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SCIENZE AGRARIE, FORESTALI E ALIMENTARI

CICLO: XXXV

CONTESTO DEI PICCOLI FRUTTI ITALIANI: FOCUS SUI PRINCIPALI PROBLEMI DI FILIERA E POSSIBILI SOLUZIONI SPERIMENTATE

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1. SUMMARY

Nel mondo dei *berry fruits* (lampone, mirtillo gigante, ribes, mora di rovo), la globalizzazione del mercato, l'aumento delle aree di produzione nei due emisferi e l'incremento esponenziale dei quantitativi prodotti e movimentati a livello mondiale stanno causando una crescente competitività sul mercato.

Nonostante l'aumento dei consumi, tale situazione sta avendo ripercussioni negative soprattutto su alcuni Paesi Europei come l'Italia dove, dati i maggiori costi di produzione rispetto ad altri paesi UE ed extra UE, la discesa dei prezzi causata da una sovra-offerta potrebbe compromettere la sostenibilità economica del comparto. Il settore è un importante motore per la crescita economica e l'occupazione, soprattutto nelle regioni del nord Italia ed ha un forte orientamento, in particolare per quello che riguarda il mirtillo, verso i mercati di esportazione. Tuttavia si osservano inefficienze nell'attuazione di strategie volte a superare i limiti della concorrenza dei mercati, a causa dell'indifferenziazione del prodotto e del processo produttivo. Tali sfide sono particolarmente significative nella filiera internazionale dei *berry fruits*, dove l'implementazione della differenziazione di prodotto e di processo si basa su standard di alta qualità e su politiche di responsabilità sociale d'impresa.

Pertanto l'elevata qualità delle produzioni e il suo mantenimento, costante e differenziabile sul mercato è l'unica strategia per aumentare il consumo generalizzato di *berry fruits* e quindi creare una domanda capace di assorbire totalmente l'offerta evitando il collasso dei prezzi sul mercato.

Per raggiungere questo obiettivo è necessario operare per un miglioramento complessivo della filiera dei *berry fruits* dal campo alla distribuzione. Tale settore presenta caratteristiche specifiche e distintive rispetto ad altri prodotti freschi, legati in particolare alla elevata deperibilità dei frutti, alle forti fluttuazioni della domanda e dei prezzi, alle crescenti preoccupazioni per la sicurezza alimentare e gli aspetti ambientali nonché alla dipendenza dalle mutevoli condizioni climatiche. Queste caratteristiche hanno un impatto notevole

sulla gestione della *supply chain* dove molto spesso sono ancora numerosi gli operatori e non sempre vi è un adeguato scambio di informazioni che porta ad un *mismatch* tra domanda e offerta (innescando la saturazione del mercato e la riduzione dei prezzi). Tutti questi fattori richiedono una maggiore condivisione delle informazioni, flessibilità e coordinamento all'interno della filiera in modo da creare un legame stabile tra la fase di produzione e le tendenze del mercato.

In Italia la formalizzazione di queste relazioni nel settore frutticolo si è sviluppata attraverso la nascita delle Organizzazioni di produttori (OP) che hanno avuto e hanno un ruolo determinante nel connettere la fase produttiva con le esigenze del mercato agevolando economie di scala, elevati standard qualitativi, aumentando la pianificazione ed il coordinamento, massimizzando la promozione e le attività di ricerca.

Il percorso di Dottorato in Regime di Apprendistato qui di seguito presentato vuole rispondere alle necessità di ricerca della società OrtofruitItalia soc. agr. coop. O.P., un'Organizzazione di Produttori che raggruppa al suo interno circa 200 aziende agricole che insistono con impianti produttivi in Piemonte, Lombardia, Veneto, Lazio, Puglia e Calabria. La società opera tradizionalmente nel mercato italiano ed europeo, prevalentemente (92% del valore della produzione) con la Grande Distribuzione Organizzata, con rapporti diretti fra l'ufficio commerciale di Ortofruit Italia e gli uffici acquisti delle varie catene. I clienti principali sono Coop (Italia), Esselunga (Italia), Conad (Italia), Dimar (Italia), Carrefour (Italia), Megamark (Italia), Edeka (Germania), Kaufland (Germania), Rewe (Germania), Lidl (Germania, UK, Slovenia, Repubblica Ceca), Spar (Austria).

Il progetto di Dottorato in Regime di Apprendistato si colloca quindi all'interno dell'impellente necessità della Società OrtofruitItalia di analizzare le criticità della filiera dei *berry fruits* ed intraprendere attività di ricerca che portino a risultati con una ricaduta nel breve e medio periodo sull'intera filiera al fine di ottimizzarne le *performances*.

Analizzando la filiera sono state scelte alcune delle criticità di maggiore interesse a livello mondiale e relative ai *berry fruits* economicamente più importanti.

Dopo una prima analisi su quelle che sono le principali criticità della filiera, gli attuali *trend* nella ricerca a livello mondiale e le produzioni ci si è focalizzati su 3 *topic* considerati di fondamentale importanza per le dinamiche di OrtofruitItalia:

1- PROBLEMATICHE PATOLOGICHE EMRGENTI: Per il mirtillo ed il lampone il *focus* della ricerca è stato legato alla fase di campo dato che la riuscita agronomica ed economica della coltura sta alla base dell'ottenimento e al mantenimento di elevate caratteristiche qualitative nei successivi *step* della filiera, in un'ottica di mantenimento di competitività sul mercato e di riduzione dei costi di produzione. Sia per lampone che per mirtillo sono state ricercate soluzioni alla comprensione di problematiche patologiche emergenti (*stem blight and dieback* su mirtillo e *cane blight* su lampone) in relazione ai cambiamenti climatici e all'intensificazione dei sistemi produttivi. Tali problematiche potrebbero causare una forte riduzione delle produzioni e degli ettari messi in coltura.

2- RACCOLTA: sempre per mirtillo è stato analizzato uno dei punti ritenuto cruciale per la competitività economica nella fase produttiva della filiera, cioè la raccolta. Tale operazione risulta, da un punto di vista economico la più onerosa a causa della richiesta di un numero elevato di ore di manodopera e nel contempo anche *step* fondamentale per il mantenimento delle caratteristiche qualitative del prodotto nelle fasi successive. E' stata quindi analizzata la possibilità di utilizzo di macchine agevolatrici della raccolta anche nell'ottica di migliorare le condizioni di lavoro degli operatori.

3- PROLUNGAMENTO DELLA *SHELF-LIFE*: per il ribes è stata studiata la tematica dell'allungamento della *shelf-life* in fase post raccolta. Questo rappresenta un obiettivo di primaria importanza al fine di limitare la perdita di prodotto, mantenere elevata la qualità del frutto fresco ed allungare il periodo di commercializzazione.

L'approccio adottato per sviluppare la ricerca è andato nella direzione di individuare un nuovo modello di collaborazione tra mondo produttivo e mondo della ricerca. Tale collaborazione può rappresentare un motore di innovazione che agevola e consolida la posizione competitiva delle imprese sul mercato nazionale ed internazionale. Per il mondo delle aziende agricole è infatti necessario creare una rete per l'innovazione, in cui l'azienda agricola stessa è uno degli attori principali e dove trova uno spazio importante anche il soggetto che a tutti gli effetti gestisce e assicura il collegamento tra produzione di conoscenza (Università), sistema produttivo e mercato, una connessione che, pur con numerose varianti, trova la sua naturale collocazione in un soggetto aggregatore come le OP. Si è quindi inteso creare un modello di ricerca che evidenzi reciproche opportunità (Università-Impresa) lungo tutta la filiera della ricerca: in fase di generazione di idee, di formazione, di sviluppo tecnologico e di valorizzazione industriale ed economica.

2. INTRODUZIONE

2.1. ASPETTI NUTRIZIONALI E CONSUMI

La ricerca scientifica degli ultimi anni legata al mondo dei *berry fruits* si è ampiamente interessata allo studio delle loro proprietà benefiche e agli effetti positivi sulla salute umana derivanti dall'introduzione di questa tipologia di frutta nella dieta quotidiana. All'interno della categoria individuata come *berry fruits*, i più importanti da un punto di vista produttivo e commerciale sono il mirtillo, il lampone, la mora di rovo, il ribes, il *cranberry* e negli ultimi anni il *baby kiwi* (*Actinidia arguta*). Oltre a queste produzioni sono presenti numerose altre specie che vengono coltivate localmente quali *gooseberry, mulberry, elderberry, bilberry, loganberry, wolfberry* ed altri ibridi derivati da incroci tra la mora di rovo ed il lampone (*tayberry*). E' ampiamente riconosciuto come il loro elevato contenuto in antociani, polifenoli, minerali e vitamine ed il basso tenore in calorie e lipidi li rendano dei *superfood* fortemente apprezzati e ricercati dai consumatori come *healty food* (Crescimanno *et al*. 2014). Infatti, rispetto ad altre tipologie di frutta e verdura, sono riconosciuti come un concentrato di sostanze benefiche. E' noto che questi composti hanno importanti attività antiossidanti, antiglicemiche, antivirali, antinfiammatorie, antiallergiche e antimicrobiche (Golovinskaia & Wang 2021). La capacità antiossidante dei *berry fruits* è quattro volte superiore rispetto a quella evidenziata da altra frutta e dieci volte superiore a quella delle verdure (Manach *et al.* 2004). In diversi studi sono state dimostrate le proprietà antiossidanti e antinfiammatorie dei *berry fruits*, dovute al loro elevato contenuto in sostanze bioattive come vitamine e polifenoli (Baby *et al.* 2018; Battino *et al.* 2021). Grazie a questi contenuti è stato provato che svolgono un'azione attiva nella prevenzione del cancro, del diabete, dell'obesità e di malattie cardiovascolari e neurodegenerative (Golovinskaia & Wang 2021; Gasparrini *et al*. 2017; Peña-Sanhueza *et al.* 2017). Relativamente alla prevenzione del cancro, numerosi studi affermano che l'azione antiossidante espressa dai *berry fruits* ha manifestato effetti benefici contro gli stress ossidativi, possibile causa di insorgenza della malattia (Krikorian *et al.* 2010; Castro & Teodoro 2015;

Skrovankova *et al.* 2015). Effetti positivi sulla riduzione dell'obesità e del diabete sono stati osservati, dato che i *berry fruits*, ricchi di antociani, possono ridurre l'aumento dei livelli di glucosio nel sangue e migliorare i disordini metabolici causati dal diabete (Stoner *et al.* 2010). I flavonoidi dei *cranberry*, ad esempio, ritardano l'assorbimento intestinale di glucosio migliorando la risposta glicemica ed inoltre possono ridurre la glicemia a digiuno, aumentando la sensibilità all'insulina (McDougall *et al*. 2005; Wilson *et al.* 2010; Wilson *et al.* 2008; Paquette *et al.* 2017). Altri risultati supportano il contributo dei *berry fruits* alla salute umana, infatti come affermato da Song et al. (2013), l'estratto della buccia di mirtillo può essere utilizzato come alternativa ai farmaci, ricchi di effetti collaterali, per il controllo dell'obesità a lungo termine (Song *et al.* 2013). I *berry fruits* hanno la capacità di proteggere la salute attraverso il contenimento dell'aggregazione piastrinica, la riduzione dello stress ossidativo, la regolazione del metabolismo e l'influenza positiva sui lipidi nel sangue (Wightman & Heuberger 2015; Rodriguez-Mateos *et al*. 2019). Infatti la maggior parte dei *berry fruits* contengono flavonoidi che migliorano il flusso sanguigno, mentre i polifenoli e gli antociani sono utili nel trattamento delle malattie cardiovascolari, mostrando una significativa attività di abbassamento della pressione sanguigna e dell'ipertensione (Karaagac & Ucurum 2019; Cassidy *et al.* 2016; Clark *et al*. 2015; Vendrame & Klimis-Zacas 2019). Per quanto riguarda le malattie neurodegenerative sia Gasparrini *et al.* (2017) che Cervantes *et al.* (2020) affermano che i *berry fruits* possono migliorare le prestazioni cognitive e di memoria, prevenire gli effetti della neuro degenerazione durante l'invecchiamento e ritardare l'invecchiamento cognitivo.

Gli affermati benefici per la salute umana sono uno dei principali motivi capaci di spiegare l'ampia crescita della domanda degli ultimi anni. Parallelamente all'aumento dei consumi, i piccoli frutti stanno evidenziando un continuo *trend* di crescita delle produzioni e quindi dell'offerta sul mercato. Tale *trend* nella produzione è strettamente connesso alla crescente richiesta, infatti questa tipologia di frutta è considerata *demand-driven*, quindi è fortemente influenzata dalla domanda dei consumatori (Bojkovska *et al.* 2020). Ad esempio in UK, dove negli anni 2000 sono state vendute circa 25.000 t di lamponi per un fatturato medio annuo di 280 milioni di sterline. Dal 2007 al 2018 il consumo di *fresh berry fruits* è cresciuto del +132% superando di molto il tasso di crescita del consumo della restante frutta fresca (+49%). Secondo quest'ultima fonte, nel 2016-2017, i *berry fruits* sono arrivati a rappresentare il 22% di tutta la frutta fresca venduta nel paese spingendo il valore della *berry industry* oltre 1,2 miliardi di sterline. Una dinamica simile si è osservata anche in Germania dove i consumi di lamponi, mirtilli e more di rovo fresche sono aumentati più del 10% annuo dal 2011 al 2015 (FarmingUk - 2022).

Inoltre, gli altri fattori che hanno inciso sull'aumento dei consumi sono: il miglioramento degli aspetti estetici e qualitativi che invogliano al riacquisto, il *branding* e soprattutto il fatto che i consumatori possono trovarli tutto l'anno a seguito della delocalizzazione e destagionalizzazione di questi frutti. (Szajdek & Borowska 2008; Blanc *et al.* 2018).

Infatti la crescente richiesta di *berry fruits* ha portato ad un rapido aumento negli scambi internazionali, modificando le dinamiche di produzione, mercato e trasporto. Storicamente il mercato era fortemente condizionato dalle problematiche legate alla conservazione ed al trasporto, creando di fatto una domanda ridotta e stagionale. I miglioramenti tecnologici abbinati alle strategie di *marketing* e di produzione, hanno aumentato la quantità e la disponibilità di questa tipologia di frutta. La delocalizzazione nei due emisferi e la coltivazione a diverse latitudini hanno permesso e permetteranno la fornitura di piccoli frutti dodici mesi all'anno superando la stagionalità. Produttori americani, ad esempio, hanno spostato parte della produzione in Messico così da avere una fornitura di prodotto anche nei mesi invernali ed estendere la stagionalità. Anche alcuni operatori europei, come la Spagna, hanno investito nella realizzazione di impianti in Marocco estendendo l'epoca di raccolta e quindi di commercializzazione.

L'aumento dell'offerta ha naturalmente anche incrementato la competitività all'interno del mercato. I principali fornitori di piccoli frutti, che muovono migliaia di tonnellate di prodotto l'anno, per far fronte alla concorrenza, senza far crollare i prezzi, cercano di fornire tutto l'anno *berry fruits* coperti da un *brand*. Negli ultimi anni la percezione del consumatore nei riguardi del prodotto da acquistare è cambiato, facendo evolvere anche il fenomeno del *branding* (Peano *et al.* 2015). Oggi infatti, specialmente per i prodotti agricoli, è più corretto parlare di *eco-branding*, ovvero di un *brand* che oltre a basarsi sulla *performance* visuale ed economica del prodotto, è fortemente sostenuto dalla *performance* ecologica (Cook 2011). In quest'ottica è proprio il marchio che, se sostenuto da una buona qualità della frutta, permette all'azienda di differenziarsi all'interno del mercato e subire meno la concorrenza. Inoltre il piccolo frutto 'brendizzato' si sposa con l'offerta del prodotto *ready-to-eat* (RTE) dato che sono anche un'ottima scelta come *snack food* (Mezzetti 2014).

2.2 IMPORT- EXPORT

In termini economici, secondo *l'International Trade Center (ITC),* l*'export* mondiale per il mercato fresco della categoria *berry fruits* - *Fresh raspberry, blackberry, mulberry e loganberry* ha evidenziato una crescita significativa dal 2018 (1,96 miliardi di euro) al 2021 (2,14 miliardi di euro). Mentre l'*import* ha segnalato un incremento da 2,45 miliardi a 3,32 miliardi di euro nello stesso periodo temporale. Nel 2021, a livello mondiale, i primi due paesi per valore e quantità di prodotto fresco esportato sono Spagna, con 68.943 t e 485 milioni di euro ed il Messico, con 94.801 t di prodotto e 448 milioni di euro di valore. A livello di *import* i principali paesi sono gli Stati Uniti (+441 milioni di euro rispetto al 2018), Germania (+83 milioni di euro) e Canada (+54 milioni di euro). In particolare la domanda di lamponi e more di rovo è aumentata notevolmente in Europa e Nord America negli ultimi anni (Mezzetti 2014; Bojkovska *et al.* 2021). Secondo i dati FAOSTAT dal 2015 al 2021, la produzione è passata da 675 mila tonnellate a 887 mila tonnellate (+24%). Parallelamente le aree coltivate a lamponi a livello mondiale sono passate da una superficie di 101.902 ettari (2015) a 110.567 ettari nel 2021, evidenziando un incremento dell'8%. Le esportazioni e le importazioni di lamponi freschi aumentano di anno in anno sia di volume che in valore. Il volume di prodotto derivante dell'*export* è aumentato del 56% nel periodo 2012-2019, mentre nello stesso arco temporale le importazioni sono aumentate del 50% (Darnell *et al*. 2006). A livello mondiale nel 2021 i quattro paesi più importanti a livello di superficie coltivata a lampone e produzione sono la Federazione Russa, con 23.809 ha, la Serbia (20.807 ha), la Polonia (19.800 ha) ed il Messico (8520 ha). Tuttavia, gran parte della produzione dei primi tre paesi elencati non è destinata al consumo fresco ma al congelato. Interessante invece è il caso del Messico dove la produzione è destinata quasi interamente al mercato del fresco ed è il secondo paese a livello mondiale, dopo la Federazione Russa (197.700 t), in termini di quantità prodotte (165.676 t) nel 2021.

La produzione europea dal 2010 (132.050 t) al 2020 (230.666 t) è aumentata del 43%. Soprattutto grazie alla crescita di paesi come Polonia, Spagna e Portogallo. Spagna che è passata da 1847 ha nel 2015 a 2420 nel 2021 e Portogallo che ha osservato un incremento di superficie del 52% e della produzione del 55% nello stesso periodo (FAOSTAT-2023).

Per quanto riguarda *Fresh raspberry, blackberry, mulberry e loganberry*, L'*export* italiano è cresciuto in valore da 8,81 milioni nel 2018 a 13,34 milioni di euro nel 2021. E' stato calcolato un incremento sul valore del +7% confrontando il 2018 con il 2019, un +28% nel 2019-2020 ed un +10 % nel 2020-2021. Tale crescita tuttavia può essere imputata ad un miglior prezzo di mercato dato che non è stato osservato un incremento nei quantitativi esportati, 1879 tonnellate nel 2018 e 1784 tonnellate nel 2021. I principali paesi in cui viene esportata questa frutta fresca sono Austria, Svizzera e Germania. Tale dato conferma l'apprezzamento crescente che il consumatore sta attribuendo ai *berry fruits*, rendendolo disponibile a spendere di più. Lo stesso *trend* è osservabile sull*'import* italiano di prodotto fresco, dove il valore è cresciuto da 36,62 milioni a 49,39 milioni di euro nel periodo 2018-2022, ma i quantitativi importati sono rimasti simili, 10.101 t nel 2018 e 9.990 t nel 2022. Circa il 50% del prodotto importato nel 2022 ha origine spagnola (*ITC* - 2023). Secondo i dati FAOSTAT l'Italia è cresciuta in termini di ettari produttivi coltivati a lampone, passando da 287 ha nel 2010 a 380 ha nel 2021. Questo ha comportato una crescita delle produzioni da 1990 t a 2650 t. Tale incremento può essere spiegato soprattutto con l'aumento delle aree produttive nelle regioni del Sud Italia, con il fine di approvvigionare per un periodo più lungo possibile il mercato italiano con prodotto italiano. La produzione piemontese si assesta su circa 65 ha.

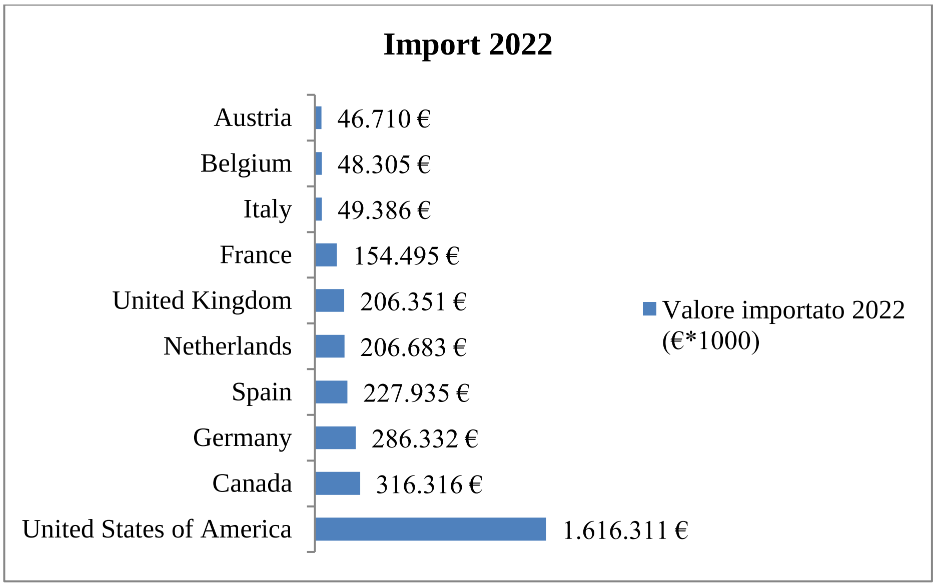

Fig. 1. I 10 paesi maggiori importatori come valore di *import* nel 2022 per la categoria *fresh raspberry fruits, blackberry fruits, mulberry fruits and loganberry fruits* (product: 081020). (Fonte: *ITC – 2023*)

Fig. 2. I 13 paesi maggiori esportatori come valore di export nel 2021 per la categoria *fresh raspberry fruits, blackberry fruits, mulberry fruits and loganberry fruits* (product: 081020). (Fonte: *ITC* - 2023)

Sempre l'*ITC* riporta che per la categoria *Berry fruits – Fresh cranberry, bilbberry e berry from gen. Vaccinium* il valore di *export* mondiale è aumentato da 2,55 miliardi di euro (2018) a 4,02 miliardi nel 2021. Dai dati del 2022 si osserva che i primi tre paesi esportatori a livello mondiale, sia per quantità che per valore, sono Perù, Spagna e Chile. Soprattutto il Perù, ha riscontrato una crescita produttiva esponenziale negli ultimi anni che gli ha permesso di diventare recentemente il primo paese esportatore di mirtillo al mondo. Questa crescita è stata legata sicuramente a fattori pedoclimatici, infatti il Perù è uno dei pochi paesi che ha una finestra di produzione e quindi di esportazione allargata su numerosi mesi dell'anno, da luglio a febbraio. L'*export* di questo paese è passato da un valore di 464 milioni di euro nel 2018, legato ad un quantitativo esportato di 72.583 t, a 1,02 miliardi nel 2021, che equivalgono a 205.831 t di prodotto. Anche la Spagna, primo paese a livello europeo, ha evidenziato uno sviluppo importante relativamente al valore di *export*, +213 milioni di euro nel periodo 2018-2021. Allo stesso modo l'*import* a livello mondiale ha mostrato una crescita considerevole dal 2018 (2,90 miliardi di euro) al 2021 (4,46 miliardi di euro). Nel 2021 gli Stati Uniti, che continuano comunque ad evidenziare un *trend* positivo anno per anno, rappresentano da soli il 33% del valore dell'*import* mondiale con un indotto di 1,47 miliardi di euro. Mentre a livello europeo Olanda, Germania e UK sono i principali sia come valore che come quantità di prodotto importato (*ITC*-2023).

Secondo i dati riportati da FAOSTAT, in termini di ettari coltivati a mirtillo a livello mondiale si è evidenziato un aumento del 33% nel periodo 2015-2021, passando da 109.302 ha a 163.741 ha. Tale crescita di superficie ha portato ad una produzione di 1,11 milioni di tonnellate nel 2021, cioè +480 mila tonnellate rispetto al 2015. A livello mondiale, i primi 4 paesi per ettaraggio e produzione sono gli Stati Uniti, il Canada, il Perù ed il Chile.

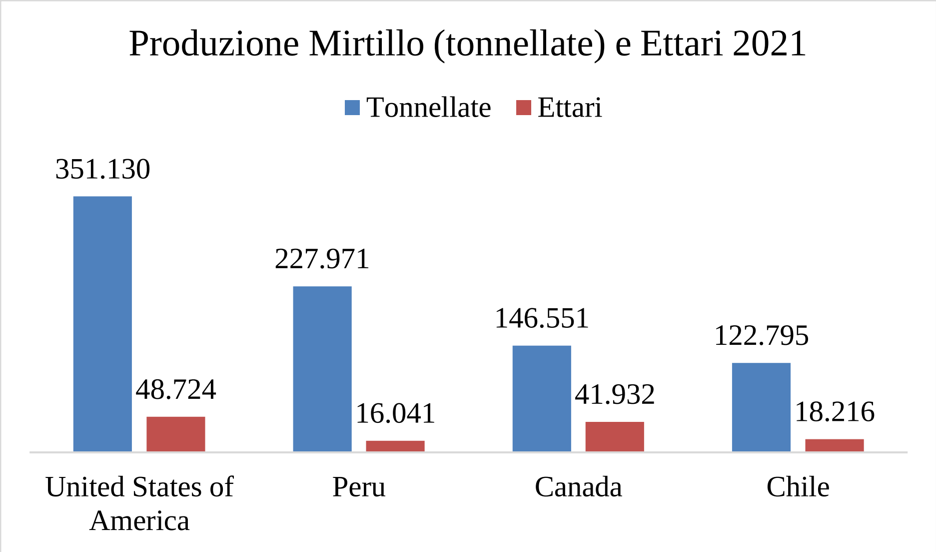

Fig. 3. I 4 principali paesi a livello mondiale per produzione di mirtillo (tonnellate) e ettari coltivati nel 2021. (Fonte: FAOSTAT – 2023)

Negli Stati Uniti, considerato paese di riferimento per il mirtillo gigante americano, si è passati da un *import* di 472 milioni di libbre nel 2019 a 657 milioni di libbre nel 2022. Il 95% del mirtillo esportato dagli Stati uniti (45 milioni di libbre) ha come destinazione il Canada. Mentre il 41.8% dell'*import* statunitense arriva dal Perù, il 24.7% dal Chile e il 22.7% dal Messico (*ITC* - 2023). In Europa l'*import* di mirtillo è passato da circa 40 milioni di kg nel 2015 a quasi 125 milioni di kg nel 2020 e si presume che tale *trend* continuerà a crescere (Rabobank - 2023). Inoltre, secondo i dati FAOSTAT, in Europa si osserva un incremento della superficie coltivata che è cresciuta da 11.355 ha nel 2010 a 29.487 ha nel 2021. Nello stesso periodo le produzioni sono aumentate del 75%. Polonia, Spagna, Portogallo e Germania sono i principali paesi europei per ettari e produzione nel 2021 e tutti hanno mostrato una crescita nel periodo 2010-2021.

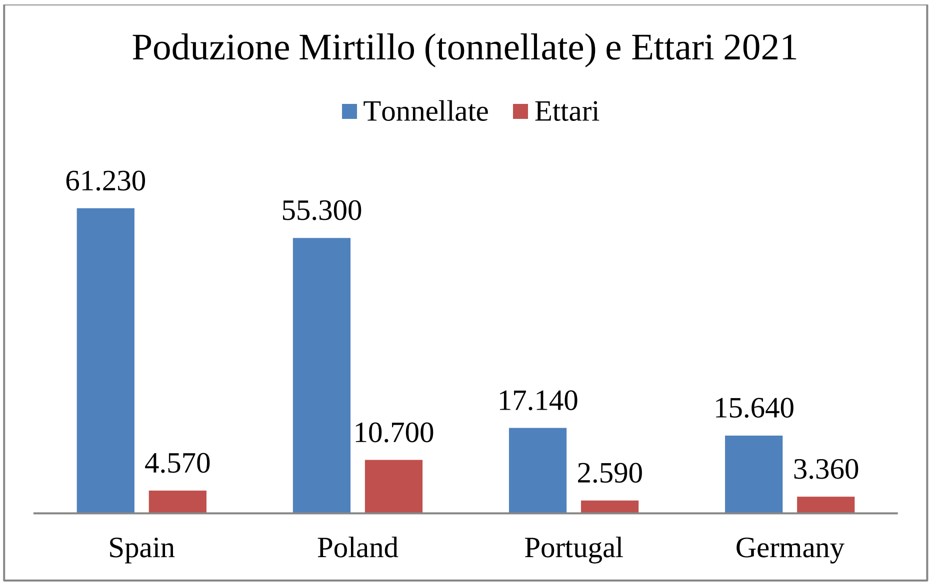

Fig. 4. I 4 principali paesi a livello europeo per produzione di mirtillo (tonnellate) e ettari coltivati nel 2021. (Fonte: FAOSTAT – 2023)

I consumi di mirtillo gigante americano negli Stati Uniti e in Canada hanno superato 1 kg pro-capite, mentre il consumo medio europeo è inferiore a 500 g pro-capite. La Cina è il paese dove si riscontra attualmente un consumo irrisorio. Pertanto, basandosi sui consumi nord americani, dove esiste già una cultura dei *berry fruits* affermata, si intravede un ampio spazio di crescita sui mercati meno sviluppati. (Rabobank - 2023).

Anche l'Italia, sia dal punto di vista dell'*import* che dell'*export* per la categoria *Berry fruits – Fresh cranberry, bilbberry e berry from gen. Vaccinium*, presenta un andamento crescente dal 2018 al 2022. Dal punto di vista dei quantitativi la crescita è stata di +1505 tonnellate di *export* e di +6825 tonnellate di *import*, con un incremento reciproco sul valore di +11,5 milioni e +23,4 milioni di euro. Se si fa riferimento al 2018 il valore dell'*export* è raddoppiato mentre l'*import* segna un incremento del 37,5%. I due principali paesi dove avviene l'esportazione italiana sono UK e Germania e rappresentato il 50% in valore dell'*export* italiano. L'Italia, dal punto di vista di tonnellate prodotte nel 2021, è il quinto paese a livello europeo (8750 t). La produzione nazionale è cresciuta di 7138 t dal 2010 (1612 t) al 2021 (8750 t) e allo stesso tempo gli ettari coltivati a mirtillo sono aumentati dell'86%, 1200 ha nel 2021. Di questi 1200 ha più della metà, circa 650 ha, sono situati in Piemonte e l'80% in provincia di Cuneo. Questa rapida crescita a livello italiano è comunque influenzata dalla situazione frutticola piemontese, dove negli ultimi anni si è osservata una crisi di mercato legata alla frutta maggiore, in particolare alle pesche, e una forte riduzione della superficie coltivata a kiwi per la problematica *PSA (Pseudomonas syringae pv. Actinidiae).*

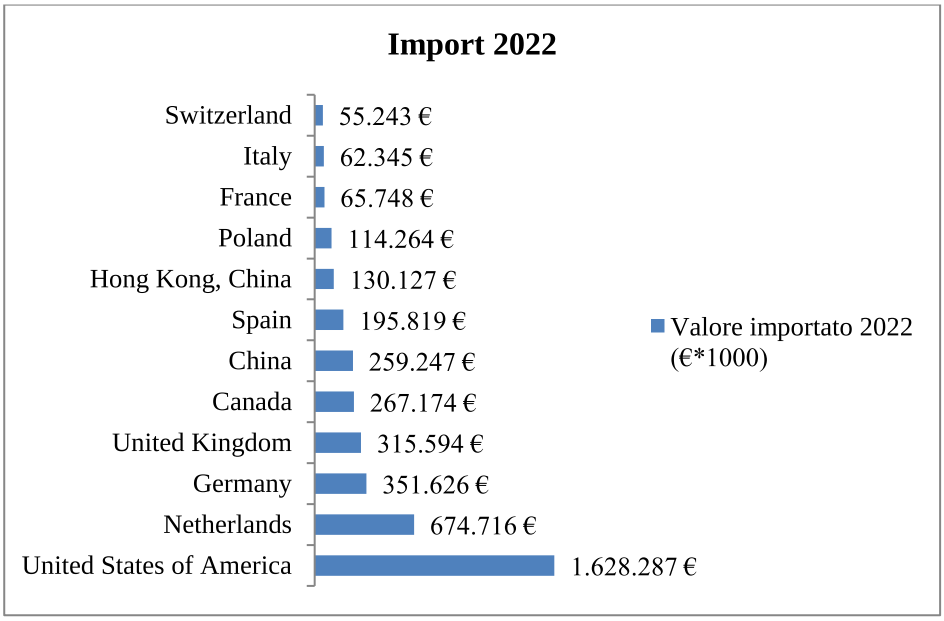

Fig. 5. I 12 paesi maggiori importatori come valore di *import* nel 2022 per la categoria *fresh cranberry fruits, bilberry fruits and other fruits of the genus Vaccinium (product: 081040)*. (Fonte: *ITC* – 2023).

Fig. 6. I 10 paesi maggiori esportatori come valore di *export* nel 2021 per la categoria *fresh cranberry fruits, bilberry fruits and other fruits of the genus Vaccinium (product: 081040)*. (Fonte: *ITC* – 2023).

Tuttavia, in questi scenari di continua crescita, Rabobank ricorda e sottolinea che nell'ultimo decennio la sfida è stata aumentare l'offerta per soddisfare la crescente domanda, ma la missione che ci si attende nei prossimi anni sarà incrementare la domanda ed evitare che l'offerta superi la richiesta da parte dei consumatori. Infatti il *trend* di crescita della produzione in termini di volume è stato superiore rispetto all'aumento della domanda. Come affermato da Segovia-Villarreal *et al.* (2019), l'unica strategia per aumentare la richiesta da parte dei consumatori sarà mantenere un'elevata qualità con continuità. Ma, dato che i *berry fruits* sono dei prodotti estremamente delicati e con una *shelf-life* piuttosto limitata, se paragonati ad altra frutta (mele, kiwi, ecc), questa affermazione non è scontata e diventa cruciale per la sostenibilità del sistema, soprattutto in uno scenario di grandi volumi.

Per fare questo, come affermato da Peano *et al.* (2017) e da Tort *et al*. (2022), sarà necessario continuare a migliorare la *supply chain* dei *berry fruits* evidenziando e cercando soluzioni ai punti critici e alle problematiche riconosciute a livello internazionale della filiera di ciascun *berry fruits,* anche con il fine di limitare le perdite di prodotto in uno scenario di crescita della popolazione mondiale (Ktenioudaki *et al.* 2021).

2.3 LA SUPPLY CHAIN DEI BERRY FRUITS

Lo sviluppo e l'efficientamento della *supply chain* nel settore della frutta e verdura fresca, è la chiave per limitare gli sprechi di prodotto e raggiungere la sostenibilità economica, sociale e ambientale in uno scenario futuro dove la sicurezza alimentare sarà una sfida (Kelly *et al.* 2019). I *berry fruits* rappresentano una categoria di frutta particolarmente suscettibile alla questione degli sprechi in relazione alla loro limitata *shelf-life* e alla elevata deperibilità dei frutti. Numerose criticità che si riscontrano nelle filiere dei singoli piccoli frutti sono comuni alle diverse tipologie di *berry fruits,* a partire dalla produzione in campo fino ad arrivare alla commercializzazione (Huynh *et al.* 2019).

Sicuramente il cambiamento climatico è una delle principali problematiche con cui sarà necessario confrontarsi in futuro e che potrà influenzare negativamente la qualità delle produzioni, l'aumento degli scarti, la gestione dei frutti in post raccolta e forse potrà anche cambiare le abitudini dei consumatori (Jacxsens *et al.* 2010; Mittler *et al.* 2010). Poiché il cambiamento climatico è associato ad una ampia variabilità climatica unita ad eventi climatici estremi sempre più marcati, le piante sono assoggettate a *stress* sempre più frequenti nelle diverse fasi del ciclo produttivo. Inoltre, la maggior parte delle nuove varietà sono state sviluppate per crescere e ottenere i massimi risultati produttivi e qualitativi in condizioni ambientali con alto livello di risorse e basso *stress* complessivo (Harkness *et al.* 2020; Zandalinas *et al.* 2017; Acuña-Rodríguez *et al.* 2022). Se queste necessità non vengono soddisfatte le perdite economiche possono aumentare e diventare ingenti. Le conseguenze negative di tali scenari possono non solo avere un impatto sulla resa delle colture (quantità e qualità dei frutti da raccogliere) ma anche sulla sopravvivenza delle piante stesse (Ktenioudaki *et al.* 2021). I *berry fruits* sono generalmente coltivati in coltura protetta data l'elevata sensibilità della frutta a fattori abiotici (pioggia, vento, ecc.) che possono peggiorarne velocemente la qualità ed aumentare gli scarti (Mitcham, 2007). Pertanto, rispetto ad altra frutta, i *berry fruits* possono subire maggiormente le negatività derivanti dal cambiamento climatico e da eventi climatici avversi (Smrke *et al.* 2021).

Inoltre il cambiamento climatico, oltre a danni diretti sulle colture e sulla produzione, può causare anche danni indiretti (Ngoy *et al.* 2020). Il primo danno indiretto per importanza è l'istaurarsi di nuovi patogeni alieni che precedentemente non trovavano condizioni favorevoli all'insediamento in areali diversi da quelli di origine. Il secondo è legato al fatto che il cambiamento climatico può modificare il ciclo biologico di funghi, batteri e di altri organismi facendoli diventare patogeni per le colture agrarie, organismi che originariamente erano presenti in natura senza rappresentare una minaccia per le coltivazioni (Guarnaccia *et al*. 2022). Questa è una tematica di grande attualità che potrebbe compromettere le produzioni sia dal punto di vista qualitativo che quantitativo (Gullino *et al.* 2017). Inoltre, unitamente alle crescenti condizioni di *stress* durante il ciclo produttivo delle piante, questi patogeni possono diventare devastanti non avendo nell'ambiente di insediamento antagonisti o non ritrovando nelle colture attaccate meccanismi di resistenza (Guarnaccia *et al*. 2021). Come affermato da Guarnaccia *et al.* (2020), il rapido sviluppo della malattia causata da *Neofusicoccum Parvum* su mirtillo in nord Italia e la sua aggressività può essere aumentata e favorita dall'incremento delle temperature durante il ciclo di produzione del mirtillo.

Il contrasto agli effetti del cambiamento climatico sulle coltivazioni, la lotta a nuovi patogeni e l'incremento dei costi delle materie prime che costituiscono i mezzi di produzione, stanno comportando un aumento delle risorse impiegate e quindi dei costi di produzione (Rabobank - 2023). Ad esempio, per la convivenza con la problematica *Drosophila Suzukii*, dittero alieno di provenienza asiatica, è stato necessario realizzare delle strutture che chiudano completamente le coltivazioni di piccoli frutti con una tipologia di rete appositamente studiata

(Cormier *et al*. 2015). Questo comporta un notevole aumento di costo nella realizzazione degli impianti (Mazzi *et al.* 2017). La problematica dell'aumento dei costi di produzione è ampiamente dibattuta dal momento che, in uno scenario di forte aumento dell'offerta e quindi di prezzi in discesa, potrebbe eguagliare o superare il valore del prodotto, rendendo la produzione economicamente non sostenibile (Singerman *et al.* 2016). Allo stesso tempo è comprensibile che limitare i mezzi di produzione comporterebbe una riduzione di qualità della frutta, quindi in contrasto con la strategia volta a stimolare la crescita dei consumi.

Parallelamente all'aumento dei costi di produzione, un'altra importante problematica osservata nella filiera dei *berry fruits*, specialmente nei paesi più sviluppati, è la carenza di manodopera da impiegare in ambito agricolo (Ferreira *et al.* 2018). Dato che il 90% del lavoro nella coltivazione dei *berry fruits* è manuale e l'80% e legato alla raccolta del prodotto, la carenza di manodopera può compromettere la riuscita della coltivazione sia da un punto di vista economico che di qualità della frutta (Eklund 2016). Questo perché il *berries*, a differenza di altra frutta, deve essere raccolto a maturazione fisiologica per esplicare il massimo valore qualitativo, ma allo stesso tempo è velocemente deperibile anche sulla pianta e presenta una limitata *shelf-life* (Ponder & Hallmann 2019). Pertanto per ottenere il massimo risultato ed evitare bassa qualità e perdita di prodotto la raccolta deve essere tempestiva ed accurata. Inoltre i *berry fruits* presentano una maturazione scalare della frutta, pertanto sono necessari più passaggi di raccolta sulla stessa pianta. Ad esempio nella coltivazione del lampone la raccolta deve essere giornaliera e quindi un giorno di ritardo può implicare che il prodotto non sia più adatto alla commercializzazione sul mercato del fresco, con ripercussioni economiche e sulla qualità delle raccolte successive (Ali, 2012).

Sempre legata alla grande sensibilità e all'alta deperibilità dei frutti un'altra importante criticità nella filiera dei *berry fruits* è il mantenimento e la gestione della corretta catena del freddo a partire dall'azienda agricola fino al punto vendita (Steynberg *et al.* 2022). La gestione della temperatura è considerata la principale causa di perdita di prodotti freschi al mondo (Lai *et al.* 2011). Questa tematica presenta due punti fondamentali per il mantenimento della qualità durante tutta la filiera. Il primo è che il tempo che intercorre tra la raccolta e la refrigerazione deve essere il più limitato possibile in modo da bloccare velocemente i processi di traspirazione e respirazione dei frutti, rallentandone i metabolismi di senescenza (Ndraha *et al*. 2018). Il secondo punto è legato al fatto che devono essere evitati gli sbalzi di temperatura dato che tali oscillazioni causano un'accelerazione dei processi metabolici del frutto e una rapida senescenza (perdita di peso, rammollimenti, ecc.), che pur riportando la temperatura al valore ottimale non vengono bloccati (Paniagua *et al.* 2014; Mahajan *et al.* 2014). Inoltre tali sbalzi di temperatura causano formazioni di essudati e condense sulla superficie dei frutti che possono innescare la formazione di *Botrytis spp.* o altre tipologie di muffe (Mercier *et al*. 2017). Tale criticità si osserva prevalentemente in due fasi della filiera: nella fase di lavorazione del prodotto, dove si opera ad una temperatura superiore rispetto alla temperatura di refrigerazione ma comunque controllata, e nella fase di distribuzione, dato che molto spesso la temperatura non è controllata e non è gestita dall'operatore che lavora nell'indotto dei *berry fruits* (Paniagua *et al.* 2014). Importanti sono anche i passaggi del prodotto tra una fase e l'altra della filiera. Per esempio è importante che la temperatura sia controllata nella fase di carico tra il magazzino frutticolo e la distribuzione refrigerata (Jedermann *et al.* 2014).

La limitata *shelf-life* e la veloce deperibilità dei *berry fruits* implica altre due criticità importanti legate alla parte finale della filiera. La prima è che la commercializzazione del prodotto deve essere tendenzialmente rapida. Parlando di varietà performanti in termini di *shelf-life* e di gestione del prodotto in atmosfera controllata (Falagan *et al.* 2020) si considera una commercializzazione entro 60 giorni per il mirtillo e ribes (Matiacevich *et al.* 2013; Duan *et al.* 2011) ed entro 10 giorni per lampone e mora di rovo. Pertanto con la vendita è difficile spalmare su lunghi periodi i picchi produttivi stagionali al fine di raggiungere finestre di mercato economicamente più vantaggiose e mantenere un'offerta stabile. Questo implica oscillazioni di prezzo da periodi con elevata offerta a periodi con scarsa offerta (Iliopoulos *et al.* 2012; Hancock *et al.* 2008). Inoltre, soprattutto per lampone e mora di rovo, è difficile esplorare mercati lontani dalle zone di produzione per via dei tempi di distribuzione, che se lunghi possono inficiare la qualità del prodotto.

La seconda criticità è legata alla gestione dei *berry fruits* all'interno dei punti vendita della grande distribuzione (Porat *et al.,* 2018). I *berry fruits* sono tra i prodotti più delicati che si possono ritrovare nel reparto dell'ortofrutta di un supermercato, pertanto l'errata gestione in questa fase finale della catena, su un prodotto che ha già subito precedentemente gli *stress* della filiera, può danneggiare in modo esponenziale la qualità del prodotto. Qualità, soprattutto estetica, che sarà quella percepita dal consumatore al momento dell'acquisto e che avrà influenza sulle scelte di quest'ultimo (Sobekova *et al.* 2013).

Con questi presupposti e attraverso il mio percorso di Dottorato in Regime di Apprendistato in collaborazione con OrtofruitItalia soc. agr. coop. O.P., azienda *leader* nella produzione e vendita di *berry fruits* a livello italiano ed europeo, si è cercato di analizzare, studiare e testare possibili soluzioni ad alcuni di questi punti critici evidenziati nella filiera dei *berry fruits*.

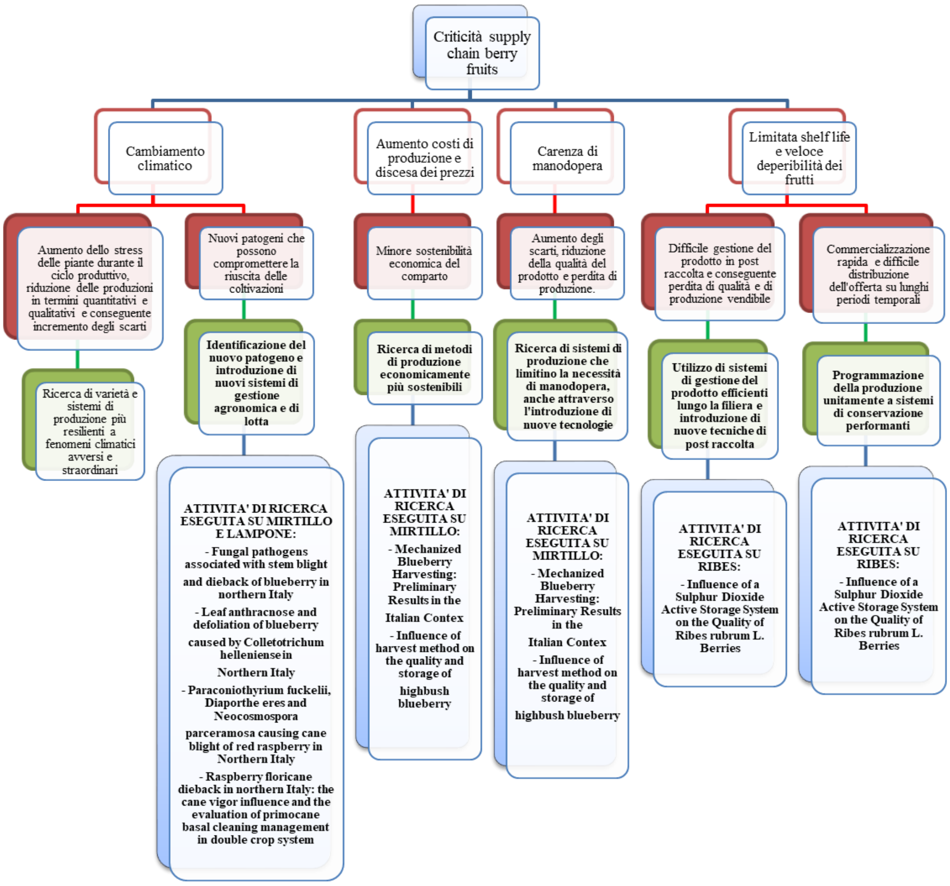

Fig. 7. Schema attività di ricerca.

3. LA PROPOSTA DI PROGRAMMA DI DOTTORATO NELL'AMBITO DELL'APPRENDISTATO E DELLA RICERCA

OrtofruitItalia soc. agr. coop. O.P., nata nel 2003, da un decennio ha iniziato il proprio lavoro di grande specializzazione nel comparto *berry fruits*. Questa è stata una necessità legata a diversi fattori. In primo luogo la possibilità di crescere e specializzarsi in un settore poco esplorato da altre aziende presenti nell'areale frutticolo piemontese, che ancora oggi presentano come *core businnes* la produzione e commercializzazione di frutta maggiore, prevalentemente mele. Questa strategia ha permesso una minore competizione territoriale nel progetto di sviluppo. In secondo luogo Ortofruititalia soc. agr. coop. O.P. ha cercato di assolvere alla necessità delle aziende agricole associate di ricercare colture alternative in un panorama dove la crisi di mercato delle pesche e le progressive problematiche legate al kiwi piemontese (*PSA*) stavano mettendo in grande difficoltà i produttori.

La grande crescita dei *berry fruits* e la globalizzazione del mercato ha aumentato notevolmente la concorrenza a cui Ortofruititalia soc. agr. coop. O.P. è assoggettata. Pertanto l'azienda, al fine di rimanere competitiva sul mercato, ha la necessità di puntare sulla produzione di un prodotto di qualità distinguibile e di migliorare le criticità presenti sulla propria filiera di produzione. Per fare questo OrtofruitItalia ha deciso di investire su un programma di ricerca con l'obiettivo di introdurre nuovi approcci volti a migliorare le problematiche della filiera dei *berry fruits* più interessanti dal punto di vista produttivo e commerciale.

Il percorso si è sviluppato nei seguenti *step*:

- Analisi delle principali necessità di filiera di OrtofruitItalia soc. agr. coop. O.P. In particolare prendendo in considerazione la tematica della raccolta e delle patologie emergenti per il mirtillo, della gestione agronomica di problematiche di campo emergenti per il lampone e del miglioramento della *shelf-life* del ribes rosso.

- Ricerca in campo internazionale di possibili approcci di analisi e soluzioni applicabili per le tematiche citate.

- Valutazione di soluzioni riconosciute interessanti in ambito internazionale.

4. I PRINCIPALI RISULTATI DEL PROGRAMMA DI DOTTORATO: I 4 ARTICOLI

4.1. *TOPIC 1*: RACCOLTA AGEVOLATA DEL MIRTILLO

Questo capitolo è dedicato ai seguenti due articoli:

Brondino, L., Borra, D., Giuggioli, N. R., & Massaglia, S. (2021). Mechanized Blueberry Harvesting: Preliminary Results in the Italian Context. Agriculture, 11(12), 1197. DOI: 10.3390/agriculture11121197.

Brondino, L., Briano, R., Massaglia, S., & Giuggioli, N. R. (2022). Influence of harvest method on the quality and storage of highbush blueberry. Journal of Agriculture and Food Research, 10, 100415. https://doi.org/10.1016/j.jafr.2022.100415.

Poiché la raccolta del mirtillo per il mercato del fresco è l'operazione che rappresenta l'80% del costo di produzione di questa coltura, ed attualmente è eseguita interamente a mano, è chiaro che la disponibilità, il costo della manodopera e l'efficienza di raccolta rappresentano parametri fondamentali per il successo economico della coltura (DeVetter *et al*. 2019; Cai *et al.* 2021).

A parità di efficienza di raccolta, l'Italia, come alcuni paesi del nord Europa, si trova economicamente svantaggiata rispetto ad altri paesi europei (Polonia, Portogallo, Spagna, ecc.) ed extra europei (Marocco, Serbia, Perù, ecc.), che sono *competitor* nel mercato del mirtillo, poiché presentano un costo orario della manodopera inferiore (ilsole24ore - 2023). La globalizzazione dei mercati comporta che il mirtillo prodotto da questi paesi può arrivare in competizione con il prodotto italiano a prezzi più bassi dato il minor costo di raccolta e quindi di produzione sostenuto (Wu & Guan 2021; Ramos *et al.* 2018). Questa situazione può far sì che l'Italia, per rimanere sul mercato, debba abbassare i prezzi di vendita con il rischio di scendere al di sotto del costo di produzione italiano e quindi compromettere la sostenibilità economica della coltura. Pertanto la domanda di ricerca che ha portato ad affrontare questo studio è: "La raccolta agevolata del mirtillo, al fine di aumentare l'efficienza della raccolta e quindi ridurre il costo e la necessità di manodopera, può essere una buona soluzione per mantenere competitiva la produzione italiana? Quali possono essere le ripercussioni sulla qualità del prodotto e la successiva gestione di quest'ultimo nella *supply chain*?". Per rispondere alla domanda di ricerca la raccolta agevolata è stata valutata nel contesto piemontese sia da un punto di vista economico che dal punto di vista della qualità post-raccolta dei frutti in relazione alla classica raccolta manuale. I risultati ottenuti sono presentati nei seguenti articoli.

Article

Mechanized Blueberry Harvesting: Preliminary Results in the Italian Context

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Abstract: This study reports some preliminary results on mechanical blueberry harvesting for the fresh market of cv. Cargo® in the Piedmont region (northwest Italy). The investigated area is one of the most productive areas of Italy, which specializes in fresh blueberry production. The automatization of harvesting operations could represent a competitive advantage for the area's blueberry supply chain but could limit the quality of fresh-picked berries. A prototype machine and a commercial harvester (Easy Harvester®) were compared with manual picking, considering the harvesting efficiency, labor productivity, harvesting cost and farm rentability. In this context, the labor cost for manual harvesting exceeds EUR 2.00 per kg of saleable product. The prototype allowed a 39% cost reduction, and the Easy Harvester® reduced it by about half. Nevertheless, these positive performances do not consider the reduction in the net sale price of EUR 0.40 due to the selection costs in the warehouse. In this study, we highlight that the transition to mechanical harvesting requires the transformation of several farming and packhouse operations, such as new crop varieties, field configurations and cultivation techniques. However, a possible technical improvement of the Easy Harvester® could represent an opportunity for Italian farms in the planning of berry production and marketing, involving all of the supply chain actors. Further research on the use of mechanization in the sector must continue and be supported.

Keywords: *Vaccinium corymbosum*; innovation; harvest; production; cost; prototype

1. Introduction

The world blueberry production has more than doubled in the last 10 years, reaching 823,328 tonnes in 2019. Of this, 58% are produced in North America (38% in the United States and 20% in Canada) [1]. Following the same trend, the Italian blueberry cultivation area has increased rapidly, from 370 ha in 2012 to 900 ha in 2019. The entire Italian blueberry production is designated for the fresh market. Piedmont is the Italian region where berry production is most widespread, occupying 550 ha [2]. This increase in production has led to a substantial change in the fresh blueberry supply chain, determining a strong need for research and innovation throughout the industry due to growing consumer interest [3–5]. The per capita consumption of blueberries worldwide virtually doubled between 2012 and 2019 due to increasing consumer awareness of their health benefits [4]. The United Kingdom consumers are the European leaders in blueberry consumption with 0.86 kg/person, which differs significantly from the European average of 0.18 kg/person [6]. However, the trend is positive: blueberry consumption is increasing in all European countries, especially Germany, Switzerland, the Benelux countries and Scandinavia [7]. This evolution has brought a radical change in the conception of blueberry production in Italy, generally, and in Piedmont, specifically. In fact, there has been a shift from production in marginal areas (foothills with a function of income integration) to intentional production in lowland areas, where blueberries are the main crop of many fruit farms.

The increased investments in blueberry cultivation have led to the need for a large number of seasonal workers, especially during the harvesting period. This phase represents

90% of the total need for workers since, today, most blueberries for the fresh market are harvested manually [8]. In general, the most important factor affecting the cost of fresh fruit production is the cost of labor (up to 50%) [9]. As reported by Brown et al. [10] and reiterated by Eurofresh Distribution [11], manual blueberry harvesting requires up to 1500 h of labor per hectare per year, which is a critical factor in finding and managing the necessary workers and the consequent high harvesting costs and low labor productivity. In 2011, in Georgia (US), 52% of highbush blueberry producers reported income losses due to a lack of workers [12].

One opportunity related to this critical issue is the mechanization of harvesting procedures. This technology could reduce the number of seasonal workers, improve labor productivity, reduce harvesting costs and improve producer incomes [13,14]. Mechanization processes could also allow farms to address shortages of seasonal workers for short periods of time (a few weeks) as these can represent a serious problem in the context of COVID-19-related travel restrictions [15].

Several studies focusing on economic performance have been conducted on the mechanization of harvesting for fruit trees [16–21]. Seavert and Whiting [22] compared the mechanical harvesting of cherries (*Prunus avium* L.) with traditional methods, pointing out that automation can reduce harvesting costs and improve producers' incomes. Baugher et al. [23] found that motorized platforms could improve worker productivity by 20% to 65% compared with ladders, with the greatest gains in harvesting operations. Klonsky et al. [24] stated that the net return per acre from the mechanical harvesting of black ripe table olives at 80% harvesting efficiency was 19% higher than the net return per acre from manual harvesting.

However, currently, the mechanization of fruit tree harvesting is only efficient for industrial products [25]. The harvest operations of fruits devoted to the fresh market evidence several difficulties, such as complex tree structure, variable outdoor environmental conditions, inconsistencies in fruits shape, sizes and color and fruit sensitivity to damage [26]. For this reason, farmers operating exclusively in the fresh market need to be supported in their harvest decisions by new research to improve mechanical harvesting's technical efficiency. Moreover, interesting results on robotic sensors have been achieved in several countries (Europe, Japan and the USA), but some critical issues remain to be addressed, such as the higher cost of robotic harvesting and the quality of the harvested fruits [27]. In the latter case, studies have shown that ripe fruits (20–30% of the product) were not detached and selected efficiently because the sensors do not recognize and identify them as being ready for harvesting. Another critical problem is related to the relatively slow harvesting speed, which means that robotic harvesting is not currently advantageous [27].

However, several researchers have reported the possibility of modifying the harvesting techniques and improving the automation process in the collection operation [28]. The first experiments on machines aimed to automate the blueberry-harvesting procedure were conducted in the United States in the late 1950s. In 1966, mechanical field pickers (OTRs) were introduced [29], mainly for harvesting blueberries for processing since the berries are very susceptible to bruising [30]. A study conducted in 2012 showed that using an OTR mechanical blueberry harvester can reduce costs by 85% and improve labor productivity by 6000% [10,30]. Takeda et al. [31] showed that pneumatic shakers could remove 3.5–15 times more blueberries than manual harvesting. Differences in the harvest rate were observed among different cultivars. Shakers removed up to six times more fruit than harvesting by hand for "Draper" and "Legacy" and nearly 16 times more for "Liberty" blueberries.

However, several disadvantages still exist relative to mechanical harvesters. As stated by Gallardo and Zilberman [12], the main problems that limit mechanical harvesters economically are yield losses and berry quality losses. Yield losses occur primarily through berries, once detached from the bush, missing the collection bins and falling to the ground. The third source of yield loss is the inability of the picking machine to distinguish between ripe and immature blueberries. Yield losses can often reach more than 30% of the gross yield [32]. Machine-harvested blueberries are also more bruised than hand-harvested ones, reducing the post-harvest life of the fruit. For these reasons, mechanical harvesters still need to be improved for picking berries for the fresh market [33].

The objective of this study was to improve the knowledge on the applicability of mechanical harvesters in the Piedmont area (northwest Italy) for highbush blueberries destined for the fresh market, evaluating the harvesting activities in terms of economic performance. Manual harvesting was compared with two harvesting machines: a commercial machine that is already used in northern Europe for the fresh market (Easy Harvester®) and a prototype of an electric machine based on bush shaking. The comparison focused on harvesting efficiency, labor productivity and harvesting costs related to the hectares of production. We aimed to study the rentability of the farms at different picking times and the total harvest. A sensitivity analysis was carried out to investigate the cost-effectiveness of mechanical and semi-mechanical harvesting compared with manual harvesting following the variation in the price paid to the farms.

The paper is organized as follows: Section 2 reports the case study investigated (involved in the 2-year experimentation), the field conditions and the employed mechanical harvesting machines, following Sargent et al. [34]; Section 3 describes the results, together with the discussion; and in Section 4 we report the conclusions and suggestions for future research.

2. Materials and Methods

2.1. Case Study

The agricultural cooperative involved in this study is Agrifrutta (a producer and member of the Ortofruit Italia association). Agrifrutta appears among the top five producers for the production and sale of berries in Italy. Over the last 10 years, the cooperative has recorded an increase in the blueberry cultivation area and, together with research organizations, has developed innovation along the entire supply chain. The Agrifrutta cooperative has transformed, over 10 years, from a type I organizational system, in which the blueberries were packaged directly by the farmer during the harvest and the product was immediately placed on the market with very short storage and conservation periods, to a type II system [34], in which the supply chain involves refrigeration and modified atmosphere systems that allow the product to be packaged in the packhouse and to be present on the market for a longer period of time [9]. Today, the Agrifrutta cooperative has the goal of reducing blueberry production costs. With this objective, the innovation has focused on reducing harvesting costs and improving labor productivity and harvesting efficiency. Accordingly, the feasibility of mechanical harvesting has been studied using a prototype machine and an Easy Harvester® for semi-mechanized harvesting. The trial was conducted on cv. Cargo®, a highbush blueberry variety, from the breeding programs of Fall Creek Farm and Nursery (Lowell, OR, USA). Cargo® can be considered a highbush blueberry plant that guarantees high performance in mechanical harvesting [35,36].

2.2. Prototype Machine

The prototype machine (Figure 1) was produced by Wgreen Technology sas, Diano d'Alba, Cuneo, Italy. It is a self-propelled structure 1.2 m wide × 2 m long, weighs 600 kg and is equipped with four steering wheels with four single 48 V motors (4 WD on a single wheel). The seat to position the extensible arm (max. length 2 m) used for agitating the bush is mounted on the motorized structure. The end of the arm is composed of a comb that, when inserted inside the plant, allows widespread transmission of the shaking motion to the bush branches to favor the detachment of ripe fruit. The "shaking" movement of the comb is impressed on the insertion seat of the arm by a lever system activated by the rotation of two drums, moved by a chain. The shaking system is powered by a fifth specific electric motor (48 V) and operated by a control panel connected via radio. It is possible to vary the speed and frequency of the comb's shaking. In accordance with Sargent et al. [34], the comb frequency used was 7 Hz. The arm and the comb are made of steel, and the insertion of the comb into the plant is performed manually. The machine is powered by electricity with two 48 V lithium batteries (autonomy: min. 8 h; max. 12 h) with 700 charge cycles at 80% (charging time 5–7 h), and the indicator charge is provided by the on-board computer.

Figure 1. Prototype machine for blueberry harvesting.

The remote-controlled steering system (steering radius 300 cm) makes it easy to move the machine in the field. Its use involves the insertion of the fins into the blueberry bush, the shaking of the latter, the subsequent withdrawal of the arm—performed manually, and the movement to the next two bushes. The machine, for a single set-up, is able to harvest two plants. The prototype does not include a fruit harvesting system at the base of the row.

The whole machine is powered by 5 motors × 1.2 KW and can move with a speed from 0 to 8 km/h. Three workers are needed to harvest with the prototype machine: one worker to drive the machine and two workers to extend/retract the arm and insert/remove the comb from the plant.

2.3. Easy Harvester® Commercial Machine

The Easy Harvester® commercial machine for semi-mechanical harvesting (Figure 2) was developed in the Netherlands by the Driesvenplant BV Company with the support of the International Blueberry Organization (IBO). The Easy Harvester® has dimensions of 3.30 m in length × 3.00 m in width (considering the two units positioned on the row for harvesting) and a weight of 250 kg. The Easy Harvester® consists of two units (UNIT 1 and UNIT 2 in Figure 2) that work simultaneously on both sides of the row. The two units can be separated from each other or joined by a frame straddling the row that allows the entire structure to move together along the row (see A in Figure 2). The single unit consists of a galvanized steel base frame (see B in Figure 2) on which the galvanized aluminum collector box (see C in Figure 2) is fixed for the collection of fruit that has fallen from the bushes. This frame rests on three rubber wheels (42 cm in diameter) in the version without straddling (see D in Figure 2), two fixed at the front and one steering at the rear. Meanwhile, in the version in which the frame straddles the row, the number of wheels per single unit is reduced to two. The internal surfaces of the collector box are inclined so that the blueberries roll into the two picking boxes (40 cm × 60 cm) placed at the collector box's base. These boxes must be inserted into the slots provided on the back of the collector box (see E in Figure 2). The collector box can be extended forwards in both units via a manual lever system (see F in Figure 2). This system enables better adherence to the basal part of the bush, avoiding product losses in the orchard. The end of the collector box is equipped with a brush (with very elastic plastic bristles, see G in Figure 2). The brush allows the two machine groups to work at the bush base during the harvest. This system enables the Easy Harvester® to be in close contact with the row, and the collector box does not damage the bushes, especially in the basal lignified part (Figure 2). The Easy Harvester® is equipped with a transport seat for the picking boxes at the front of the wheel frame, while the full picking boxes must be left in the orchard along the row and will be removed from the field later. The Easy Harvester® picks two plants at the same time and requires four workers for picking (two per machine unit). The blueberry harvest is carried out through manual shaking by workers. After shaking, the four workers retract the two collector boxes and manually move the machine towards the next two blueberry bushes.

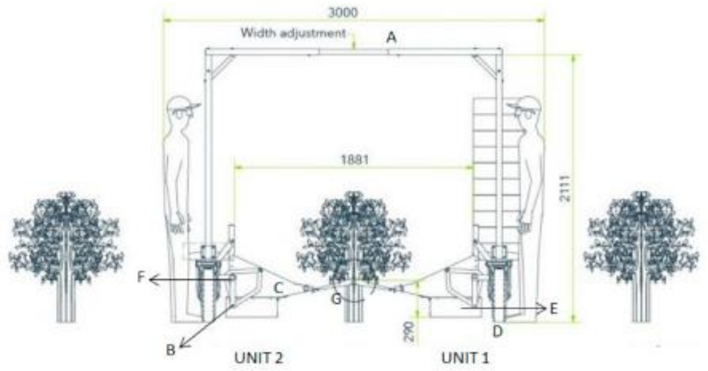

Figure 2. Blueberry collection by the Easy Harvester®.

2.4. Field Conditions and Data Collection

The study ran, as conducted in similar studies [37], for two years (2018/2019) on three experimental plots (harvested with a prototype machine (PH), an Easy Harvester® (EH), and manual harvesting (MH)) formed by 600 Cargo® bushes (200 plants for each plot) at the fourth (for 2018) and fifth (for 2019) year of age. The trial was performed in a 4 ha commercial orchard in Lagnasco (province of Cuneo) with a planting pattern of 1 m × 3.2 m (2875 plants/ha), trunk on the row (0.20 m high), covered with mulching (black plastic) and inter-row grass. The orchard was equipped with a fertigation system and anti-hail nets. Three picking times were performed on each plot. As suggested by Gallardo and Zilberman [12] and Cai et al. [38], mechanical and semi-mechanical picking were delayed by 3 days compared with manual picking. In all three experimental harvests, the three picking times were performed every 7 days. The parameters monitored and measured in each of the 2 years of experimentation were the gross production (P600y1 and P600y2), the percentage of harvested product ($[\%ph\ ^{t}{}_{n}]^{y}$), the harvest performance (kg/h) ($[hp^{t}{}_{n}]^{y}$), the number of plants harvested at the same time, the time needed to harvest for mechanical harvesting (set up + harvesting) and the percentage of berries lost after manual selection in the packhouse (green/immature fruits and overripe/damaged product) ($[\%bl\ ^{t}{}_{n}]^{y}$).

- "t" indicates the harvest time (t = I: first harvest time; t = II: second harvest time; t = III: third harvest time);
- "n" denotes the harvesting technique (n = A: manual harvest; n = B: prototype harvest; n = C: Easy Harvester®)
- "y" stands for the year (y1 = 2018; y2 = 2019)

To extend the trial to the hectare (2875 plants) for the three types of harvest, direct measurements from the three experimental plots were used for adapting the calculation methods used by Gallardo and Zilberman [12]. To determine the production per tree, the average production per plant obtained in year 1 and year 2 was calculated. The average production for each year was calculated on the 600 plants that make up the 3 plots:

$$\text{Production per tree}^{-} = ((\text{P600y1}/600) + (\text{P600y2}/600))/2 \quad (1)$$

The percentage of harvested product, the harvest performance and the berries lost in each picking were obtained as follows:

$$\%\ \text{products harvested}\ ^{t}{}_{n} = ([\%ph\ ^{t}{}_{n}]^{y1} + [\%ph\ ^{t}{}_{n}]^{y2})/2 \quad (2)$$

The harvest performance and the percentage of berries lost for the total harvest of each harvesting technique were calculated as reported in the following equations:

$$\text{harvest performance}\ {}^{t}{}_{n} = ([\text{hp}\ {}^{t}{}_{n}]^{y1} + [\text{hp}\ {}^{t}{}_{n}]^{y2})/2 \quad (3)$$

$$\text{harvest performance}_{\ n} = \sum \text{harvest performance}\ {}^{t}{}_{n}/3 \quad (4)$$

$$\%\ \text{bl}\ {}^{t}{}_{n} = ([\%\text{bl}\ {}^{t}{}_{n}]^{y1} + [\%\text{bl}\ {}^{t}{}_{n}]^{y2})/2 \quad (5)$$

$$\%\ \text{bl}_{\ n} = \sum \%\ \text{bl}\ {}^{t}{}_{n}/3 \quad (6)$$

The production/ha for each picking time is described in the following equation:

$$\text{Production/ha}\ {}^{t}{}_{n} = (\text{production per treex2875 plants/ha})\text{x}\%\ \text{products harvested}\ {}^{t}{}_{n} \quad (7)$$

The production/ha of the total harvest, for each harvesting methodology, was calculated with the sum of the production*ha^{-1} for each picking time:

$$\text{Production/ha}_{n} = \sum \text{production/ha}\ {}^{t}{}_{n}\ 8 \quad (8)$$

The saleable production for each picking time (Equation (9)) was calculated, for each harvesting method, by multiplying the production/ha ${}^{t}{}_{n}$ and the percentage of saleable product, while the saleable production for the total harvest was obtained as the sum of the saleable production for each picking time Equation (10):

$$\text{Saleable production}\ {}^{t}{}_{n} = \text{production/ha}\ {}^{t}{}_{n}\ \text{x}\ (1 - \%\ \text{bl}\ {}^{t}{}_{n}) \quad (9)$$

$$\text{Saleable production}_{\ n} = \sum \text{saleable production}\ {}^{t}{}_{n} \quad (10)$$

The picking hours for each picking time (Equation (11)) were estimated by dividing the production/ha for the harvest performance, considering each harvesting method. The picking hours for the total harvest were calculated as the sum of the picking hours for each single picking time:

$$\text{Picking hours}\ {}^{t}{}_{n} = \text{production/ha}\ {}^{t}{}_{n}/\text{harvest performance}\ {}^{t}{}_{n} \quad (11)$$

$$\text{Picking hours}_{\ n} = \sum \text{picking hours}\ {}^{t}{}_{n}8 \quad (12)$$

For the manual harvest, 12 workers per hectare were considered, based on the information provided by the farm where the trial was conducted. In addition, 8 h of daily work were assumed. The picking days for each single picking time were estimated by dividing the picking hours for the multiplication between the number of workers and the 8 picking hours per day. The picking days for the total harvest were derived from the sum of the picking days for each picking time.

$$\text{Picking days}\ {}^{t}{}_{n} = \text{picking hours}\ {}^{t}{}_{n}/(\text{number of workersx8 picking hours per day}) \quad (13)$$

$$\text{Picking days}_{n} = \sum \text{picking days}\ {}^{t}{}_{n}8 \quad (14)$$

2.5. Economic Evaluation

The economic evaluation considered all the costs associated with the harvest operations (fixed and variable costs) for each type of harvest. The costs for the economic evaluation of the three types of harvesting and the expected life of the machines and batteries were provided by the Agrifrutta cooperative and are shown in Table 1. The difference between the revenue of the total saleable production and the harvesting costs was used as an indicator of rentability (calculated for each harvest typology). The values of the total saleable production were the revenues from the sale of blueberries, for which the yields considered were those calculated for 1 hectare of production from the data measured in the orchard trial, and the prices were based on the average prices obtained by the farmer in the 2-year period of experimentation for manually harvested blueberries (4.00 €/kg).

Table 1. Overall costs of harvesting from the Agrifrutta cooperative.

Production Factors	Unit	Manual Harvest	Prototype	Easy Harvester®
Non-specialized employee	€/h	10.98	10.98	10.98
Machine market price	€		60,000.00	5000.00
Expected years of life of the machine	years		15	15
Market price of lithium batteries	€		2400.00	
Expected years of battery life	years		5	
Electricity cost for a single recharge	€/days		2.00	
Machine maintenance	€/years		100.00	200.00

A sensitivity analysis of the rentability, similarly to Gallardo and Zilberman [12], was undertaken by testing the effect of consistent price changes (up to ±25%), taking into consideration the fact that the prices of berries have started to face significant fluctuations in the last few years [30,31]. In addition, for mechanically and semi-mechanically harvested fruit, the value of the processing operations undertaken at the packhouse to make the product saleable on the fresh market (0.40 €/kg) was subtracted from the price paid by the Agrifrutta cooperative to the farmers. This amount corresponds to the processing costs charged by the packhouse to the farmer in the period 2018 and 2019 (data provided by the Agrifrutta cooperative).

3. Results and Discussion

3.1. Harvest Efficiency and Labor Productivity

The technical results for the three types of harvest, calculated for 1 hectare of production, are shown in Table 2. Mechanical and semi-mechanical harvesting (PH and EH) showed a higher harvest performance than traditional MH. MH's performance, over the entire harvest, was three times lower than that for PH and two times lower than that for EH. This result is in line with Takeda et al.'s observations [31]. The gap between the manual harvest and the two mechanical harvests was even more pronounced for the second picking time: PH and EH showed 25.4 kg/h and 18.7 k/h more harvesting than MH, respectively. These results can be attributed to the fact that the second picking time, on the Cargo® cv., had the highest percentage of ripe fruit on the plant, thus considerably increasing the amount of time spent on mechanical and semi-mechanical harvesting [39]. The harvesting gap performance evidenced by MH has repercussions for the picking hours and picking days per hectare of workers. In fact, considering as a whole the three picking times, PH showed −71.6% of man-hours required per hectare compared with MH, while EH showed −40.8% of picking hours compared with MH. However, it is necessary to consider that the percentage of berries lost is higher in mechanical harvesting than in manual harvesting in all three picking times. This data confirms that berry loss is the major weakness evidenced by mechanical harvests [40]. PH in the experimentation had a product loss that was 27.4% higher than manual harvesting (in accordance with the results of Gallardo et al. [41] and Van Dalfsen and Gaye [42]) and 16.3% higher than harvesting with EH. This finding confirms what Rodgers reported in 2014 [32]. The higher product loss may be related to the fact that plant shaking with EH is performed manually and is thus dictated by human judgement, while plant shaking with PH is totally mechanical. For both types of mechanical harvesting, the most important factor was product losses. According to the results obtained by Olmstead and Finn [39], more product losses are found at the first picking time, 39% for PH and 22% for EH. This is due to the percentage of mature product on the plant being lower at the next two picking times, and therefore, a higher percentage of green and immature berries are detached from the bush during the picking operation [39]. Hence, for EH, the losses are significantly reduced (−13%) from the first to the second picking time. Therefore, in contrast to the statement of Sargent et al. [34], the picking time can have a significant effect on the technical data considered. These product losses affect the saleable production. PH and EH show, compared with MH in the saleable berries, a reduction respectively of 27.5% and 11.0%.

De Vetter et al., in 2019 [43], observed a loss in terms of saleable production with an OTR harvester used for the fresh market of 16% in "Duke" and 26% on "Draper". Sargent et al., in 2021 [44], observed two varieties of southern bush blueberry losses ranging from 8% to 24% with the use of an OTR harvester on berries for the fresh market.

3.2. Harvesting Cost

The costs for each of the experimented harvesting techniques are shown in Table 3. The costs of MH were derived entirely from the labor cost for harvest, and the second picking time accounted for 47% of the costs of the entire MH. For the total harvest, PH and EH showed, respectively, a −71–59% for harvest labor cost with respect to MH. Gallardo and Zilbermann [12], in 2016, observed that an OTR harvester reduced labor cost for harvesting by 93%; such reductions were due to the fact that the OTR machine needs only an operator, and its hourly productivity is broadly higher with respect to PH and EH.

At the second picking time, the largest differences in fixed plus variable costs between MH and the two mechanical types of collection were −69% for PH and −72% for EH.

The total costs calculated for 1 hectare of MH were significantly higher than those for mechanical and semi-mechanical harvesting: + 55% compared with PH harvesting and +57% compared with EH harvesting. However, PH had nine times higher fixed costs than EH since the initial purchase price of the two machines is very different, and the same number of years of life for PH and EH was considered. Gallardo and Zilbermann [12] evidenced in terms of total costs a +71% of cost harvesting of manual methods with respect to OTR harvesting.

The labor costs exceed EUR 2.00 per kg of saleable product in manual harvesting (Table 3). These results are in accordance with Takeda et al. [31].

The use of PH allows a reduction of 39% of this cost considering the total harvest, and the use of EH allows a reduction of about half of the cost per kg of saleable blueberries (−52%). It should be emphasized that these positive performances of EH and PH in terms of the unit costs of production do not consider an important criticality: the reduction of the net selling price of EUR 0.40 per kg due to the costs of manual selection charged by the Agrifrutta cooperative to the farmer.

3.3. Rentability and Sensitivity Analysis

To obtain an overall comparison of the effect on rentability of the three harvesting types, in accordance with Gallardo et al. [12], the rentability per hectare for each harvesting type was analyzed within a range of net producer liquidation prices from EUR 3 to 5 kg^{-1} of saleable production (Table 4). The harvesting technique that provides, at any price level analyzed, the highest rentability for the total harvest is EH (Table 4). PH, for most of the price scenarios analyzed, was the least cost-effective. Only for prices of EUR 3.20 or less (the manual harvest price) does PH become competitive with manual harvesting relative to the entire harvest. However, the analysis of rentability for each type of harvest showed that the best overall results of EH depend mainly on the performance at the second picking time. At a mid-price of EUR 4, EH at the second picking time showed an increase of EUR 9909.79 in rentability compared with MH and an increase of EUR 6496.68 compared with PH, in accordance with Gallardo et al. [41], which affirms that the modified OTR methods have higher economic performances with respect to manual harvesting. However, MH guarantees higher margins with medium-high prices (from EUR 3.70 to 5.00) at the first picking time. This result can mainly be explained by the high percentage of berries lost with EH and PH at the first picking time due to the lower percentage of ripe berries on the plants [39]. In addition, MH showed better rentability than PH and EH at the third picking time for the whole range of prices analyzed. This can be attributed to the lower percentage of berries harvested from the plant, and thus a smaller amount of saleable product at the third picking time with PH (−13.8%) and EH (−12.9%) compared with MH.

Table 2. Technical data (collected in the 2-year evaluation period) of the three types of harvest analyzed for the 1-hectare production of cv. Cargo blueberries at the three picking times.

		First Picking Time			Second Picking Time			Third Picking Time			Total Harvest		
	Unit	MH	PH	EH	MH	PH	EH	MH	PH	EH	MH	PH	EH
Production per tree	Kg										4.8	4.8	4.8
% product harvested	%	21.9%	28.0%	24.8%	48.3%	56.0%	58.3%	29.8%	16.0%	16.9%	100%	100%	100%
Harvest performance	Kg/h	5.1	15.4	8.9	5.3	30.7	24.0	5.1	8.8	6.4	5.2	18.3	12.7
Plants harvested at the same time	Unit		2	2		2	2		2	2		2	2
Time to harvest	Min		3.5	4.0		3.5	3.5		3.5	3.8		3.5	3.8
% berries loss	%	2	39	22	1	27	9	1	14	8	1.0	28.4	12.1
Production/ha	Kg/ha	3022	3864	3422	6665	7728	8045	4112	2208	2332	13,800	13,800	13,800
Saleable production	Kg/ha	2962	2342	2669	6599	5641	7321	4071	1899	2146	13632	9882	12136
Picking hours	Total hours/worker s/ha	592	252	383	1258	252	335	806	252	364	2657	755	1083
Picking days	Total days/worker /ha	6	10	12	13	10	10	8	10	11	27.7	31.4	33.8

Notes. MH: manual harvesting, PH: prototype harvesting, EH: Easy Harvester®.

Table 3. Overall costs of harvesting.

	Unit	Total Costs			Cost of First Picking Time			Cost of Second Picking Time			Cost of Third Picking Time		
		MH	PH	EH	MH	PH	EH	MH	PH	EH	MH	PH	EH
Total fixed cost			4580.00	533.33		1526.67	177.78		1526.67	177.78		1526.67	177.78
Machine depreciation	€/year		4000.00	333.33		1333.33	111.11		1333.33	111.11		1333.33	111.11
Battery depreciation	€/year		480.00			160.00			160.00			160.00	
Machine maintenance	€/year		100.00	200.00		33.33	66.67		33.33	66.67		33.33	66.67
Total variable costs	€/year	29,169.07	8349.36	11,890.43	6506.62	2783.12	4209.00	13,808.70	2783.12	3682.88	8853.76	2783.12	3998.55
Electricity cost	€/year		62.89			20.96			20916.96			20.96	
Labor cost	€/year	29,169.07	8286.47	11,890.43	6506.62	2762.16	4209.00	13,808.70	2762.16	3682.88	8853.76	2762.16	3998.55
Fixed + variable costs	€/year	29,169.07	12,929.36	12,423.76	6506.62	4309.79	4386.78	13,808.70	4309.79	3860.65	8853.76	4309.79	4176.33
Fixed + variable costs on saleable production	€/kg	2.14	1.31	1.02	2.20	1.84	1.64	2.09	0.76	0.53	2.17	2.27	1.95

Notes. MH: manual harvesting, PH: Prototype harvesting, EH: Easy Harvester®.

Table 4. Rentability for the different picking times and the total harvest for the three types of harvesting tested.

Price of Blueberries (€/kg)		Total Rentability (€)			Rentability: First Picking Time (€)			Rentability: Second Picking Time (€)			Rentability: Third Picking Time (€)		
Manual Harvest	Mechanical Harvest	MH	PH	EH	MH	PH	EH	MH	PH	EH	MH	PH	EH
5.00	4.60	38,989.82	32,527.40	43,403.73	8302.16	6461.50	7892.79	19,185.03	21,640.84	29,817.39	11,502.62	4425.06	5560.08
4.90	4.50	37,626.64	31,539.21	42,190.09	8005.99	6227.34	7625.85	18,525.16	21,076.69	29,085.26	11,095.50	4235.17	5345.52
4.80	4.40	36,263.46	30,551.02	40,976.45	7709.81	5993.18	7358.90	17,865.28	20,512.55	28,353.13	10,688.37	4045.29	5130.96
4.70	4.30	34,900.29	29,562.83	39,762.80	7413.63	5759.02	7091.95	17,205.41	19,948.41	27,621.00	10,281.24	3855.40	4916.40
4.60	4.20	33,537.11	28,574.64	38,549.16	7117.46	5524.87	6825.00	16,545.53	1984.26	26,888.87	9874.11	3665.51	4701.83
4.50	4.10	32,173.93	27,586.45	37,335.52	6821.28	5290.71	6558.06	15,885.66	18,820.12	26,156.73	9466.99	3475.62	4487.27
4.40	4.00	30,810.75	26,598.26	36,121.88	6525.11	5056.55	6291.11	15,225.79	18,255.97	25,424.60	9059.86	3285.73	4272.71
4.30	3.90	29,447.57	25,610.07	34,908.24	6228.93	4822.39	6024.16	14,565.91	17,691.83	24,692.47	8652.73	3095.85	4058.15
4.20	3.80	28084.40	24,621.88	33,694.60	5932.76	4588.23	5757.22	13,906.04	17,127.69	23,960.34	8245.60	2905.96	3843.58
4.10	3.70	26,721.22	23,633.69	32,480.96	5636.58	4354.07	5490.27	13,246.16	16,563.54	23,228.21	7838.48	2716.07	3629.02
4.00	3.60	25,358.04	22,645.50	31,267.32	5340.41	4119.92	5223.32	12,586.29	15,999.40	22,496.08	7431.35	2526.18	3414.46
3.90	3.50	23,994.86	21,657.30	30,053.68	5044.23	3885.76	4956.37	11,926.41	15,435.25	21,763.95	7024.22	2336.29	3199.90
3.80	3.40	22,631.69	20,669.11	28,840.04	4748.05	3651.60	4689.43	11,266.54	14,871.11	21,031.81	6617.09	2146.41	2985.34
3.70	3.30	21,268.51	19,680.92	27,626.39	4451.88	3417.44	4422.48	10,606.66	14,306.97	20,299.68	6209.97	1956.52	2770.77
3.60	3.20	19,905.33	18,692.73	26,412.75	4155.70	3183.28	4155.53	9946.79	13,742.82	19,567.55	5802.84	1766.63	2556.21
3.50	3.10	18,542.15	17,704.54	25,199.11	3859.53	2949.12	3888.59	9286.91	13,178.68	18,835.42	5395.71	1576.74	2341.65
3.40	3.00	17,178.97	16,716.35	23,985.47	3563.35	2714.97	3621.64	8627.04	12,614.53	18,103.29	4988.58	1386.85	2127.09
3.30	2.90	15815.80	15,728.16	22,771.83	3267.18	2480.81	3354.69	7967.17	12,050.39	17,371.16	4581.46	1196.97	1912.52
3.20	2.80	14,452.62	14,739.97	21,558.19	2971.00	2246.65	3087.74	7307.29	11,486.25	16,639.03	4174.33	1007.08	1697.96
3.10	2.70	13,089.44	13,751.78	20,344.55	2674.82	2012.49	2820.80	6647.42	10,922.10	15,906.90	3767.20	817.19	1483.40
3.00	2.60	11,726.26	12,763.59	19,130.91	2378.65	1778.33	2553.85	5987.54	10,357.96	15,174.76	3360.07	627.30	1268.84

Notes. MH: manual harvesting, PH: prototype harvesting, EH: Easy Harvester®.

Rentability and Sensitivity Analysis of Integrated Harvests

The evidence derived from the technical and economic performances observed should recommend that farmers perform an integrated harvest (IH), that is, combining MH and EH. EH could be used at the second picking time when this harvesting technique shows the best yield for the farmer in relation to the maximum percentage of products harvested and the minimum percentage of berry loss. On the other hand, at the first and third picking times, MH could be used since it shows higher rentability than EH for most of the prices analyzed in accordance with Gallardo et al. [12]. Figure 3 presents the comparison between IH and EH in terms of rentability for the total harvest. IH is compared with EH since the latter shows the highest overall rentability among the harvest types analyzed. In the total harvest, IH had higher rentability than the total harvest with EH for all the price levels analyzed. The harvest with MH + EH showed rentability of +5.15% compared with the entire harvest with EH at a price of EUR 5.00, and the gap decreases to +3.31% with a price of EUR 3.00.

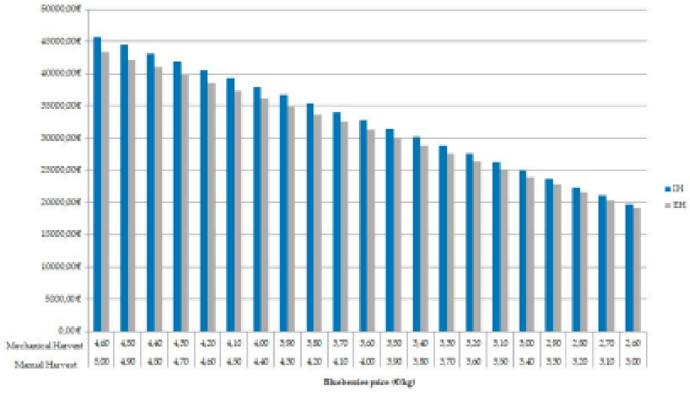

Figure 3. Total harvest rentability comparing EH and IH.

4. Conclusions

The labor constraints related to growing blueberries and other tree crops in the investigated area are increasing [25]. The need to experiment and develop harvesting technologies that are convenient for producers and can ensure a product of similar quality to hand-picked blueberries is urgent. The preliminary results of this study, focusing on the mechanical and semi-mechanical harvesting of 1 hectare of blueberry cv. Cargo®, provide several interesting points regarding both technical and economic aspects. PH evidenced two severe technical flaws: the damage of the bush and the percentage of damaged berries determine the economic unfeasibility of its adoption without relevant changes in the machinery and its equipment. EH represents an opportunity for a blueberry harvesting technique in the investigated context.

The wholesale blueberry price variability documented [41] in the fresh market in the last three years (2018–2020) seems to support the results highlighted by the trial. The rentability achievable in both high- and low-price scenarios shows higher overall rentability associated with EH [41]. This harvesting technique also presents advantages in terms of reduced investment needs and the adaptability of mechanical harvesting to existing orchards in the production context investigated compared with the widespread mechanized solution used in North America: the OTR [34]. However, the two key factors that determine if mechanical harvest is rentable or not, ar berry loss and labor productivity [12].

However, some technical aspects of EH could be improved to increase its field performance further:

- The inclusion of a motorized system (electric motor) permitting the machine to be moved in the field and reducing the physical labor of the operators;

- The use of materials that are lighter than steel in some EH components (e.g., the collector box) to reduce the weight of the machine, reducing the energy consumption in case of adoption of an electric motor;
- The use of tires with a larger diameter to facilitate machine handling on uneven terrain;
- The addition of a system that permits the inclination of the collector box to be modulated to allow EH to adapt better to the characteristics of the orchard (the height of the trunk, height of the plants and bearing of different cultivars).

In order to limit the criticalities evidenced by PH with the introduction of force sensors (shake movement of the bush) and color/ripe fruit sensors to limit berry loss [27,45].

Furthermore, the technical performance of the mechanical harvest could be increased if the orchard management were modified to facilitate mechanical harvesting. Indeed, the bush structure could be adapted to mechanical harvesting by following the suggestions of different authors [37,46,47]:

- Reduce branch bending by using tutoring wires along the row;
- Modify pruning to favor a vertical architecture of the plant, reducing the number of branches in the basal part and pushing the production to the upper part of the bush. These measures will increase the adherence of the collector box to the row, ease the insertion of the collector box at the base of the plant and thus facilitate the manual shaking work of workers, increasing the harvest performance.

Other critical points, as affirmed by [39,44], are represented by both the choice of the variety and varietal innovation, such as varieties more adaptable to mechanical harvest with the higher detachment force of unripened fruits than ripened fruits [48].

Furthermore, the use of EH in the organization of IH harvesting, in addition to showing superior rentability for all the prices analyzed, could improve the management of farm labor, avoiding both personnel peaks (picking hours) that occur with MH at the second picking time and labor shortages. This solution would also allow the labor saved at the second picking time to be used to pick more fruit on the farm since, in the area investigated, farms generally have mixed crops of major fruits, berries and vegetables. Alternatively, it would allow farmers to increase the average blueberry acreage on their farm for the same amount of labor employed.

The integration of manually and mechanically harvested berries also suggests some strategies for storing and marketing blueberries:

- Store mechanically harvested berries for a short period of time (max. 15 days): immediate sale [35];
- Store blueberries that have been harvested manually in a modified atmosphere (MA) to prolong the product life (storage 30–40 days) [3,49].

As reported by Huffman [50], switching to efficient mechanical harvesting requires the transformation of a farming operation, including new varieties, new field configurations and new packaging processes.

In conclusion, it can be suggested that the technical improvement of EH and its possible integration with MH in the harvest plan, together with the evolution of post-harvest management of blueberries, could represent an opportunity for Italian blueberry growers in the future planning of berry production and marketing, involving all the actors of the supply chain. Moreover, the post-harvest management of berries should subsequently be investigated to compose a complete scenario.

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

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A B S T R A C T

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 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:

0–9% = 1; 10–25% = 2; 26–50% = 3; 51–75% = 4; 76–100% = 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 ®.

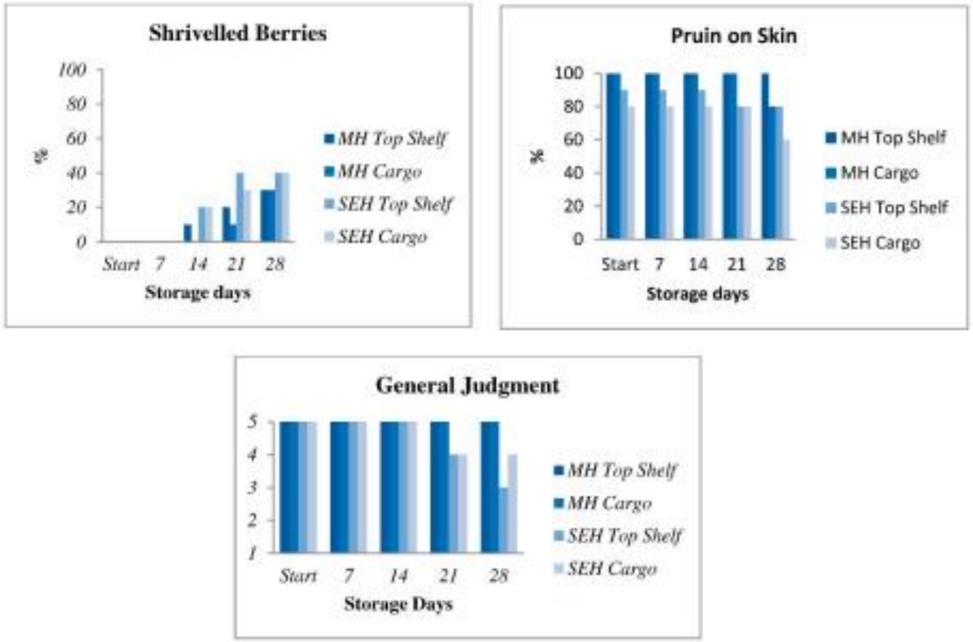


Fig. 2. Visual evaluation of external aspects (from 0 to 28 days) in postharvest storage for the Cargo and Top Shelf cultivars. Simulation of mechanical harvest (SEH) and manual harvest (MH) in 2018: % shrivelled berries (A), % pruin on skin (B) and general judgement (C). Number of blueberries samples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

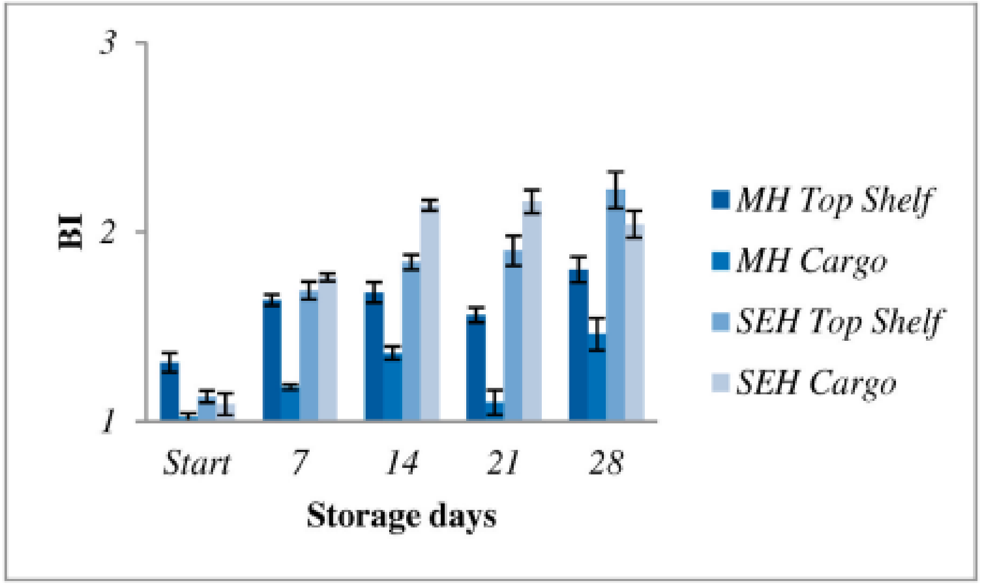


Fig. 3. Bruising index of berries in postharvest storage (from 0 to 28 days) for Cargo® and Top Shelf® after simulation of mechanical harvest (SEH) and manual harvest (MH) in 2018. Number of blueberries sampled = 300 for each variety and harvest method. BI categories: 1 (0–9%), 2 (10–25%), 3 (26–50%),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

4.2. Activity 2

In both years of research, the blueberries yield per hectare at the

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

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.

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,

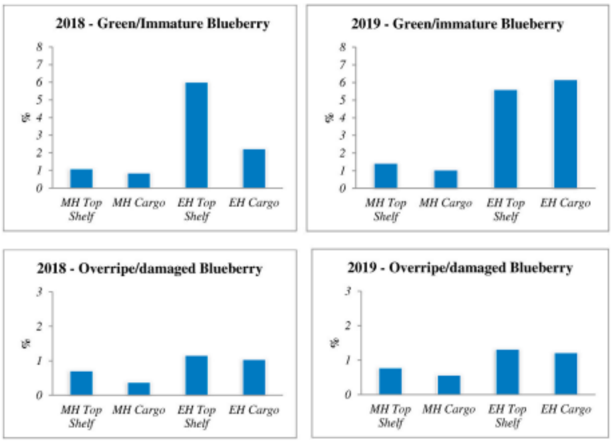


Fig. 4. Percentage of green/immature blueberries and overripe/damaged blueberries of Cargo® and Top Shelf®, derived from manual selection after harvest with Easy Harvest (mechanical harvest—EH) and manual harvest (MH) in 2018 and 2019 at day 0. (For interpretation of the references to colour in this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

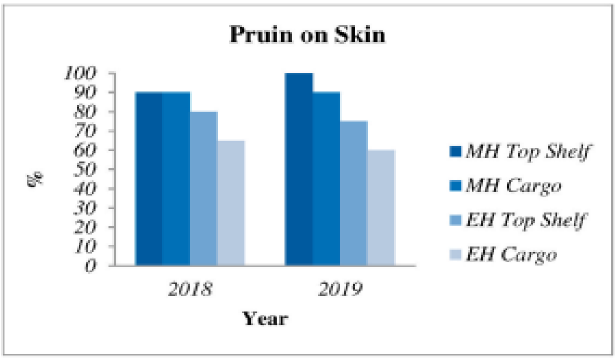


Fig. 5. Percentage of pruin on marketable berry skin at 0 days for Cargo® and Top Shelf® after harvest with Easy Harvest (EH) and manual harvest (MH) in 2018 and 2019. Number of sampled blueberries = 300 for each variety and harvest method.

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.

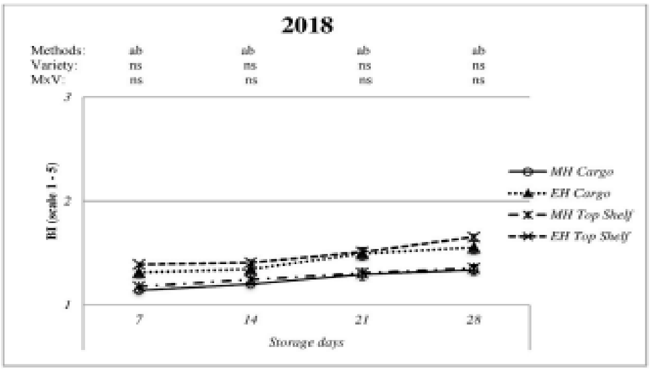
In activity 2, the highest berries losses were observed for the EH samples; these results were in agreement with Cai et al. [19]. Mechanical harvest negatively influence the marketable yield when compared to manual harvest.

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.



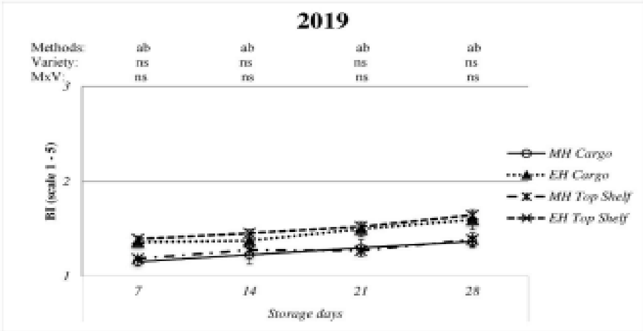


Fig. 6. Bruising index of Cargo® and Top Shelf® berries from 7 to 28 days in postharvest storage after harvest with the Easy Harvest (mechanical harvest-EH) and manual harvest (MH) methods in 2018 (A) and 2019 (B). Number of sampled berries = 300 for each variety and harvesting method. BI categories: 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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4.2. *TOPIC 2*: CRITICITA' EMERGENTI NELLA COLTIVAZIONE DEL LAMPONE

Questo capitolo è dedicato al seguente articolo pubblicato:

Brondino L., Giuggioli N. R., Peano C., (2022). Raspberry floricane dieback in northern Italy: study of the cane vigor influence and evaluation of primocane basal defoliation managment in double crop system. Acta Horticulturae - in press.

L'intensificazione delle produzioni di lampone nelle aree storicamente dedicate alla coltivazione della frutta maggiore, unitamente agli effetti del cambiamento climatico e all'eccessivo sfruttamento del suolo, stanno causando l'insorgenza di problematiche agronomiche e patologiche emergenti (Dolan et al. 2018) che potrebbero compromettere le rese produttive e qualitative delle aziende agricole associate ad OrtofruitItalia soc. agr. coop. O.P. Inoltre, la riduzione della produttività e della qualità corrisponde ad un ritorno economico inferiore per l'azienda agricola. Situazione che potrebbe inficiare la sostenibilità economica della coltivazione (Serret-López *et al*. 2017). La domanda di ricerca è volta ad analizzare se l'introduzione di nuove tecniche di gestione agronomica del lamponeto possono ridurre la problematica emergente evidenziata in Piemonte.

Raspberry floricane dieback in northern Italy: the cane vigor influence and the evaluation of primocane basal cleaning management in double crop system

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Keywords: *Rubus idaeus*, floricane production, cultural practice, primocane defoliation, cane vigor

ABSTRACT

Rubus idaeus L. are increasing in the Piedmont, North Italy due the high attention of red raspberries consumption from the consumers. Intensive cropping has caused emerging cane diseases that affect the raspberries production; the main symptoms are on the floricanes that show as brittle, snap off easily, died and with buds stunted development. The control and effective disease management are necessary to guarantee the quantitative and qualitative production. The aim of this work was to evaluate the symptoms on cane diseases of cv Grandeur® in Piedmont (Cuneo province) where plantations intensive systems are developing. Two activities were carried on between 2020 and 2021 years. In the first year a disease rating scale with six classes was created (0 = no cane symptoms and 5 = high cane symptom) and in the orchard the floricane were selected in function of pruned cane vigor (diameter >0.99 cm; <0.99 cm and control). Then, the cannes were classified in relation to the disease symptoms and the vegetative data (total buds, open buds, number of flowers) and production data (harvest) were collected. In the second year the basal primocane defoliation effect was evaluated on the severity disease reduction. The healthier canes with the better performances in terms of open buds, number of flowers and fruit harvested were those with the diameter <0.99. The basal cleaning management compared to the control showed statistically significant differences in terms of harvested raspberries. In conclusion, this work increases the understanding of intensive raspberry cultivation in the Piedmont area suggesting possible agronomic management strategies.

INTRODUCTION

In Europe the per capita consumption of berryfruits grows constantly. In fact, the world berryfruit market recorded an average annual growth rate of 34.2% in the period 2000-2017 (International Trade Center, 2019). This rapid growth in demand and in global berryfruit consumption is explained by the daily need of consumers to search healthy foods with health benefits to be included in their diet (Girgenti et al., 2016). Among them raspberries (*Rubus idaeus* L.) satisfy this need of consumers because they are considered superfoods in relation to their nutritional properties (Schulz and Chim, 2019, 2017). Currently raspberries production in North Italy and in Piedmont particularly has involved a vast expansion and in this area the cultivations presents significant challenges due to the number of canes affected by anomalies. Raspberry cultivars can be divided into floricane-fruiting and primocane-fruiting types (Heide and Sønsteby, 2011). In the floricane cultivars the canes are maintained and are productives for two years.

New agronomic and management approaches are urgently required to limit the raspberry floricane dieback.

The aim of this work was to evaluate the symptoms on cane diseases of cv Grandeur® in Piedmont (Cuneo province) where plantations intensive systems are developing increases. The understanding of intensive raspberry cultivation in the Piedmont area can suggest possible agronomic management strategies.

MATERIALS AND METHODS

Plant material and growing conditions

Two activities were carried on in 2020 and 2021 years. The activity 1 was performed in 2020 and replicated in 2021. While the activity 2 was carried on between 2020 and 2021 year. Both fields experiments were carried on red raspberry cv. Grandeur® that is the most cultivated among farmers in the investigated area (Norht West Italy, Piedmont, Cuneo Province). A total of 13300 plants * ha^{-1} covered the field and the following parametres were setted 3m x 0.25m, the row was covered with mulch (black plastic), and the inter-row was grassed. The orchard was equipped with a fertigation system and covered with rainproof plastic under the tunnel.

Activity 1

The aim of activity 1 was to understand the relationship between the vigor of floricane (diameter of the canes), the rate of lesion and basal necrosis of the cane and vegetative-productive parameters (open buds/total buds ratio, number of green-flower buds, yields) (Glisic, et al., 2009). A digital caliper (Borletti CDJB15-20 series) with a resolution of 0.01 mm and accuracy of ±0.02 mm was used in order to measure the diameter of 200 floricane in January 2020. All canes were chosen randomly in the orchard and the measurement was performed at the height of 20 cm from the ground. This measurement was performed in order to define an average diameter of the cane (0.99 cm), useful for the floricane selection pruning according to three vigor theses. Then to evaluate the basal lesions / necrosis a disease rating scale with six classes was applied on 25 cm of lenght of the cane (0 = no cane symptoms and 5 = high cane symptom) to determine the level of cane disease (Shternshis, et al., 2015) (figure 1).

Fig.1. cv Grandeur® disease canes rating scale.

0= no infections, no lesions, integrity of the canes; 1= Sporadic necrosis on the surface of canes (<20% area). Single necrosis of limited extension at the level of the epidermis. No lesions; 2= Necrosis in the range of 20-40%. Necrosis of limited extension at the level of the epidermis. No lesions; 3= Necrosis in the range of 40-60%. Extensive necrosis while the lesions remain small (<1 cm). Necrosis and lesions affecting the sub-epidermal and phloematic tissues.;4= Necrosis in the range of 60-80%. Necrosis of significant extension and presence of lesions with a length between 1 cm and 3 cm. Necrosis and lesions that affect the sub-epidermal and phloematic tissues more markedly;5= Necrosis in the range of 80-100%. Necrosis of significant extension and presence of lesions longer than 3 cm. Necrosis that markedly affect the sub-epidermal and phloematic tissues and lesions that can reach up to the xylem tissue.

Raspberry plants were pruned following the vigor of the canes (cane section >0.99 cm; cane section <0.99 cm) to be compared with control samples (traditional pruning by the farmer). For each of the theses, 3 blocks of 3 m each (21 canes) were created and the unit investigated was the linear meter (7 canes). Then, the canes kept for production for each thesis were then classified in the field according to the disease canes rating scale. A value per linear meter which is the average of the 7 values attributed to the 7 canes present in one meter. With regard to the vegetative parameters analyzed, the count of the total buds, of the awake buds, of the number of floral buttons and flowers was performed by the linear meter by two different operators at a distance of one day from each other with the use of a mechanical counter to limit the human error. The harvest of the product for the evaluation of the yield was carried out by a dedicated specialized operator. The latter was performed every other day for a total of nine harvest time. The product was collected in ventilated rigid polyethylene terephthalate (PET) baskets (INFIA s.r.l., Forlì, Italy) containing 0.125 kg of fruit and then weighed at the Agrifrutta warehouse.

Activity 2

Activity 2 was carried out between 2020 and 2021 to evaluate the introduction of an agronomic technique to limit the die-off of the canes from winter. This technique has the purpose of creating a better habitat of growth (lower relative humidity and greater ventilation) in the basal part of the primocane in order to limit the possibility of proliferation of pathogens that can be conveyed in the herbaceous tissue of the primocane. The primocane grown in 2020 will perform the floricane production in 2021. Agronomic technique which consists in the removal of the basal leaves in the first 25 cm of the primocane (cut with scissors at the level of the leaf stalk to limit wounds on the shoot of the sucker). This activity allows both to reduce the relative humidity in the lower part of the row and to increase the effectiveness of the disinfection treatments performed at the base of the cane during the growing season. In order to evaluate the effectiveness of the agronomic technique at the level of development of necrosis and basal lesions, 2 theses were analyzed: Primocane basal cleaning and No Primocane Basal cleaning. For each of the theses, 3 blocks of 3 m each were created and the basal cleaning was performed on 17 July 2020. The agronomic management at the level of treatments was the same for both theses. 3 classifications of the primocane were performed during the growing season using the cane classification scale previously created for activity 1. The three classifications were performed at the time of basal cleansing, at the change from herbaceous to lignified cane (October 16, 2020) and at completely lignified tissue (26 February 2021). In spring 2021, in order to evaluate the interaction between basal cleaning and cane selection pruning based on cane vigor, activity 1 was performed randomly on the blocks belonging to the primocane basal cleaning and No primocane basal cleaning. The data measured and the methodologies used are the same reported for the activity 1.

Statistical analysis

All statistics were performed using SPSS for Windows version 27.0. The data obtained were treated with one-way analysis of variance (ANOVA), and the means were separated using the Tukey test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Activity 1

Results of the activity 1 are reported in the figure 2 for 2020 and 2021. The cane rate diseases scale show for both the years significantly statistically differences among thesis, particularly pruned samples with cane diameter > 0.99 showed higher values meaning that the canes with a strong vigor are more susceptible to necrosis and basal lesions. The most vigorous canes are the primocane developed rapidly in the previous season. For this reason the herabaceus tissues of the primocane are thin and with an high cellular turgor and for this more susceptible to abiotic stress damage (mechanical damage, wind, temperature changes). This damage could be ulteriorly aggravated by the N fertilization that is necessary for the floricane production. This fertilization is excessive for the balanced growth of the primocane. However, this situation is difficult to manage since the birth and the growth of the primocane will always coincide with the floricane production and it will always be necessary to fertilize to support the floricane. The formation of these micro-lesions in conditions of high relative humidity, present at the base of the row (>78%) (Guarnaccia et al.) , represent an good development conditions and an easy enter way for the pathogens. These pathogens can be the cause the formation of internal necrosis and occlusion of phloem and xylem vessels that cause the cane death after the winter in the restart vegetative phase. The highest susceptibility of the canes with diameter >0.99 could be due to their prolonged vegetative activity. This means that the primocane maintain a herbaceous tissue for a longer time, with a greater delay in change to lignified cane. This physiological condition of the primocane can collide with cold and early autumn frosts that can cause direct damage to the phloem and xylem tissue, primocane dehydration and the onset of micro-lesions on the no lignified primocane tissues. Again, these micro-lesions may represent a gateway for raspberry fungal pathogens. Both in 2020 and 2021 larger diameter canes show significantly lower open buds / total buds ratio than smaller diameter canes and Control. This result highlights a less uniform opening of the buds on the larger diameter canes. In 2020 the thesis of selection pruning with canes <0.99 showed significantly higher results for the number of green buds and flowers and for the quantity of fruit harvested. The same was observed also in 2021. This result is due to the fact that the lower vigor canes having been less stressed by the formation of internal lesions and necrosis in the previous primocane cycle, have a more balanced vegetative restart and vegetative cycle and more performing production.

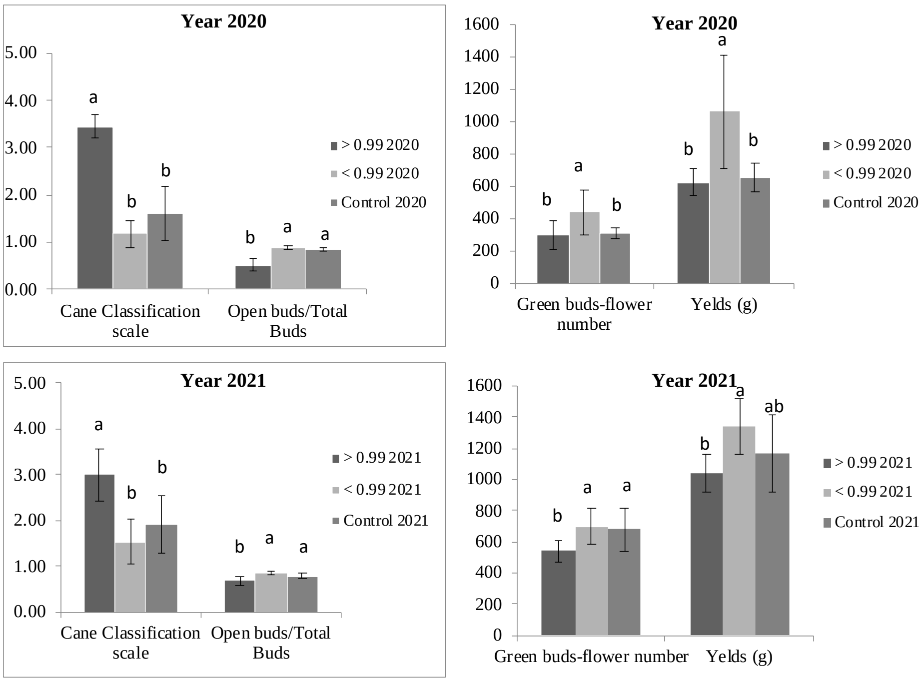

Fig. 2. Vegetative parametres (cane classification scale, open buds/total buds, green buds-flower number and yelds) for the three pruning theses of the floricane according to the vigor (section) of the cane (cane section >0.99 cm, cane section <0.99 cm and the control pruned by the farmer for 2020 and 2021. For each parameter, values followed by the same letter do not differ significantly according to Tukey's HSD test ($P \leq 0.05$). Vertical bars represent standard deviation.

Activity 2

The basal defoliation management didn't show important improvements if compared to the traditional management of the farmer.

The introduction of the agronomic technique of basal primocane cleaning (table 1) in 2020 in order to reduce the relative humidity in the basal part of the canes didn't influence significantly data if compared to the control (No basal cleaning). This result suggest that the micro-lesions aren't affected by the agronomic technique adopted. Furthermore, this result may be undermined by the fact that the agronomic technique was adopted on a small unit of the orchard, surrounded by no basal cleaning rows and therefore the air circulation in the field was limited.

	17-lug-20 (herbaceus tissues)			16-ott-20 (partial lignification of tissues)			26-feb-21 (total lignification of tissues)		
Control	1.38	0.317	ns	2.91	0.559	ns	3.07	0.389	ns
Basal Cleaning	1.27	0.339	ns	2.81	0.336	ns	2.98	0.510	ns

Table 1: Cane classification scale values (0-5) at different vegetative levels of the primocane in 2020.

The interaction between the primocane basal cleaning and the floricane selection pruning (table 2) show that the vigor of the cane is always a significant factor and the canes with a diameter <0.99 are significantly better for all the parameters analyzed, as found in activity 1. The primocane basal cleaning has a significant effect only on the yelds while no differences are found for the other parameters. Furthermore, the interaction between the primocane basal cleaning and the floricane section pruning is not significant for all the parameters studied.

Treatment	Cane Classification scale			Open buds/Total Buds			Green buds-flower number			Yelds (g)		
Cane section pruning												
> 0.99 2021	3.17	0.71	a	0.72	0.09	b	562	44.12	b	1195	155.8	b
< 0.99 2021	1.62	0.55	b	0.93	0.04	a	782	97.94	a	1395	172.2	a
Control 2021	3.24	0.55	a	0.78	0.14	ab	684	130.5	ab	1227	219.6	ab
Basal cleaning												
Yes	2.67	0.97	ns	0.81	0.09	ns	720	139.6	ns	1404	166.8	a
No	2.76	0.9	ns	0.8	0.16	ns	631	109.9	ns	1141	119.9	b
p>F-value												
Cane section pruning	0.001			0.015			0.005			0.037		
Basal cleaning	0.739			0.764			0.062			8E-04		
Pruning x Basal cleaning	0.251			0.843			0.749			0.763		

Table 2: Vegetative-productive parameters analyzed in activity 2 (classification scale, open buds / total buds, number of green-flower buds and Yields) in relation to the agronomic practice of basal cleaning from the leaves (25 cm) of the primocane in interaction with the three theses of floricane pruning based on the vigor (section) of the cane (section >0.99 cm, section <0.99 cm and the control pruned by the farmer without diametr section information).

CONCLUSIONS

The results obtained in this study indicate that a good floricane selection pruning based on vigor can be a useful technique to limit the disease that recently are affecting the raspberries production in Piedmont. The primocane basal cleaning management didn't show important improvements if compared to the traditional farmer management, however this practice need to be ulteriorly studied and applied in the raspberry fields management to best evaluate and improve it. The best way and time to execute the primocane basal cleaning represent critical factors for the real feasibility and it will be also necessary to investigate the costs for the farm management. Fields investigations need to be implemented by phytopathological analyses to evaluate differences in terms of cane infections between the different adopted practices.

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Inoltre, la ricerca svolta sulle problematiche emergenti nella coltivazione di mirtillo e lampone ha portato ai seguenti risultati:

- Guarnaccia, V., Martino, I., Tabone, G., Brondino, L., Gullino, M. L., (2020). Fungal pathogens associated with stem blight and dieback of blueberry in northern Italy. Phytopathologia Mediterranea, 59(2), 229-245. DOI: 10.14601/Phyto-11278.
- Guarnaccia, V., Martino, I., Brondino, L., Garibaldi, A., & Gullino, M. L. (2021). Leaf anthracnose and defoliation of blueberry caused by Colletotrichum helleniense in Northern Italy. Phyto-pathologia Mediterranea, 60(3), 479-491. DOI: 10.36253/phyto-12377.
- Guarnaccia, V., Martino, I., Brondino, L., & Gullino, M. L. (2022). Paraconiothyrium fuckelii, Diaporthe eres and Neocosmospora parceramosa causing cane blight of red raspberry in Northern Italy. Journal of Plant Pathology, 1-16. DOI: 10.1007/s42161-022-01068-4.

4.3. *TOPIC 3: SHELF LIFE* RIBES ROSSO

Questo capitolo è dedicato al seguente articolo:

Brondino, L., Cadario, D., Giuggioli, N. R., (2021). Influence of a Sulphur Dioxide Active Storage System on the Quality of Ribes rubrum L. Berries. Polish Journal of Food and Nutrition Sciences, Vol. 71, No. 3, 279–288. DOI: 10.31883/pjfns/139997.

L'assoluta necessità di allungare la *shelf-life* dei piccoli frutti mantenendo inalterate le caratteristiche qualitative dei frutti sul lungo periodo è maggiormente espressa per il ribes (Kuźniar *et al.* 2022) dal momento che, rispetto a mirtillo, lampone e mora di rovo, i consumi di prodotto fresco tal quale sono decisamente inferiori e, come affermato da OrtofruitItalia soc agr. coop. O.P., la vendita di grandi quantitativi in breve tempo è molto difficile. Questo soprattutto perché il ribes ha un mercato diverso rispetto agli altri piccoli frutti, cioè è meno consumato come "*snack*" tal quale ma più utilizzato fresco all'interno di ricette o comunque in abbinamento con altri alimenti. Inoltre, la produzione molto concentrata fa in modo che ci sia un'offerta altrettanto concentrata in determinati periodi dell'anno dove i prezzi bassi non riescono a mantenere economicamente vantaggiosa la coltivazione (Panfilova *et al*. 2021). Pertanto la domanda di ricerca che mi sono posto è: "Sarà possibile allungare la *shelf-life* del ribes al fine di arrivare in periodi di mercato decisamente più vantaggiosi dal punto di vista economico e di mercato?". L'articolo che segue analizza l'utilizzo di SO_2 in abbinamento alla *MAP (active modified atmosphere)* per allungare la *shelf-life* del ribes rosso e valutarne le caratteristiche qualitative dopo 60 giorni di conservazione.

Influence of a Sulphur Dioxide Active Storage System on the Quality of *Ribes rubrum* L. Berries

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Key words: red currant, storage, modified atmosphere packaging, SO_2, taste

The aim of this study was to evaluate the post-harvest changes in the quality of red currants (*Ribes rubrum* L.) cv. 'Rovada' after 60 days of storage under modified atmosphere packaging (MAP) conditions. The storage unit was a pallet, and two treatments were performed. The CO_2-MAP treatment was used as a control, while the SO_2-MAP treatment was CO_2-MAP plus SO_2. The initial gas composition was 15.0 kPa O_2 and 10.0 kPa CO_2 inside all MAPs, while SO_2-generating active sheets were added to pellets in SO_2-MAP treatment. Weight loss, total soluble solid content, titratable acidity, total phenolic and anthocyanin contents, antioxidant activity, microbial count, and visual and sensorial appearance were monitored after 30 and 60 days. The results showed that berries stored with SO_2 maintained the quality parameters for up to 60 days. Exposure to SO_2 was effective in controlling yeast evolution, reducing the population both at 30 and 60 days at one and two orders of magnitude, respectively. Red currants stored under SO_2 MAP obtained better visual quality score compared to CO_2 MAP-treated berries throughout storage.

Active emitters of SO_2, such as those proposed in this study, can be promising solutions to improve the post-harvest storage of red currants and the berries marketability.

INTRODUCTION

Red currants, belonging to the *Ribes* genus of the Saxifragaceae family, are minor crops among berries. They are berry-bearing deciduous shrubs mainly consumed as processed in juices, jams, jellies, syrups, marinades, and wines [Kampuss & Pedersen, 2003; Stępniowska *et al*., 2016]. Consumption of fresh red currants is largely related to visual appearance, and raceme and stalk freshness are the main quality indices of shelf life. 'Jonkheer van Tets', 'Rondom', 'Rovada', 'Rosetta', 'Rotet', 'Jonifer', 'Laxton no. 1', 'Red Lake', 'Stanza', and 'Laxton's Perfection Red Dutch' are the most common red currant cultivars grown in Europe, where Poland is the most important producer [www.freshplaza.com]. Similar to other berries, red currants (*Ribes rubrum* L.) are important species for the human diet, especially due to the highest capacity to scavenge free radicals [Laczkó-Zöld *et al*., 2018; Orsavová *et al*., 2019]. Vitamin C (ascorbic acid) is well known to be the most important free radical scavenger, with average content in fresh berries reported at 41 mg/100 g [Talcott, 2007]. Red currants are also an important source of macro- and microelements (349.90 mg P; 1,876.94 mg K; 8.25 mg Na; 281.08 mg Ca; 1.18 mg Mn; 94.43 mg Mg; 3.73 mg Fe; and 2.41 mg Zn per 100 g of dry weight) [Plessi *et al*., 1998].

Due to limited fresh market volumes compared to other soft berries, no larger studies on post-harvest techniques have been carried out on *R. rubrum*. Storage temperatures in the range of 0–1°C combined with high values of relative humidity (95%) have been suggested as optimum conditions in a normal atmosphere (NA) to maintain fresh berries for up to 3 weeks, but the evolution of biochemical properties is mainly associated with ripeness at harvest time and the cultivar. Management of the surrounding storage atmosphere (18 to 20% CO_2 + 2% O_2) can extend the storage time [Agar *et al*., 1997; Roelofs & Waart, 1993], but in some cultivars, high CO_2 concentrations can result in physiological disorders, affecting berry colour and the internal breakdown [Roelofs & Waart, 1993; Thompson, 1998]. Furthermore, some physiological disorders generally manifested by flesh browning and breakdown appear in berries stored with CO_2 above 20%. The modified atmosphere pallet system has been evaluated in the post-harvest storage of berries and other fruits as an alternative preserving technique [Giuggioli *et al*., 2019; Macnish *et al.,* 2012; Peano *et al.,* 2017] and is commercially available as a logistic solution to reduce fruit loss and optimise space in the warehouses of different fruit companies. The employment of active gas controlled-release pads or ethylene absorbers (C_2H_4) can be positively associated with this technology to improve the success of storage management for different products. Red currants are not ethylene producers and are not susceptible to C_2H_4, but sulphur dioxide (SO_2) release pads could be positively associated with a modified atmosphere strategy to control the decrement of the overall quality and limit the microbial growth in berries [Ahmed *et al*., 2018; Saito *et al*., 2020]. Similarly to other berries, red currants are not washed during the supply chain process (harvesting, packing, and transportation); therefore, approved sanitisers, such as chlorine or sodium hypochlorite, cannot be added to control possible microbial contamination. The SO_2-generating pads have largely been used in the post-harvest process of different fruits, such as table grapes [Ahmed *et al.,* 2018; Carter *et al*., 2015; Ozkaya *et al*., 2008; Sortino *et al*., 2017; Zutahy *et al*., 2008], blueberries [Rodriguez & Zoffoli, 2016; Saito *et al*., 2020], fragola [Hakimi *et al.,* 2017], figs [Cantín *et al*., 2011], raspberries [Spayd *et al.,* 1984], and lemons [Smilanick *et al.,* 1995]. The amount of SO_2 required to be effective is a function of the storage temperature and the time of release of SO_2 of the emmittor used [Rivera *et al*., 2013]. A critical point that needs to be considered in SO_2 treatment is the maximum absorption by the human body; the daily intake value permitted by the Joint FAO/WHO Expert Committee on Food Additives [JECFA, 2019] is 0–0.7 mg per kg of human body weight.

To improve the knowledge about post-harvest storage of red currants, which has so far been underreported in literature, the aim of this study was to evaluate the influence of an SO_2 active storage system on the quality of *R. rubrum* berries stored for up to 60 days.

MATERIALS AND METHODS

Fruit source and sample preparation

Red currants (*R. rubrum* cv. Rovada) were harvested in an orchard located at Peveragno (Cuneo, Piedmont, Italy) at the harvesting maturity stage and were free of decay or mechanical or insect injury. The currants were transported directly within 30 min to the Agrifrutta Cooperative warehouse (Peveragno, Cuneo, Piedmont, Italy) for sample preparation and storage. Selected fruits were packed in rigid ventilated polyethylene terephthalate (PET) open baskets containing 0.150 kg of fruit each. Ten PET baskets were placed in a cardboard flat. Eight flats were assembled in a single layer on a 100×120 cm wood pallet base. A total of 20 layers of eight flats each were stacked onto a pallet commercial storage unit (Figure 1).

Pallet treatments and storage conditions

The red currants were sampled in two groups. The first group was palletised in an active modified atmosphere (CO_2-MAP treatment) and used as a control. The second group was palletised

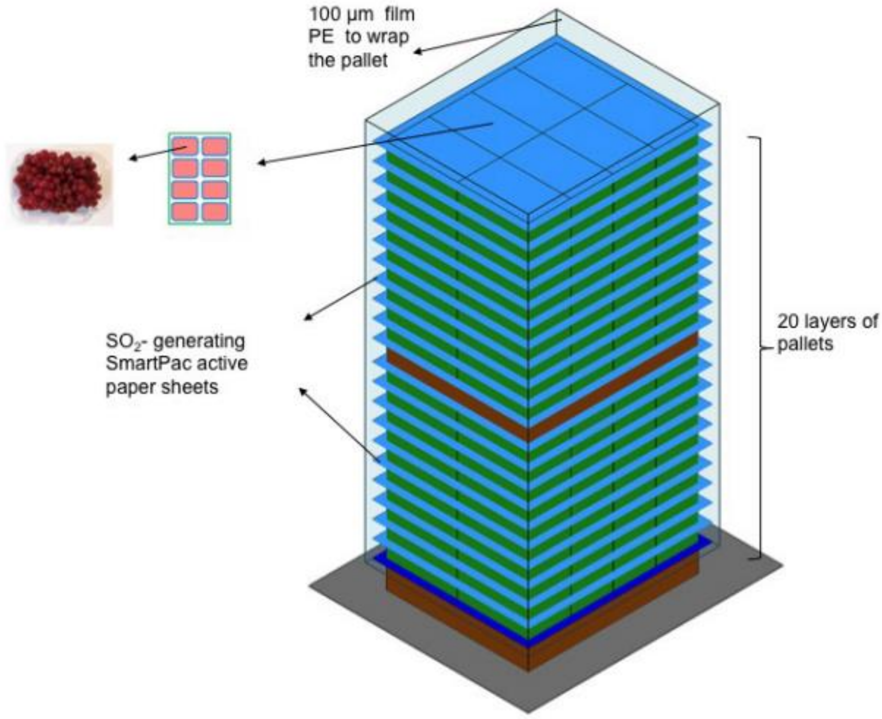

FIGURE 1. Design of the pallet unit used for storage of red currants in SO_2 modified conditions.

with CO_2 + SO_2 (SO_2-MAP treatment). Each pallet was wrapped with a 100 μm thick polyethylene film (PE) (thermally sealed at the base) with values of O_2 (O_2TR) and CO_2 (CO_2TR) transmission rates of 1572 cm^3/m^2/d/bar and 6111 cm^3/m^2/d/bar, respectively, measured at 23°C and at 50% relative humidity (RH) with a MultiPerm oxygen and carbon dioxide analyser (Extra Solution s.r.l., Pisa, Italy) according to ASTM F 2622–08 and ASTM F 2476–05 standard guidelines [Briano *et al*., 2015].

The injection system for CO_2-MAP treatment was operated as reported by Peano *et al*. [2017] to have initial gas values of 15.0 kPa O_2 and 10.0 kPa CO_2. These values were based on previous experimental storage studies on red currants (data not published). The SO_2-generating SmartPac active paper sheets (Serroplast, Bari, Italy) were applied directly to cover each of the total 20 layers stacked onto the storage unit pallet. All samples were stored for 60 days in a cold and dark room at 1±1°C and 90–95% RH. Data were collected at 0 (at the beginning of storage treatment), 30 (middle of the total storage time), and 60 days (long-term storage). For each treatment and storage time, three pallets were considered, sampling 30 random baskets in total. Figure 1 shows the experimental design of the pallet commercial unit.

Pallet atmosphere and SO_2 evaluation

A gas analyser (CheckPoint II, PBI Dansensor, Milan, Italy) was used to measure the relative changes in the carbon dioxide and oxygen concentrations. The gas composition values were measured every 10 days over the trial period and were expressed in kPa. The SO_2 concentration was measured in ppm with dosimeter tubes (Gastec 5DH, Gastec Corporation, Ayase-City, Japan). The results were expressed as an average of three replicates.

Weight loss and quality parameters

Baskets were coded before the treatments. Weight loss (%) was determined using an electronic balance (model SE622, VWR Science Education, Radnor, PA, USA), with a 10^{-2} g accuracy. Weight was monitored during the entire storage period and was calculated as the difference between initial (W_0) and final (W_t) basket weights.

$$\text{Weight loss (\%)} = \frac{W_0 - W_t}{W_n} \times 100 \qquad (1)$$

The results were expressed as an average of 30 replicates.

After sample blending, the total soluble solids (TSS) were evaluated with a digital refractometer Atago® Pal-1 (Atago Co. Ltd., Tokyo, Japan) and expressed as °Brix. For each quality control, the instrument was calibrated with distilled water. The titratable acidity (TA) was measured using an automatic titrator (Titritino 702, Methrom, Herisav, Switzerland), and determined potentiometrically using 0.1 N NaOH to the end point of 7.0; it was expressed as g of malic acid equivalents per 100 g of berries [Djordjević *et al*., 2010].

Total anthocyanin content, total phenolic content, and antioxidant capacity

Twenty-five mL of an extraction solvent (500 mL methanol, 23.8 mL deionised water, and 1.4 mL 37% hydrochloric acid) were added to 10 g of fruit. After 1 h storage in the dark at room temperature, the samples were thoroughly homogenised for 1 min with an Ultra-Turrax homogeniser (IKA, Staufen, Germany) and then centrifuged at 3,000×*g* for 15 min. The supernatant obtained by centrifugation was collected, transferred into glass test tubes, and stored at -20°C until analysis. The total phenolic content (TPC) was determined by visible spectrophotometry using the Folin–Ciocalteu reagent according to the method described by Slinkard & Singleton [1977]. Gallic acid was used as a standard and absorbance of reaction mixtures was measured at 765 nm. The results were expressed as mg of gallic acid equivalents per 100 g of fruit fresh weight (mg GAE/100 g fw). The total anthocyanin content (TAC) was quantified according to the pH differential method described by Cheng & Breen [1991]. Anthocyanins were estimated by their absorbance (A) difference at 510 and 700 nm in buffers at pH 1.0 and pH 4.5, where $A_{tot} = (A_{515} - A_{700})$ pH 1.0 $- (A_{515} - A_{700})$ pH 4.5. The results were expressed as mg of cyanidin 3-*O*-glucoside (C3G) equivalents per 100 g of fruit fw. Antioxidant activity was determined as the ferric reducing antioxidant power (FRAP) following the methods of Pellegrini *et al*. [2003], with some modifications. The absorbance was read at 595 nm 4 min after the addition of appropriately diluted extracts or standard to the FRAP reagent. The results were expressed as mmol Fe^{2+} per 1 kg of fw of red currants. These analyses were performed with a UV-Vis spectrophotometer 1600 (PC VWR International, Milan, Italy).

Microbial count determination

Microbial evaluation was performed considering the count of total yeast, mould, and bacteria. Total yeasts and mould were examined according to the methods reported by the Compendium of Methods for the Microbiological Examination of Foods [Vanderzant & Splittstoesser, 1992]. The same equipment used in a previous work on strawberry was applied [Chiabrando *et al*., 2018]. All plates were incubated at 30°C for 5 days. Three replicates were analysed, and the microbial counts were expressed as colony-forming units (CFU) per g of berry sample. Total aerobic bacteria (TAB) counts were determined according to ISO 4833–2 [2013]. Three replicates were analysed, and the microbial counts were expressed as colony-forming units (CFU) per g of berry sample.

Sensorial evaluation

Evaluation of the red currant fruits was also determined by means of sensory analysis, involving 10 panellists (five men and five women, 25–60 years old) who were previously trained using commercial berry samples. They received 15 bunches from each sample and provided sample descriptions based on consistency and taste (including sweet, acid, herbaceous, and astringent taste), and total aroma. All attributes were evaluated using a 9-point scale (ranging from 'very intense' as '9' to 'none' as '1'). The taste test was performed 1 h after red currants were taken out of the stored pallet at room temperature (20±1°C).

Visual evaluation

Visual evaluation was performed considering raceme and pedicel desiccation, healthy bunches, and visual quality.

The same panellists as for sensory analysis were recruited. Healthy bunches were defined as the percentage of not damaged fruit. All attributes of freshness of the rachis and pedicels and the visual quality were scored using a 5-point scale. Desiccation scores were 1 = as green as at harvest; 2 = slight browning; 3 = browning but no shrivelling; 4 = browning and some shrivelling; and 5 = dry and brown. Visual quality scores were 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = unusable. Scores above 3 were considered unmarketable [Sortino *et al*., 2017].

Statistical analyses

All pooled data were analysed using SPSS Statistics 24 (2017, IBM, Milan, Italy) for MAC. Analysis of variance (ANOVA) was performed, followed by Tukey's post-hoc test ($p \leq 0.05$), when the differences were significant.

RESULTS AND DISCUSSION

Pallet atmosphere and SO_2 evaluation

MAP technology is well known to be applied as the most easy and convenient tool to extend shelf life and protect berries from external contaminants. The fruit respiration rate, storage temperature, and selectivity of the wrapping film to gas are key factors that contribute to maintaining the required gas composition. Changes in the storage atmosphere composition in the range of 18 to 20% CO_2 and 2% O_2 could be successful in extending the shelf life of *R. rubrum* up to 14 weeks [Thompson, 1998]. As reported in Figure 2, the initial gas composition in the different units of storage was 15.0 kPa O_2 and 10.0 kPa CO_2. A different trend was observed between the two MAP treatments. Considering O_2, a general decrease was observed for each pallet system, even if it was more evident for the berries stored with only CO_2. After 40 days of storage, the O_2 content was under 5.0 kPa, achieving values of 1.5 kPa at the end of storage. Berries stored with SO_2 instead maintained values of 5.6 kPa at the end of storage. The different concentrations of O_2 could be explained by the increase of microbial counts (moulds and bacteria) in red currants stored with the MAP-CO_2 treatments. As a consequence, different levels of CO_2 were recorded among treatments. Up to 30 days, a similar evolution was monitored, then an increase of up to 15.0 kPa (60 days) was achieved for the MAP-CO_2 treatment stored pallets. In blueberries, Smilanick & Henson [1992] reported concentration of SO_2 in 100 ppm at 0°C to control decay diseases. The success of SO_2 treatments is a function of the time of exposure to gas multiplied by the concentration. SO_2-generating SmartPac active sheets were active throughout the entire storage time; furthermore, the gas was recorded for up to 60 days (Figure 3). The highest concentration (20 ppm) was observed after 10 days of storage. Subsequent measurements recorded lower SO_2 concentrations, achieving 0.8 ppm at the end of storage, indicating effective adsorption from the surface of red currants.

Weight loss and quality parameters

The loss of marketable berries along the entire supply chain is registered at around 45% [Temocico *et al*., 2014].

Weight loss is affected by water loss, which is the major cause of post-harvest deterioration and compromises the visual appearance, chemical content, and flavour of the product [Lufu *et al.*, 2020]. Berry turgidity and raceme and stalk freshness are the main visual quality criteria for the final consumer, and their status is a function of the hydration of fruit tissues. As reported in Figure 4, both MAP treatments were able to limit the weight loss of red currants up to 60 days, and no statistically significant ($p>0.05$) differences were observed among the different treatments. Both CO_2 and SO_2 gas controlled weight loss to under 5%, which can be considered the limit value for soft berries' marketability [Giuggioli *et al.*, 2019]. Weight loss of the samples analysed in our study was in the range of 0.67–0.73% and 1.00–1.15% after 30 and 60 days of storage, respectively. The maintenance of high humidity around the stored berries thanks to MAP action limited the transpiration activity of red currants, and this is probably due to the proper water transmission rates of the PE film.

The total soluble solid (TSS) contents of fresh and stored red currants are shown in Table 1. The TSS content of fresh berries was in line with data reported by Djordjević *et al.* [2010]. Moreover, similarly to the results reported by Temocico *et al.* [2014], the change in atmospheric composition during storage did not affect the soluble solid content in all samples (Table 1). Storage for up to 60 days caused no significant ($p>0.05$) decrease in the TSS content, moving from 10.9 °Brix to 10.1 °Brix and 9.7 °Brix for CO_2 and SO_2 MAP treatments, respectively. No significant differences were observed

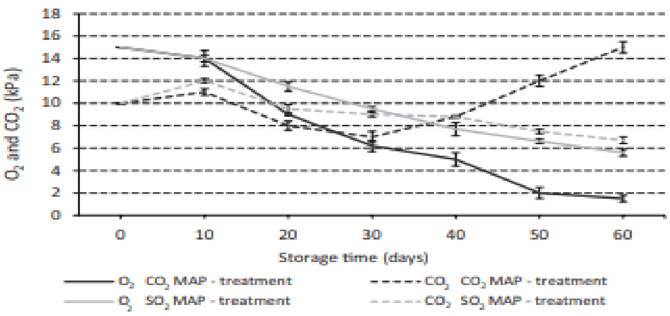

FIGURE 2. Gas evolution (O_2 and CO_2) during red currants 60 days storage.

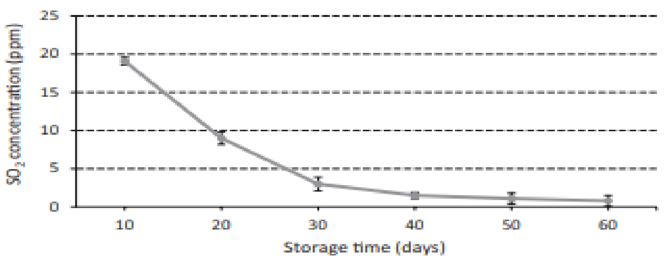

FIGURE 3. SO_2 concentration during red currants 60 days storage under modified atmosphere packaging (MAP) conditions.

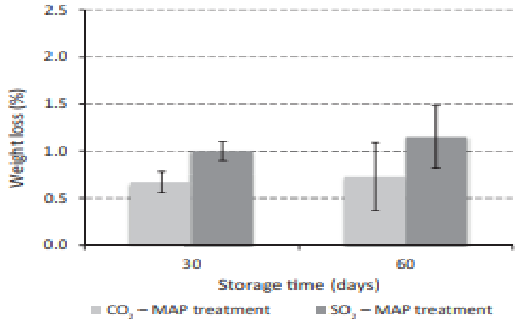

FIGURE 4. Weight loss of red currants during storage under modified atmosphere packaging (MAP) conditions.

among red currant samples exposed to SO_2 and CO_2 at the time, while differences ($p \leq 0.05$) were determined among MAP treatments only after 30 days of storage. Generally, SO_2 and CO_2 treatments, as observed on other fruits, did not affect the total soluble solid content during storage [Cantín *et al*., 2011, 2012]. The titratable acidity (TA) of red currants ranged from 1.2 to 1.0 g/100 g fw at 60 days of storage, but TA changes during storage and differences between MAP treatments were not significant ($p \leq 0.05$) (Table 1). Generally, losses of total acidity were reported to be accelerated by storage in elevated CO_2 atmospheres [Harb & Streif 2004]; in this case, the concentration of CO_2 achieved in the stored pallet was appropriate for the maintenance of titratable acidity levels to values similar to those at harvest.

Total anthocyanin content, total phenolic content, and antioxidant capacity

The contents of phenolic compounds of fresh and stored red currants are reported in Table 2. The total anthocyanin content (TAC) of fresh fruits of cultivar Rovada was 22.1 mg C3G/100 g fw. This value was in the range of 18–34 mg/100 g fw as suggested by Benvenuti *et al*. [2004] for red currants grown in Italy and was lower than that recorded for cultivars grown in Finland (26.5–104 mg/100 g fw) [Mattila *et al*., 2016]. Among anthocyanins, red currants are rich in cyanidin glycosides including cyanidin 3-*O*-glucoside, cyanidin 3-*O*-sambusoside, cyanidin 3-*O*-rutinose, cyanidin 3-sophoroside, cyanidin 3-glucosylrutinoside, and cyanidin-3-xylosylrutinoside [Jara-Palacios *et al*., 2019; Mattila *et al*., 2016]. No statistically significant ($p > 0.05$) differences were observed over time for each MAP treatment, and between treatments (Table 2). The total phenolic content (TPC) of red currant before storage was 233 mg GAE/100 g fw, which is consistent with values reported in the literature [Laczkó-Zöld *et al*., 2018]. Similarly to anthocyanins, TPC showed the same evolution among samples over time, and statistically insignificantly lower content was determined in red currants under SO_2 MAP storage. Storage atmospheres enriched in CO_2 could prevent the increase in total antioxidant activity; however, the mechanism of control is still not clear, as no available data have been reported on the effect of SO_2 on evolution of total antioxidant activity in red currants. The initial antioxidant capacity of fresh

TABLE 1. Total soluble solids (TSS) content and titratable acidity (TA) of red currants stored under modified atmosphere packaging (MAP) conditions.

Parameter	Treatment	Storage time (days)		
		0	30	60
TSS (°Brix)	CO_2-MAP	$10.9\pm0.5^{aA*}$	9.5 ± 0.1^{aB}	10.1 ± 0.3^{aA}
	SO_2-MAP	10.9 ± 0.5^{aA}	10.8 ± 0.4^{aA}	9.7 ± 0.6^{aA}
TA (g/100 g)	CO_2-MAP	1.2 ± 0.1^{aA}	1.0 ± 0.2^{aA}	1.0 ± 0.1^{aA}
	SO_2-MAP	1.2 ± 0.1^{aA}	1.1 ± 0.2^{aA}	1.0 ± 0.1^{aA}

*Mean values with different lowercase letters within a row and capital letters within a column for each parameter measured are significantly different ($p\leq0.05$).

TABLE 2. Total anthocyanin content (TAC), total phenolic content (TPC), and ferric reducing antioxidant power (FRAP) of red currants stored under modified atmosphere packaging (MAP) conditions.

	Treatment	Storage time (days)		
		0	30	60
TAC (mg C3G/100 g fw)	CO_2-MAP	$22.1\pm6.1^{a*}$	20.5 ± 9.2^{a}	27.4 ± 11^{a}
	SO_2-MAP	22.1 ± 6.1^{a}	19.7 ± 1.6^{a}	17.2 ± 4.3^{a}
TPC (mg GAE/100 g fw)	CO_2-MAP	233 ± 11^{a}	267 ± 20^{a}	203 ± 21^{a}
	SO_2-MAP	233 ± 11^{a}	70 ± 18^{a}	197 ± 20^{a}
FRAP (mmol Fe^{2+}/kg fw)	CO_2-MAP	44.5 ± 1.7^{a}	37.1 ± 0.9^{b}	36.9 ± 1.1^{b}
	SO_2-MAP	44.5 ± 1.7^{a}	35.8 ± 1.1^{b}	34.6 ± 1.2^{b}

*Mean values in the row with different letters are significantly different ($p\leq0.05$); GAE – gallic acid equivalents; C3G – cyanidin 3-*O*-glucoside equivalents; fw – fresh weight.

red currants was 44.5 mmol Fe^{2+}/kg fw. It is well known that the total anthocyanin and phenolic contents influence the antioxidant capacity in fruit [Orsavová *et al.*, 2019]. Significant ($p\leq0.05$) differences were observed for FRAP of stored red currants when compared with fresh berries.

Microbial hazard evaluation

The microbial population is an important factor that influences the quality and safety of fresh fruit [Mostafidi *et al.*, 2020], and can be affected by different pre- and post-harvest sources. Clean pallets and sanitised containers during storage should be available for freshly harvested berries. The maintenance of the high humidity level required in storage makes red currants more susceptible to decay; therefore, sanitisation tools are necessary. MAP is generally considered a good technique to preserve fruits, and CO_2 or other gasses, such as O_3 and SO_2, can minimise contamination due to the sanitiser effect of their molecules [Daeschel & Udompijitkul, 2007]. Berries at picking (0 days) showed a microbial count of 13,000, 15,000, and 3,100 CFU/g for yeast, mould, and bacteria, respectively (Table 3). After that time, the two storage treatments showed different effects in terms of controlling

TABLE 3. Microbial counts of red currants stored under modified atmosphere packaging (MAP) conditions.

Microorganism	Treatment	Storage time (days)		
		0	30	60
Yeast (CFU/g)	CO_2-MAP	13,000±465[a*]	22,000±1,200[a]	6,000±115[b]
	SO_2-MAP	13,000±465[a]	2,800±150[b]	100±14[c]
Mould (CFU/g)	CO_2-MAP	15,000±330[b]	17,000±930[b]	100,000±980[a]
	SO_2-MAP	15,000±330[b]	400±72[c]	19,000±1,100[a]
Bacteria (CFU/g)	CO_2-MAP	3,100±124[b]	2,800±100[b]	250,000±1,500[a]
	SO_2-MAP	3,100±124[a]	100±25[c]	1,500±88[b]

*Mean values in the row with different letters are significantly different ($p \leq 0.05$).

microbial evolution. SO_2 was effective in controlling yeast evolution, reducing the population both at 30 and 60 days at one and two orders of magnitude, respectively. Less of an effect was observed for the CO_2 treatment but only at 60 days. When berries were exposed to SO_2, its dissolution into a water solution developed three molecular species, namely SO_2 ($SO_2 \times H_2O$), bisulphite (HSO_3^-), and sulphite (SO_3^{2-}) [Divol *et al.*, 2012]. The toxic effect against yeast is mainly ascribed to SO_2 because it has no charge; consequently, it should easily pass through the microbial cell membranes. Moreover, the high acidity and the low pH of red currants would be unfavourable to yeast intracellular processes [Divol *et al.*, 2012]. Considering mould, no treatments successfully inhibited them for 60 days when compared to their presence at harvest (0 days). SO_2 samples had 19,000 CFU/g, and CO_2–treated samples had 100,000 CFU/g. The increase in the mould content in the control samples (CO_2 MAP treatment) was probably due to the high humidity in the pallet system because it could not be adsorbed by the SO_2-generating SmartPac active paper sheets. For the same reason, bacterial proliferation was also very high at 60 days of storage for the sample stored in CO_2-MAP. Exposure to SO_2 deeply reduced the initial bacterial microbial count (3,100 CFU/g); 97% after 30 days and 52% after 60 days.

Sensorial evaluation

Sensorial quality was expressed by the personal preferences of the panellists, and the results are reported in Figure 5. Sensory studies on fresh red currants about the hedonistic overall quality are scarce in the literature, but it is well known that one of the most distinctive attributes of *R. rubrum* is the astringency of fruits, which is mainly affected by flavonol glycosides, derivatives of hydroxycinnamic acids, and various nitrous compounds [Schwarz & Hofmann, 2007a,b]. At harvest (0 days) (Figure 5), red currants ranked a high score in terms of consistency attribute, astringent and acid taste, and total aroma, while the herbaceous and sweet taste were of moderate intensity. A similar profile in terms of sensorial properties among treatments was reported both at 30 (Figure 5A) and 60 days (Figure 5B), indicating that the gas (CO_2 and SO_2) inside the MAP does not differentiate the taste of berries. In fact, after 30 and 60 days the same number

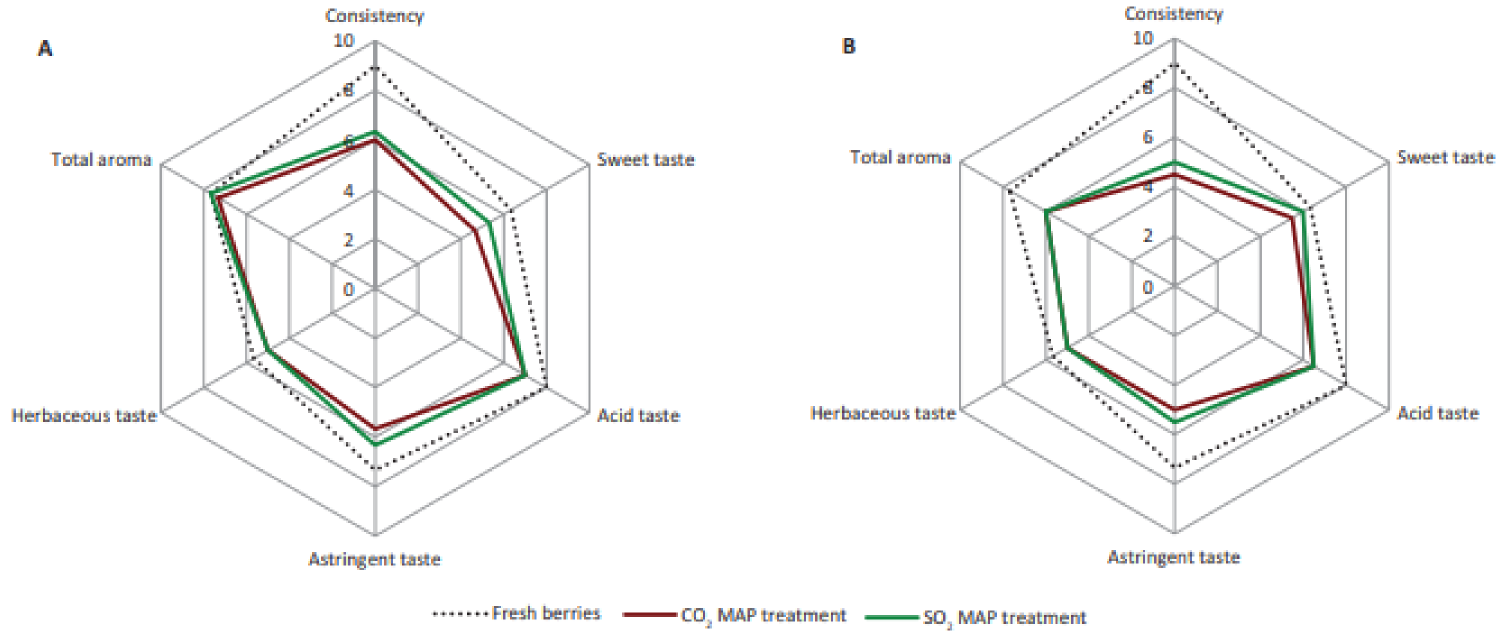

FIGURE 5. Sensory attributes of red currants after 30 days (A) and 60 days (B) of storage under modified atmosphere packaging (MAP) conditions.

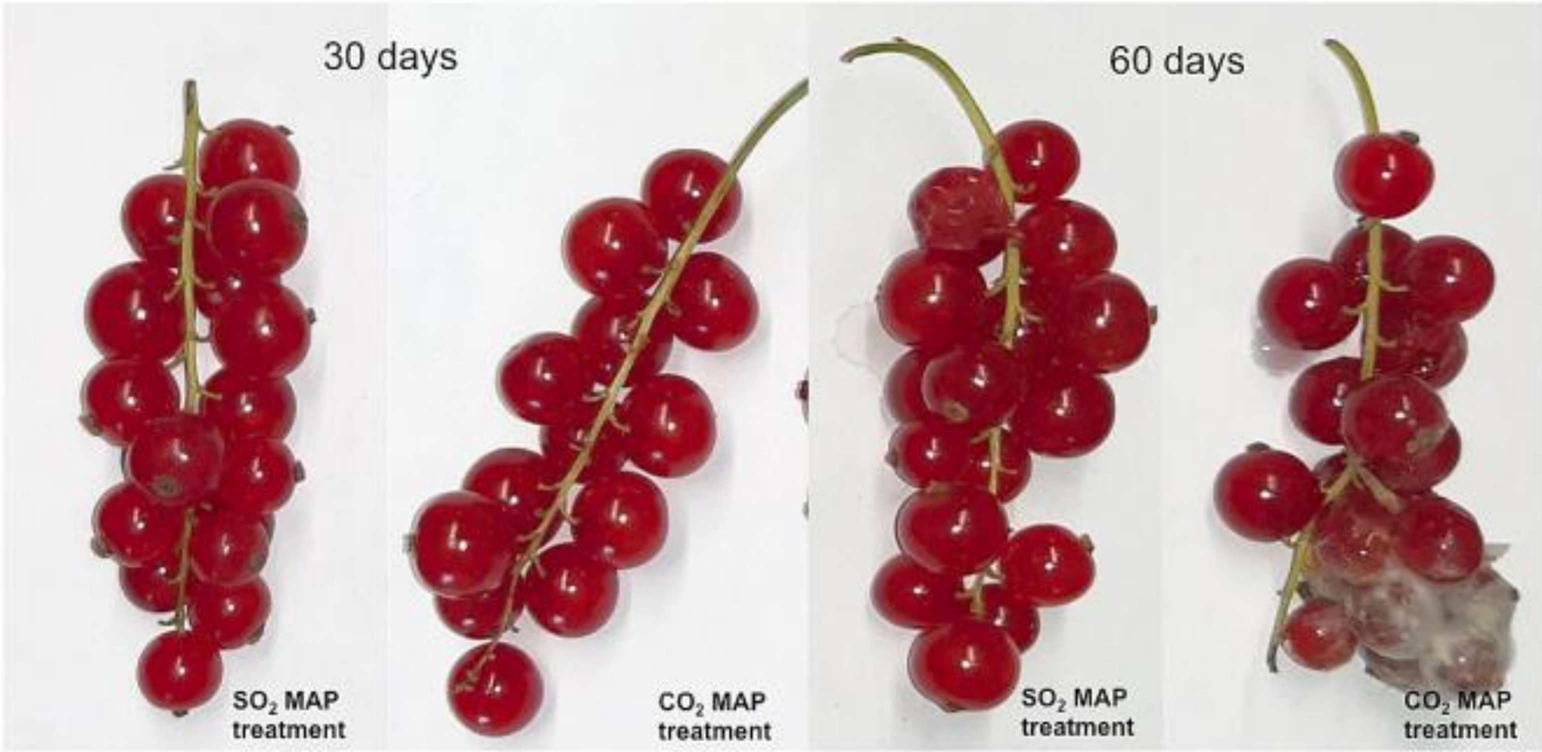

FIGURE 6. Red currants during the storage under modified atmosphere packaging (MAP) conditions.

of points were scored for acid (7.0 and 6.5) and herbaceous notes (5 both after 30 and 60 days), while for the others attributes no more than 0.5 of differences (no significant differences, $p>0.05$) were scored. After 30 days, berries maintained the highest properties in terms of overall total aroma and acid taste. The perception by panel test decreased at 60 days, while the consistency had already changed (decreasing the score) during the short storage time (30 days). By observing the sensorial profile at the end of storage (60 days), it was possible to determine that astringent and acid notes of taste were the principal hedonistic indicators that influenced the overall acceptability of red currant cv. Rovada samples when stored. Sulphite residues are generally responsible for the decline in the flavour of fruit and affect consumers' willingness to fruit consumption [Shoaei *et al.,* 2019]. However, in this study, there seemed to be no aversion to the red currants; in fact, a similar profile was observed between samples stored in CO_2 and SO_2 MAP.

Visual evaluation

The acceptance of fresh fruits in terms of marketability of the product was preliminary linked to an ideal visual appearance, which is expressed in terms of the absence of defects concerning external and internal parts of fruits, colour, and shape development. In red currants, a high number of berries per raceme, large and uniform fruits throughout the cluster, their complete red coloration, and the maintenance of a green raceme and pedicel are important visual quality criteria for the fresh market. Results of the visual evaluation of berries stored in CO_2 and SO_2 MAP treatments were expressed as raceme and pedicel desiccation, percentage of healthy bunches, and an overall visual quality (Table 4). Generally, the visual evaluation decreased over time, but red currants stored under SO_2 MAP obtained better visual quality score compared to CO_2 MAP treatment berries throughout storage. Figure 6 provides the images of red currants over storage.

TABLE 4. Parameters of visual evaluation of red currants stored under modified atmosphere packaging (MAP) conditions.

Treatment	Storage time (days)	Raceme and pedicel desiccation[1]	Healthy bunches (%)	Visual quality[2]
Fresh berries	0	$5.0\pm0.0^{a*}$	100 ± 0.0^{a}	5.0 ± 0.0^{a}
CO_2-MAP	30	4.3 ± 0.2^{b}	85 ± 12^{a}	4.0 ± 0.3^{b}
SO_2-MAP	30	4.5 ± 0.1^{b}	95 ± 5.0^{a}	4.8 ± 0.2^{a}
CO_2-MAP	60	3.0 ± 0.3^{c}	68 ± 10^{c}	2.0 ± 0.1^{d}
SO_2-MAP	60	3.3 ± 0.4^{c}	75 ± 8.0^{b}	3.5 ± 0.4^{c}

*Means values in the column with different letters are significantly different ($p\leq0.05$). [1]Expressed in desiccation scores, were 1 = as green as at harvest; 2 = slight browning; 3 = browning but no shrivelling; 4 = browning and some shrivelling; and 5 = dry and brown. [2]Expressed in visual quality scores, were 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = unusable.

CONCLUSION

Red currants are an interesting fruit belonging to the berries with a high potential in terms of health properties. The extent of the fresh market, which is still limited compared to those of other soft berries, such as blueberries or raspberries, needs to be supported by advances in post-harvest research. In this study, *R. rubrum* berries were stored at low temperatures under different MAP treatments, and external appearance traits, as well as internal quality properties, were examined for up to 60 days. Exposure to SO_2 gas controlled microbial decay, resulting in a good visual appearance and promising maintenance of the most important sensorial attributes. Active emitters of SO_2, such as those proposed, can be useful for the storage of red currants in extended storage after harvesting. Moreover, this technique could also be promising in the transport of red currants. Regardless of the bioactive compounds, future advances will be necessary regarding detailed phenolic composition to analyse and enhance this application.

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5. CONCLUSIONI:

La domanda globale di *berry fruits* è cresciuta in quanto sono stati riconosciuti come "superfrutto" grazie alle loro proprietà nutrizionali. Nonostante ciò si intravedono, per l'immediato futuro, problematiche di mercato dovute ad una forte concorrenza sui prezzi delle varie aree produttive, tutte in crescita in termini di superfici e produzioni. E' quindi evidente che è necessario per le imprese produttrici italiane individuare futuri percorsi che permettano di generare un vantaggio competitivo. L'importanza strategica della comprensione e gestione della filiera dei *berry fruits*, nonché la necessità di ricerca del settore sono stati punti focali su cui OP e Università si sono confrontati grazie al percorso di Dottorato in regime di Apprendistato presentato. E' chiaramente emerso che un'adeguata gestione delle problematiche in un'ottica di filiera può consentire alle aziende agricole e a tutti gli attori di massimizzare le *performances* del sistema aumentando la loro competitività e differenziandosi dai concorrenti attraverso l'aumento della qualità, la riduzione dei costi e la migliore gestione dei tempi di commercializzazione.

La ricerca sviluppata e i risultati ottenuti hanno fornito una base di informazioni e di approcci metodologici e applicativi trasversali al settore dei *berry fruits*, utilizzabili anche in contesti diversi da quello di applicazione. A seguito di un'analisi approfondita del settore sono stati scelti alcuni temi su cui sviluppare la ricerca, considerati prioritari in quanto scarse erano le informazioni provenienti sia dal mondo tecnico sia da quello scientifico.

Per quanto riguarda la fase di campo sia per lampone che per mirtillo sono state analizzate criticità emergenti e sono stati individuati gli agenti patogeni che causano una serie di problematiche nella gestione degli impianti. Grazie ai primi risultati ottenuti si sono individuate e sono in corso di applicazione in campo alcune soluzioni di lotta chimica ed agronomica. Nel caso del lampone rifiorente (utilizzato con doppio ciclo annuale in pieno campo), si è potuto dimostrare che un'oculata potatura nella fase unifera, sviluppata scegliendo i tralci fruttiferi in funzione del vigore dei tralci stessi, ha ripercussioni positive sul contenimento dello sviluppo dei patogeni e di conseguenza un miglioramento delle *performances* vegetative e produttive delle piante. Non si può parlare di lotta diretta al patogeno ma di un nuovo modello di potatura, adottabile in qualsiasi impianto, che rappresenta un'azione di prevenzione importante. Sono in corso di attuazione ulteriori ricerche che vanno nella direzione di lotta diretta al patogeno oltre che l'analisi del comportamento dello stesso in sistemi produttivi fuori suolo, oggi particolarmente diffusi. Le prime osservazioni su impianti fuori suolo suggeriscono che la gestione agronomica attuata ed in particolare l'attenzione posta alla gestione della fertirrigazione possa contribuire, insieme alla potatura, ad un forte contenimento dell'infezione. E' in ogni caso auspicabile la messa in atto di ulteriori sperimentazioni, anche in areali produttivi differenti, per acquisire ulteriori informazioni sulla relazione tra patogeno e parametri ambientali oltre che una valutazione relativa alla combinazione *cultivar*-patogeno. Per quanto riguarda il mirtillo, l'aver individuato l'agente patogeno permetterà di testare strategie di difesa dirette ed indirette già adottate su altre colture dove *Neofusicoccum Parvum* è già riconosciuto come patogeno, come ad esempio negli agrumi. Il meccanismo di azione e la sintomatologia del patogeno è similare al Mal dell'esca della vite, quindi l'ingresso del fungo avviene principalmente attraverso ferite del legno. Pertanto, sicuramente le principali strategie di prevenzione e di lotta che saranno testate dovranno prendere in considerazione il periodo della potatura. Cioè proprio la fase in cui le pianta è assoggettata ad un maggior numero di ferite sul legno e quindi il rischio di infezione è esponenzialmente più elevato. Come per il lampone anche per il mirtillo sarà necessario comprendere meglio la relazione tra *cultivar* e patogeno dato che è già stata osservata una differente suscettibilità varietale e per cercare in futuro di selezionare *cultivar* meno sensibili al patogeno.

Sempre per quanto riguarda la fase di campo il tema del miglioramento della gestione della raccolta è stato considerato prioritario per i produttori, soprattutto in un'ottica di gestione della manodopera e riduzione dei costi di produzione. Si è però anche tenuto in considerazione il punto di vista del magazzino e cioè della necessità di avere adeguata *shelf-life* per il prodotto raccolto con le agevolatrici. Tecniche di raccolta completamente meccanizzate (scavallatrici) sono già in uso su impianti di grandi dimensioni negli Stati Uniti e nel Nord Europa principalmente per frutti destinati alla trasformazione, ma nel caso studio preso in considerazione si è fatto riferimento a macchine agevolatrici, a più basso costo, facilmente gestibili anche su superfici di più ridotta dimensione e con destinazione del prodotto il mercato fresco. I primi risultati sono incoraggianti in quanto dalla sperimentazione è emerso che la raccolta con l'agevolatrice può essere economicamente vantaggiosa e i frutti raccolti presentano caratteristiche qualitativamente sostenibili nella fase post-raccolta. Dalla ricerca è però anche emersa la necessità di modificare in parte la tecnologia utilizzata per meglio adattarla alla tipologia di impianto e cioè baulature di 30 cm e posizionamento di pali per il sostegno delle reti antigrandine ogni 10 metri sulla fila. Dalle osservazioni effettuate in campo è inoltre emerso chiaramente la necessità di approfondire il tema della combinazione tra la raccolta agevolata e la varietà, così come la sperimentazione di modelli di potatura dedicati. E' infatti in corso di attuazione un'ulteriore approfondimento su impianti con nuove varietà di mirtillo a portamento più procombente e maggiore facilità di distacco della bacca, una volta giunta a maturazione. In ogni caso con i primi risultati ottenuti si è individuata una strada concretamente percorribile ed infatti circa 10 ha di produttori aderenti alla OP quest'anno saranno raccolti con l'agevolatrice. Anche nel caso della raccolta del mirtillo sarà interessante in futuro prendere in considerazione la possibilità di utilizzo dell'agevolatrice in impianti fuori suolo, nuova frontiera delle produzioni in Italia e nel mondo. Il tema della gestione del prodotto nella fase del post-raccolta, trattato già per il mirtillo raccolto con l'agevolatrice è stato anche affrontato per quello che riguarda il terzo *berry fruit* in ordine di importanza nella filiera di OrtofruitItalia: il ribes. Con questa specie e con le *cultivar* oggi a disposizione è difficile ampliare il calendario di raccolta mentre da un punto di vista commerciale vi sono buone possibilità su un calendario di vendita ampio. Per tale motivo la ricerca sviluppata sul prolungamento della conservazione è di fondamentale importanza per il consolidamento della fase commerciale della filiera. Partendo da esperienze sull'uso della SO_2 su uva da tavola se ne è testato l'uso su ribes con risultati positivi nella fase di conservazione in magazzino. lo *step* futuro di questa ricerca è l'uso di SO_2 nella fase distributiva oltre che l'ampliamento di utilizzo anche su altri *berry fruits* come ad esempio il mirtillo. Per la diffusione nell'uso di questi sistemi per il prolungamento della *shelf-life* sarà comunque necessaria una valutazione di tipo economico costi-benefici andando a valutare anche le potenzialità di riduzione dello scarto.

Le collaborazioni tra impresa e Università sono oramai pervasive in tutte le agende politiche che si occupano di sviluppo locale, scienza, tecnologia e innovazione. Il percorso avviato con questo Dottorato in Regime di Apprendistato è la dimostrazione che i collegamenti tra le due istituzioni possono generare vantaggi per entrambi i lati della collaborazione. Innanzitutto per la OP ha significato acquisire un profilo professionale altamente qualificato in grado di comprendere e interpretare in modo innovativo la *supply chain* dei *berry fruits*, una tra le più complesse in termini di gestione è presidiare i nuovi paradigmi produttivi. Per quello che riguarda l'Università questa collaborazione ha significato mettere a disposizione le proprie competenze per la soluzione di problemi concreti del mondo della produzione, con un approccio tipico della ricerca-azione, strumento fondamentale per avviare trasformazioni a partire dal basso. Impresa e Università sono diventate 'comunità di ricercatori' con il compito di interrogarsi sullo *status quo*, di mettere in discussione valori e comportamenti che sono tacitamente accettati e impliciti che spesso determinano l'insorgere di problemi. Anche se i risultati di un qualsiasi progetto di ricerca-azione sono da considerarsi pertinenti principalmente al contesto preciso al quale è legato, nel caso del percorso presentato è possibile affermare che i dati raccolti e i risultati ottenuti possono essere di estrema utilità per il mondo tecnico e della ricerca in contesti simili. Sarà importante per il futuro aumentare le occasioni di collaborazione tra questi due mondi e ci si augura di assistere ad una sempre maggiore condivisione di dati in modo da permettere un’accelerazione nella ricerca e nella soluzione dei problemi che affliggono le imprese agricole italiane.

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