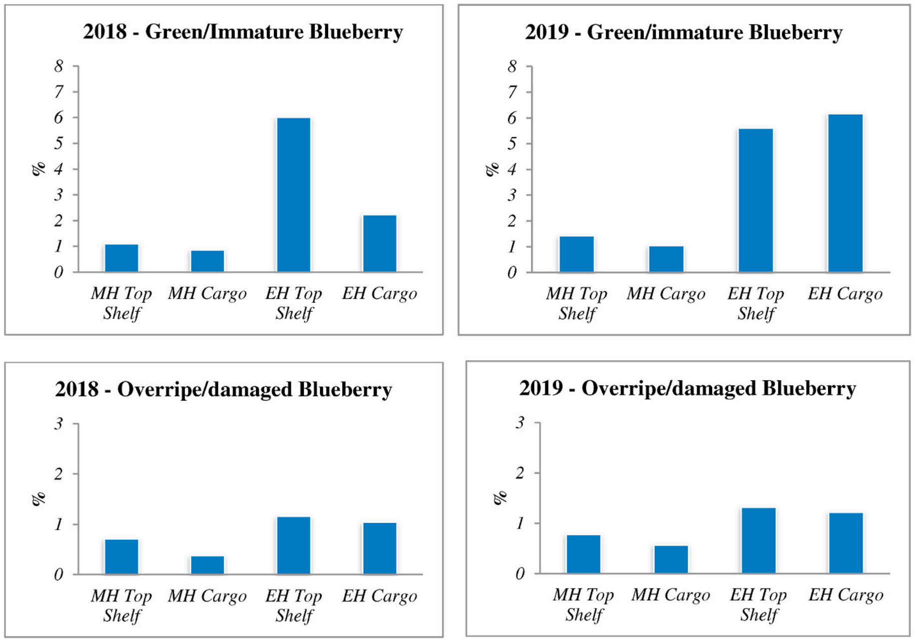

Fig. 4. Percentage of green/immature blueberries and overripe/damaged blueberries of Cargo® and Top Shelf®, derived from manual selection after harvest with Easy Harvest (mechanical harvest—EH) and manual harvest (MH) in 2018 and 2019 at day 0. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the green and immature EH fruits were, on average, 3.40% higher than the MH harvest, while the overripe and damaged berries showed an average increase of 0.58% with EH.

In the 2 years of the research and for the two harvesting methods, Cargo® showed the lowest percentage of no-marketable blueberries, both as green/immature and overripe/damaged fruits.

Comparing the two harvesting methods, in terms of green and immature berries over the two years, Cargo® had a lower average annual percentage difference of no-marketable products (2.25%) compared to Top Shelf® (4.55%). Top Shelf® highlights the greatest differences between the two harvest methods, both in 2018 (4.91%) and 2019 (4.18%).

Considering EH over the two years, Cargo® showed a global average annual loss (green/immature + overripe/damaged) of 4.33%, while Top Shelf 7.07%. In 2018, EH Cargo® led to 3.27% of global losses, compared to 7.17% for EH Top Shelf. In 2019, EH Cargo® showed a total loss of 5.39%, compared with 6.93% in EH Top Shelf®.

The external visual analysis carried out on day 0 didn't highlight the presence of shrivelled fruit, and no differences were observed on the general judgment, which both had a value of 5 for the two harvest methods and for the two cultivars in the research years (data not shown).

Differences between EH and MH for both varieties were detected (both in 2018 and 2019). The percentage of pruin present on the EH fruits showed an average of 70.0%, which was −22.5% compared to MH (Fig. 5).

EH on Cargo® showed a berry pruin percentage of 65% in 2018 and 60% in 2019. These percentages were lower than the EH Top Shelf® samples (80% in 2018 and 75% in 2019).

In both years of the research, Cargo® showed the greatest difference in terms of pruin percentage between EH and MH (−25% in 2018 and −30% in 2019).

In the internal and qualitative visual analyses performed on day 0, both in 2018 and 2019, the two varieties and two harvesting methods evidenced significant differences considering the TSS, TA and BI parameters. The interaction between harvesting methodology and variety was significant in the two years for the TA.

Regarding the TSSC, EH had significantly higher values (13.63 in

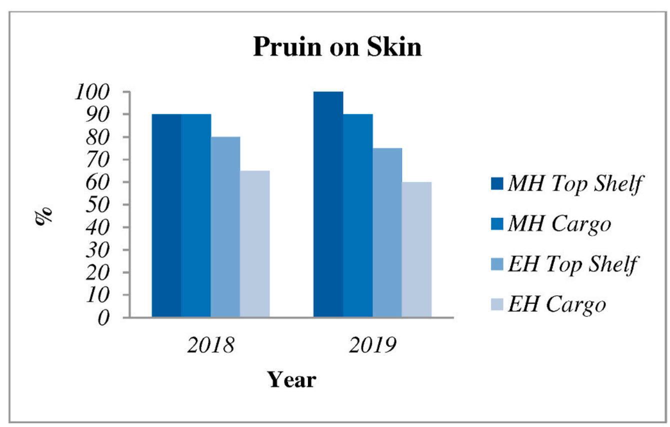

Fig. 5. Percentage of pruin on marketable berry skin at 0 days for Cargo® and Top Shelf® after harvest with Easy Harvest (EH) and manual harvest (MH) in 2018 and 2019. Number of sampled blueberries = 300 for each variety and harvest method.

2018 and 11.90 in 2019) than MH (13.05 in 2018 and 11.28 in 2019) (Table 3). TA showed discordant results in the two-year period. In the first year, EH had a significantly higher TA than MH, while in the second year, it was significantly lower. Regarding BI, EH had a significantly higher index than MH (+0.14) in both 2018 and 2019.

However, considering the cultivars, the TSSC and TA were significantly higher in Cargo® than Top Shelf® for the two research years. The BI on Cargo® was significantly lower than Top Shelf® in the two year period.

The external visual analysis conducted for the 28-day storage test showed that the pruin percentage tended to be lower on the EH product for both varieties (Table 4). On the 28th day of observation, EH Cargo® and EH Top Shelf® highlights an average pruin percentages of 45% and 52.5%, calculated over the two years, while the two MH samples showed 70% and 75% pruin presence, respectively.

Furthermore, starting on the 14th control day, EH had an higher shrivelled berries percentage if compared the same variety and for both

Table 3
Qualitative analyses (TSSC, TA, and TSSC/TA) and internal fruit evaluation (BI) on marketable blueberries at 0 days after harvest for Cargo® and Top Shelf® with Easy Harvest (mechanical harvest—EH) and manual harvest (MH) in 2018 and 2019. The results were expressed as an average of 3 replicates of 300 berries each.

Year	Factor	TSSC (%)		TA meq/L		TSSC/ TA		BI	
2018	**Picking method (P)**								
	MH	13.05	b	8.497	b	1.537	ns	1.122	b
	EH	13.63	a	8.850	a	1.543	ns	1.265	a
	Variety (V)								
	Cargo	14.18	a	8.870	a	1.600	a	1.168	b
	Top Shelf	12.50	b	8.477	b	1.479	b	1.218	a
	Significance (p value)								
	P	0.000		0.031		0.845		0.000	
	V	0.000		0.034		0.003		0.038	
	P x V	0.153		0.003		0.006		0.528	
2019	**Picking method (P)**								
	MH	11.28	b	6.22	a	1.81	b	1.12	b
	EH	11.90	a	5.72	b	2.08	a	1.26	a
	Variety (V)								
	Cargo	12.22	a	6.71	a	1.82	b	1.15	b
	Top Shelf	10.97	b	5.22	b	2.11	a	1.23	a
	Significance (p value)								
	P	0.027		0.040		0.038		0.001	
	V	0.007		0.000		0.001		0.008	
	P x V	0.073		0.018		0.100		0.738	

research years.

About the general judgment, after the 21st day, more negative assessments were observed for the EH berries in both years. However, even for EH, the overall rating never dropped below 3; therefore, the product could be marketed after 28 cold storage days.

The BI analysis during the post-harvest test showed that the harvesting methods were significantly different from each other at each analysis date, both in 2018 and 2019 (Fig. 6). No significant BI differences were observed between the varieties, and there wasn't interaction between harvesting method and variety.

In the two research years, for both varieties and for the 4 observation dates, EH had significantly higher BI. However, the BI evolution over time maintained a linear growth trend for both EH and MH. In 2018, EH showed an BI increase from 1.31 for Cargo® and 1.39 for Top Shelf® on the 7th day to 1.55 and 1.65, respectively, on the 28th day. Similarly, in 2018, the manually collected samples showed an evolution from 1.14 to 1.34 for Cargo® and from 1.18 to 1.35 for Top Shelf®.

In 2019, EH's BI increased from 1.36 to 1.60 for Cargo® and from 1.39 to 1.64 for Top Shelf®. However, for MH the BI increased from 1.15 to 1.37 for Cargo® and from 1.19 to 1.39 for Top Shelf®.

In 2018, for EH and MH, there was an average BI increase between the two varieties (0.25 and 0.19, respectively) from 7 to 28 cold storage days. In 2019, this average increase was 0.25 for EH and 0.21 for MH.

On the 28th cold storage day, the two varieties were significantly different for all qualitative parameters analysed in both research years. The two types of funding were significantly different from each other in 2018 and 2019 in relation to the TSSC (Table 5). In 2019, EH and MH didn't show significant differences for TA and TSSC/TA. The interaction between variety and harvesting methods was never significant.

TSSC were significantly higher in the EH group for both years. A varieties comparison in 2018 and 2019 showed that both TSSC and TA were significantly higher in Cargo® than Top Shelf® while the TSSC/TA ratio was significantly lower in Cargo® than Top Shelf®.

5. Discussion

The higher percentage of shrivelled berries for the SEH (activity 1) and EH samples (activity 2) in the post-harvest period was probably due to the low % of pruin on berries skin content at the harvest time (0 days). The decreased exocarp wax content is due to the surface mechanical abrasion during the harvest. The berry wax layer is a natural barrier against abiotic stress and berries respiration. The surface wax reduction causes an increase in the respiration rate and blueberries with a low pruin surface are more susceptible to water and weight loss [25]. However, SEH (activity 1) and EH samples (activity 2) achieved a quality assessment equivalent to still marketable berries after 28 days of storage. The highest pruin decrease was observed in Cargo®, but the percentage of shrivelled berries was similar for both cultivars, which may be related to the two varieties berries size [26]. In fact, Cargo® is smaller than Top Shelf® suggesting a lower water content. Therefore, the weight and water loss may be less pronounced in Cargo® fruit than in Top Shelf under the same storage conditions.

The % of pruin on skin, as reported by Ref. [27], was not critical for blueberry consumption; moreover, the existing grading machines in the blueberry packhouse remove the fruit surface wax during processing.

In activity 2, the highest berries losses were observed for the EH samples; these results were in agreement with Cai et al. [19]. Mechanical harvest negatively influence the marketable yield when compared to manual harvest.

The bush manual shaking performed with EH negatively affects the berries ripening selection and leads to the unripened blueberries

Table 4
Visual analysis of the external berry aspects for Cargo® and Top Shelf® in postharvest storage from 7 to 28 days after harvest using Easy Harvest (mechanical harvest-EH) and manual harvest (MH) methods in 2018 and 2019.

2018												
	7	14	21	28								
	% S. B.	% P	G. J.	% S. B.	% P	G. J.	% S. B.	% P	G. J.	% S. B.	% P	G. J.
MH Top Shelf	10	90	5	10	90	5	10	80	5	20	80	4
MH Cargo	10	90	5	10	80	5	10	80	5	20	70	5
EH Top Shelf	10	70	5	20	70	5	20	60	4	30	50	4
EH Cargo	0	50	5	20	40	5	30	40	4	40	40	4
2019												
	7	14	21	28								
	% S. B.	% P	G. J.	% S. B.	% P	G. J.	% S. B.	% P	G. J.	% S. B.	% P	G. J.
MH Top Shelf	10	80	5	10	80	4	20	70	4	40	70	4
MH Cargo	0	80	5	20	75	4	30	70	4	20	70	4
EH Top Shelf	10	75	5	20	75	4	30	65	3	50	55	3
EH Cargo	10	60	5	30	60	4	40	50	3	40	50	3

% S.B. = % shrivelled berries; % P = % pruin on skin; G.J. = quality assessment.
Number of sampled berries = 300 for each variety and harvest method.

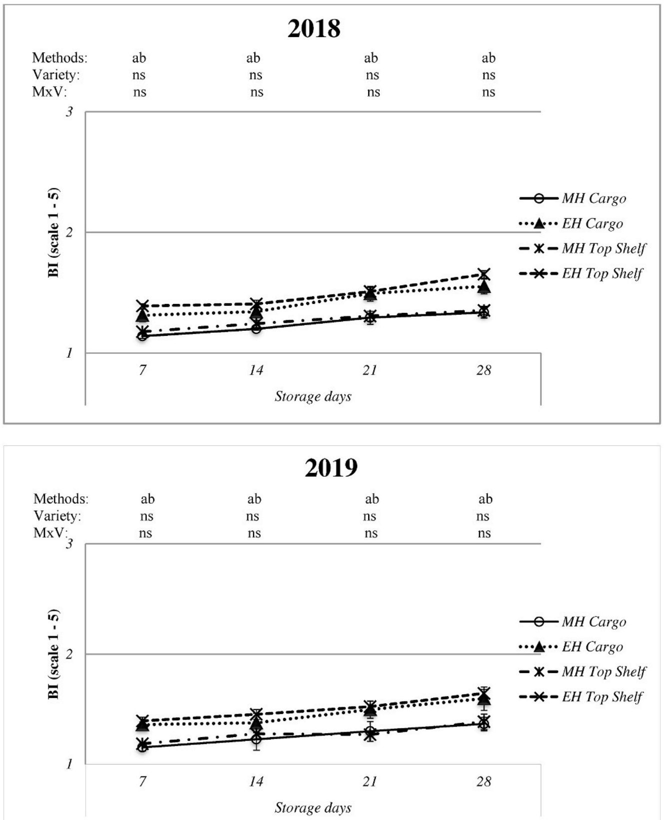

Fig. 6. Bruising index of Cargo® and Top Shelf® berries from 7 to 28 days in postharvest storage after harvest with the Easy Harvest (mechanical harvest-EH) and manual harvest (MH) methods in 2018 (A) and 2019 (B). Number of sampled berries = 300 for each variety and harvesting method. BI categories: 1 (0–9%), 2 (10–25%), 3 (26–50%), 4 (51–75%), and 5 (>75%).

Table 5
Qualitative analyses (TSSC, TA, and TSSC/TA) of marketable blueberries after 28 days of postharvest storage for Cargo® and Top Shelf® after harvest with Easy Harvest (mechanical harvest—EH) and manual harvest (MH) methods in 2018 and 2019. The results were expressed as an average of 3 replicates of 300 berries each.

Year	Factor	TSSC (%)		TA meq/L		TSSC/TA	
2018	MH	13.65	b	7.57	a	1.80	b
	EH	13.88	a	6.93	b	2.00	a
	Variety (V)						
	Cargo	14.57	a	7.740	a	1.88	a
	Top Shelf	12.97	b	6.76	b	1.92	b
	P	0.006		0.000		0.000	
	V	0.000		0.000		0.016	
	P x V	0.148		0.162		0.332	
2019	**Picking method (P)**						
	MH	11.82	b	5.88	ns	2.07	ns
	EH	12.23	a	5.65	ns	2.16	ns
	Variety (V)						
	Cargo	12.48	a	6.85	a	1.82	b
	Top Shelf	11.03	b	4.68	b	2.40	a
	P	0.048		0.452		0.672	
	V	0.001		0.000		0.016	
	P x V	0.013		0.695		0.073	

harvest. In fact, the green and immature blueberry represents the highest percentage of lost fruits for EH when compared with overripe and damaged blueberries for both varieties analysed. Additionally, for the EH samples of both cultivars, unripened blueberries were the main source of lost fruit. However, the fruit loss obtained with EH is lower than the data observed by Refs. [28,29] with OTR harvesters. The cultivars selection, as reported in previous studies [10,28,30], is one of the main factor affecting the mechanical harvesting process efficiency. Cargo® recorded the lowest green and unripe fruit losses in 2018 and 2019. In 2018, Top Shelf® lost more than double those of Cargo®. This result can be influenced by two features observed in Cargo®: at the second picking time the variety has the ability to concentrate more ripe fruit on the plant and to keep them qualitatively suitable for longer than Top Shelf®. Furthermore, the whole fruit colour change from green to blue faster and more uniform in Cargo®. In addition, Cargo® present a more open cluster and the berries have a more elongated peduncle. This feature allows the individual berries to be freer from each other, thus increasing the harvest shaking efficiency and effectiveness. Another important element is the berries detachment force from the peduncle during harvest [31]. Cargo® and Top Shelf® showed differences in their unripe berries abscission properties.

The unripe berries were more strongly maintained on the bush by Cargo®. As also affermed by Ref. [17], these characteristics influence the mechanical harvest quality in terms of ripe fruit homogeneity. Finally, the bush erect vegetative habitus is more easy to pick for the manually shaker operator. The working posture is more ergonomic, favoring greater effectiveness and precision in the shaking practice.

Considering the qualitative analyzes performed at 0 and 28 days of storage (activity 2), the highest TSSC was in the EH samples of both cultivars. Therefore, EH could harvest more mature berries than a manual harvester. The highest TSSC observed in EH may be related to the bush shaking collection mode performed with mechanical harvest. The branch shaking firstly detaches the ripe fruits with an higher TSSC, while a manual harvester can pick not completely ripe fruits due to visual selection errors during the harvest operation. Therefore, in the marketable fruit derived from the two harvest types, it is possible that the product harvested with EH has a higher ripeness and is more uniform after the packhouse selection. The same results was observed by Ref. [15]. The TSSC difference with the MH samples may have been amplified by the packhouse manual selection, as only complete blue fruits were selected.

About the varieties, TSSC and TA were higher in Cargo® than in Top Shelf®. The cultivars genetics and characteristics make Cargo® and Top Shelf® berries different from each other. The higher TSSC and TA indicate Cargo® berries as better fruit for long term storage than Top Shelf® berries [32,33]

Differences between cultivars were observed for the BI value. The Cargo® blueberries were less bruised than Top Shelf® fruits, although the difference was only significant at 0 days. This result, also according to the observations of Refs. [26,34], can be due to the Cargo®'s berry characteristics, the fruits are smaller and rounded, have a thicker peel and have a greater pruin layer than Top Shelf®.

A smaller berry has the pulp cells with a lower cell volume, providing more compact and resistant structure to the fruit's pulp. In addition, smaller cells have less water content and, therefore, greater external impacts resilience that can cause cell rupture.

At the same time, the thicker skin is made by larger cell walls cells. Therefore, about the various reasons discussed, Cargo® was more suitable for EH harvesting.

Regarding the harvesting method, EH showed a higher BI for both varieties. However, after 28 days cold storage, a marketable product was obtained. In according to Ref. [12] the impacts of the mechanically harvested fruit, especially in relation to the berries fall, caused the pulp cells rupture of the pulp in the peripheral berry area, with subsequent necrosis development.

However, the EH product BI maintained the same growth trend observed for the manually harvested berries and no sudden growth was highlighted in the post-harvest observations. The trend don't indicates an rapid berry quality decay.

EH fruits showed a global senescence process similar to MH sample.

Therefore, mechanically harvested berries are also suitable for a post-harvest process.

Considering the overall fruits management in the packhouse, the EH product will be manually selected at the packhouse entrance in order to improve the post-harvest performance. Furthermore, the EH fruits must be marketed before the MH product, considering a 30 days maximum life in post-harvest. The MH berries must be destined for a storage process longer than 30 days.

MAP could extend the EH fruits life in post-harvest process, since the modified atmosphere would further reduce the berries transpiration, even if they showed a lower % of skin pruin.

6. Conclusion

This study showed how mechanical harvesting represents a concrete possibility for the fresh market blueberry harvest. The blueberry harvest automation didn't significantly affect fruit quality after short post-harvest process. The more suitable blueberry cultivar choice was an important element for have the best quality performance management in the orchard and post-harvest activities. The harvest mechanisation in the blueberry supply chain should be considered a possibilities for optimise the farm rentability. However, in the future it will be necessary to evaluate further parameters in relation to the blueberry mechanical harvest, such as berries nutraceutical analysis and any MAP positive effects on fruits in the post-harvest process.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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