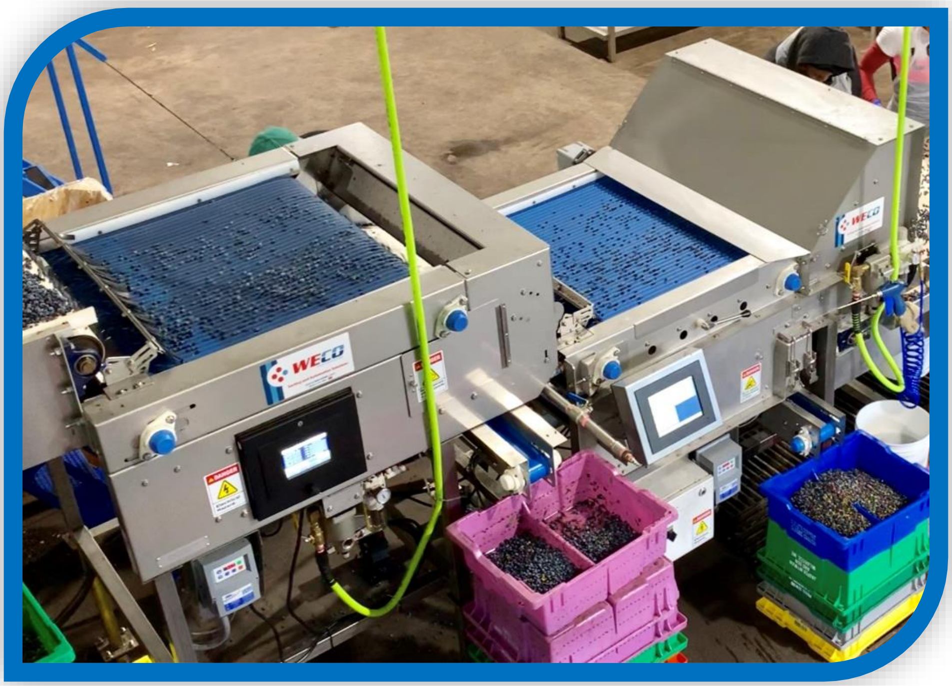
Final Report

Performance Evaluation of an Impulse Soft Sorter and BerryTek Color Sorter for Wild Blueberry Fresh Fruit Packing Lines



Submitted to
Wild Blueberry Producers Association of Nova Scotia

By
Dr. Travis Esau, PEng, PAg

November 6, 2019

Executive Summary

Wild Blueberry Producers Association of Nova Scotia, through the Building Tomorrow Fund agreement with the Nova Scotia Department of Agriculture, initiated the evaluation of optical sorting technology and innovative packaging for fresh wild blueberries.

Wild blueberries (*Vaccinium angustifolium* Ait.) are an important horticultural crop in Quebec and the Atlantic Provinces of Canada, producing 132 million kg of fruit, and contributing $600 million annually to provincial and federal economies (Statistics Canada, 2017). Canada is the largest producer and exporter of wild blueberries in the world, with 68,992 ha in production (AAFC, 2016) and 11.1% of Canada's production volume coming from Prince Edward Island, 23% from Nova Scotia, 28% from New Brunswick, and 37% from Quebec (Statistics Canada, 2017). Rising production cost and declining farm gate price have decreased the profit margins for wild blueberry growers in Atlantic Canada. To date, the large majority (>95%) of harvested wild blueberries are processed and sold as a frozen fruit product. Wild blueberry farmers in Nova Scotia are looking toward expanding the existing higher-value fresh fruit market to increase profit margins. Traditional equipment used for fresh wild blueberry processing is highly labour intensive and requires round the clock personnel to operate seasonally during a very short harvesting season. Advanced color sorting technologies have been developed for the fresh processing of several fruits and vegetables, but little research has been done to evaluate mechanized sorters for wild blueberries. The objectives of this project are to 1) compare the ability of an automated optical sorter to remove unripe and overripe wild blueberries and debris as compared to a traditional manually operated processing line, 2) determine their effective operating speeds and handling capacity and, 3) develop an economic analysis comparing the two fresh fruit processing methods. The overarching goal of this project is to effectively grow the supply of quality fresh fruit to increase the value of wild blueberries while minimizing processing labor and costs. A scientific comparative analysis of the two fresh fruit processing methods was conducted to aid wild blueberry farmers, processors and stakeholders in making informed decisions when pursuing options for processing wild blueberries for fresh market.

The objectives of this research project was accomplished utilizing methodology developed in phase-I prior to harvest. Phase-II took place during harvest season at Millen's Farm in Glenholme, Nova Scotia where an existing manually operated fresh fruit processing line was compared to an advanced soft sorter and color sorting automated line. Following the harvest season, phase-III encompassed a complete statistical comparison of raw data collected throughout the harvest season. An economic analysis was completed and summarised in this report.

Results from this study suggest that the automated equipment was able to significantly reduce pick over line labor requirements by 56.75% while achieving reasonable accuracy results. On average the Impulse soft sorter removed 23.63% soft or damaged wild blueberries (weight-basis) while only mistargeting 0.37% good berries. The BerryTek color sorter removed an average of 52.43% of the foreign debris and unripe berries while mistargeting 2.3% good berries. In comparison to the automated system, manual workers on average removed the remaining 76.37% soft berries and 47.57% debris and unripe berries while also mistakenly removing 0.75% good berries.

A 10-year payback is achievable when leasing the Impulse and BerryTek sorters by reducing the labor requirement following a 24-day season operating at 12-hour shifts per day. Additionally, a relatively large financial gain (<1-year payback) can be achieved if the Auto-line can be operated 24-hours per day throughout the harvest season which helps offset the yearly lease cost.

Further evaluation is suggested using different combinations or additional auto sorters in parallel to determine if increased labor savings can be achieved. It would be valuable to understand any potential benefits from effectively pre-cooling berries prior to sorting in conjunction with monitoring the moisture content. Other advanced systems including automated weighing and packaging could also improve efficiencies over the current labor-intensive manual process. Further research is also suggested to determine the effectiveness of the automatic sorters with berries that are mechanically harvested or raw supply (berries/debris) that were previously frozen. It was noted that manual labor was required to weigh and package the processed fruit which could potentially be reduced using an automated system.

Table of Contents

1. Research Site..4

2. Project Objectives..4

3. Phase I: Initial Site Visit, Equipment Assessment and Experimental Design Setup............4

4. Phase II: On Site Performance Evaluation and Data Collection 5

4.1. An Overview..5

4.2. The WECO Automated Blueberry Sorting System..6

4.3. Method of Berry Sorting..9

4.4. Data Collection..10

5. Data Analysis..12

6. Phase III: Findings..14

6.1. The Limitations of the Work Done..14

6.2. Feed, Output Rates and Shrinkage..17

6.3. Overview of Manual and Auto-line Components Feed, Output Rates and Shrinkage......
....18

6.4. Manually Removed Berries and Debris from the Pick Over Line (Both Manual and Auto-lines)
....20

6.5. Performance of the Impulse Soft Sorter..21

6.6. Performance of the BerryTek Color Sorter..22

6.7. Energy Requirements..23

6.8. Payback Period..23

6.9. Conclusions and Recommendations..25

7. Appendix..27

1. Research Site: Millen Farms, 80 Little Dyke Rd, Great Village, NS B0M 1L0

2. Project Objectives

This report summarises the activities performed during four weeks (August 15 to September 11, 2019) at the research site in Great Village, Nova Scotia. The objectives of this project were to 1) compare the ability of an automated dynamic impulse sensor and optical sorter to remove unripe and overripe wild blueberries and debris as compared to a traditional manually operated processing line, 2) determine their effective operating speeds and handling capacity and, 3) develop an economic analysis comparing the two fresh fruit processing methods. The overarching goal of this project is to effectively grow the supply of quality fresh fruit to increase the value of wild blueberries while minimizing processing labor and costs. Through a scientific comparative analysis of the two fresh fruit processing methods, the intent of this project is to aid wild blueberry farmers, processors and stakeholders in making informed decisions when pursuing options for processing wild blueberries for fresh market.

The methodology to perform the analysis was developed in phase-I of this project. Phase-II took place during harvest season at Millen's Farm in Glenholme, Nova Scotia where an existing manually operated fresh fruit processing line was compared to an advanced soft sorter and color sorting automated line. Following the harvest season, phase-III encompassed a complete statistical comparison of raw data collected throughout the harvest season. An economic analysis was completed and summarised in this report.

3. Phase I: Initial Site Visit, Equipment Assessment and Experimental Design Setup

An initial meeting was held on June 21, 2019 with Research Staff, Building Tomorrow Fund Representative (Nova Scotia Department of Agriculture) and administration of Millen Farms. Variables and factors to measure during performance evaluation were determined and start and end dates were established based on early and late season picking availability.

A site visit was held on August 13, 2019 with research consultants and administration of Millen Farms at the fresh wild blueberry processing facility in Great Village, Nova Scotia. Initial assessment of the newly installed Impulse soft sorter and BerryTek color sorting system (commonly referred to as Auto-line from here onward) and the manual berry sorting system (referred as Manual-line from here onward). The consultants were briefed about the basic logistics of upcoming berry processing activities. They were instructed to follow the set protocols of working at the facility; that is, the use of prescribed clothing and protective masks/hairnets to ensure cleanliness, disinfection, and prevention of berries from physical, chemical and biological damages. The team followed all protocols accordingly during their data collection activities from August 16 to September 11, 2019.

Experimental design sessions were held prior to August 16 to derive the work process and schedule to achieve project objectives. After considering the variables, factors to be measured, available resources, time constraints, human resources available from the Millen Farms, the work was thoroughly planned and scheduled.

4. Phase II: On Site Performance Evaluation and Data Collection

4.1 An Overview

Wild blueberry farmers in Nova Scotia are looking toward expanding the existing higher-value fresh fruit market to increase profit margins. Traditional equipment used for fresh wild blueberry processing is highly labour intensive and requires personnel working round the clock to operate seasonally during a very short harvesting season. Advanced color sorting technologies have been developed for fresh processing of several fruits and vegetables, but little research has been done to evaluate mechanized sorters for wild blueberry. A variety of mechanical sorting machines are available in the market from various manufacturers. The Woodside Electronics Corporation (WECO) is based in California, USA (1311 Blue Grass Pl, Woodland, CA 95776) and offers different sorters including the Impulse soft sorter and BerryTek color sorter for blueberries. Performance of the WECO Impulse soft sorter and BerryTek color sorting systems have not yet been conducted and/or reported in the literature, especially for low-bush wild blueberries.

The goal of this project is to evaluate the performance of i) an automated Impulse soft sorter for removing the ruptured/damaged/overripe soft berries, ii) an automated BerryTek color sorter for removing unripe and/or off-colored berries, and iii) any increase in the processing capabilities and/or decrease in the labor and time required by the Auto-line in comparison to the traditional Manual-line. Through a scientific comparative analysis of the two fresh berry processing methods, this project report provides data to help wild blueberry processors make informed decisions on available equipment for processing wild blueberries for fresh market.

4.2 The WECO Automated Blueberry Sorting System

The WECO sorting system is a multi unit arrangement composed of both an Impulse soft sorter and a BerryTek color sorter. The soft sorter has been designed to remove the overripe (soft) berries from a population of undamaged fruit. The color sorter removes off-colored berries and other foreign material from the processing line. In many instances, automated sensor-based sorters make it possible to significantly increase the efficiency and output of a traditional manual operated system. The main goal of such automation is to increase output and product quality and reduce overall costs of operation in addition to a number of additional benefits including food safety. The berry sorting process at the Millen Farms has traditionally been done using a conventional fresh fruit processing line purchased from Maine Blueberry Equipment Co (Columbia, ME 04623) coupled with manual labour to remove unwanted debris prior to fresh packing wild blueberries for retail.

The automated system being evaluated encompasses the previously used conventional sorting equipment but includes the addition of an 0.81 m wide Impulse soft sorter and BerryTek color sorter just prior to the final pick-over line where manual labor discards any remaining unwanted berries or debris before fresh packing occurs. The conventional sorting operation included a set of four input units (similar to those used for the Manual-line) each consisting of a feed belt (1st conveyer belt) that was manually fed with freshly harvested berries that were transported via small plastic blueberry boxes (**step 1**). The hand harvested boxes (~10 kg) included ripe undamaged berries, soft bruised or damaged berries, unripe berries and foreign debris (Figure 1). Leafy material was removed (**step 2**) using electric blower fans (winders) that expelled unwanted material into debris bins, which were manually dumped and replaced once filled (Figure 2). A berry sizing belt (**step 3**), separated the unripe or smaller sized berries (< 1.25 cm) from the remaining large berries (Figure 3). In **step 4**, the remaining larger sized berries from the 2nd conveyer belt were transferred onto a tilt table sloped downward at a 13° angle (Figure 4). Following this the berries were then transported onto an intermediate collection belt that fed the berries into the Impulse soft sorter (Figure 4). The Impulse soft sorter, with the help of dynamic impulse sensors (tactile sensors) separated soft berries (damaged or ruptured) from the healthy berries in **step 5** of the cleaning process. The targeted soft berries were redirected using rapid shots of pressurized air onto a conveyer belt that expelled into a collection bin (Figure 5). Product not rejected from the Impulse soft sorter then followed a grooved belt (the 4th conveyer belt) and passed on to the BerryTek color sorter (**step 6**). In **step 6**, a two-view color and defect BerryTek optical sensor sorted the berries. Rubber fingers positioned on the input belt of both the Impulse soft sorter and the BerryTek color sorter helped to distribute the berries evenly on the grooved belting and keep the berries travelling at a consistent speed. It was noted that without the use of the fingers or if not adjusted properly the targeted berries were not ejected with the air blast system because of inconsistency in berry velocity. The system was calibrated specifically for berries that were travelling at the same speed as the feed belt. Rejected off-colored berries or debris was blasted with air onto an exit conveyor and collected in a replaceable bin (Figure 6). At the final stage (**step 7**), any foreign material or remaining soft and unripe berries skipped from the previous sorting steps were manually removed by workers prior to filling the gauged marketable berry boxes (**step 8**) of 0.35, 0.70, 1.25, or 2.25 kg (Figure 7).

Figure 1: Hand harvested berries being fed into the system for processing.

Figure 2: Debris (leafy material) being ejected via blower fans and collected in bins.

Figure 3: Sizer belt used to remove berries and debris of less than 1.25 cm diameter.

Figure 4: Tilt tables (left/right) used to remove stems and clumped berries. The collection belt (center) evenly distributes the berries from the tilt tables and transports them to the Impulse soft sorter.

Figure 5: Impulse soft sorter removing soft berries via small conveyor belt to a collection box.

Figure 6: BerryTek optical sorter ejecting off-colored berries via a small conveyor belt to a collection box.

Figure 7: Clean berries packed in boxes of size 2.25 kg (left) and 0.7 kg (right) were recorded as output before they were sent to market.

4.3 Methods of Berry Sorting

The two methods of berry sorting that operate at the facility include a) Manual-line (Figure 8), which encompass steps 1, 2, 3, 4, 7 and 8 and b) Auto-line (Figure 9), which encompasses each of the eight steps including automated soft sorting (step 5) and color sorting (step 6).

Figure 8: Manual-line showing blower fan (step 2), sizer belt (step 3), tilt table (step 4), and final pick over belt (step 7).

Figure 9: Auto-line showing automated soft sorter (step 5) and color sorter (step 6).

4.4 Data Collection

The hand raked berries fed into each of the processing lines, the processed packed clean berries, rejected berries (unripe, soft, damaged, off-colored), and other materials including leaves and debris were collected separately and weighed at the end of each shift (referred as replication from here onward). The data was collected in multiple replications twice a week over a four-week harvesting season (Table 1). A complete data set including the number of workers involved, energy requirements, and system characteristics was also collected during each replication. The manual labor that was considered in this report was the workers involved with stocking the input berries, feeding the input berries into the processing line, pick over line hand sorting, packing and overall processing line cleaning and quality control (Table 1).

Table 1: Per week number of replications and workers involved in processing operation for Manual and Auto-line over the four-week harvesting season.

Week	Date	Manual-line		Auto-line	
		# reps	Line workers	# reps	Line workers
1	16-Aug-19	-	-	5	18.40
	17-Aug-19	4	8.00	4	17.75
2	23-Aug-19	3	8.00	4	18.75
	24-Aug-19	3	8.00	4	18.25
3	30-Aug-19	2	8.00	2	19.00
	01-Sep-19	3	8.00	3	18.67
4	10-Sep-19	3	8.67	4	19.50
	11-Sep-19	3	9.00	3	18.67

Data was collected from random samples of rejected berries from the Impulse soft sorter and BerryTek color sorter on the Auto-line. Additionally, samples of input berries were manually sampled, sorted, counted and weighed to understand the quality of berries being processed. Random samples were taken from the rejected berries and debris on the final pick-over line from both the Auto and Manual-lines. These samples were analyzed to calculate percent berries mistakenly removed (mistargeted) as compared to percent unwanted berries/debris properly targeted by the Impulse soft sorter and BerryTek color sorter at steps 5, 6, as well as manually at step 7 (Figure 10).

Figure 10: Processing of random samples collected at steps 5, 6, and 7 to calculate percentage of properly targeted unwanted berries/debris as compared to mistargeted good berries mistakenly removed and/or left (skipped).

5. Data Analysis

The data collected from each processing step from both the Manual and Auto-lines; i.e., steps 1 through 8, were analyzed in order to get meaningful information for system assessment. In addition to the data from the processing steps, the random data collected at various points of processing were also analyzed and used to support the findings about the berry processing performance. Analyses of the energy consumption and economic parameters were also considered to calculate the payback period of the automated Impulse soft sorter and BerryTek color sorting system under conditions of its use at Millen Farms. A number of evaluation parameters were considered for assessment and comparison of the performance of the Auto-line with the Manual-line (Table 2).

Table 2: Evaluation parameters and the methods of their calculation.

Parameter description	Method of calculation
Feed rate (kg/h)	$\frac{Input\ at\ step\ 1\ (kg)}{Time\ of\ replication\ (h)}$
Feed rate per person (kg/person-h)	$\frac{Input\ at\ step\ 1\ (kg)}{\#\ Pick\ over\ line\ workers * Time\ of\ replication\ (h)}$
Output rate (kg/h)	$\frac{Output\ at\ step\ 8\ (kg)}{Time\ of\ replication\ (h)}$
Output rate per person (kg/person-h)	$\frac{Output\ at\ step\ 8\ (kg)}{\#\ Pick\ over\ line\ workers * Time\ of\ replication\ (h)}$
Shrink (%)	$\frac{Input\ at\ step\ 1\ (kg) - Output\ at\ step\ 8\ (kg)}{Input\ at\ step\ 1\ (kg)} * 100$
Removed at blower fan (%)	$\frac{Blower\ fan\ output\ (kg)}{Blower\ fan\ input\ (kg)} * 100$
Removed at sizer belt (%)	$\frac{Sizer\ belt\ output\ (kg)}{Sizer\ belt\ input\ (kg)} * 100$
Removed at tilt table (%)	$\frac{Tilt\ table\ output\ (kg)}{Tilt\ table\ input\ (kg)} * 100$
Removed at Impulse soft sorter (%)	$\frac{Impulse\ soft\ sorter\ output\ (kg)}{Impulse\ soft\ sorter\ input\ (kg)} * 100$
Removed at BerryTek color sorter (%)	$\frac{BerryTek\ color\ sorter\ output\ (kg)}{BerryTek\ color\ sorter\ input\ (kg)} * 100$
Removed at pick over line (%)	$\frac{Output\ at\ step\ 8\ (kg)}{Pick\ over\ line\ input\ (kg)} * 100$

6. Phase III: Findings

6.1 The Limitations of the Work Done

There were several limitations that have posed challenges in assessment of the automated Impulse soft sorter and BerryTek color sorter system. For example, the data collection was done twice a week over a 1-month time period; whereas, the system remained in operation each day throughout the season. Therefore, the data is only a representative snapshot that covered the early, mid and late harvesting season. Secondly, the input berries came from different fields each week. Visual observation revealed inconsistency in the quality of harvested berries. This inconsistency along with varying harvesting temperatures and moisture conditions continued throughout the four weeks of data collection. In order to confirm this inconsistency, random samples were collected from the raw supply batches on August 31 and on September 01, 10, and 11 to analyze them for their constituents including good quality berries, unripe berries, soft/damaged berries, and debris including leaves and sticks. A snapshot showing mean values of the multiple replicates were plotted as a bar chart to compare weights of each component from the raw supply (Figure 11).

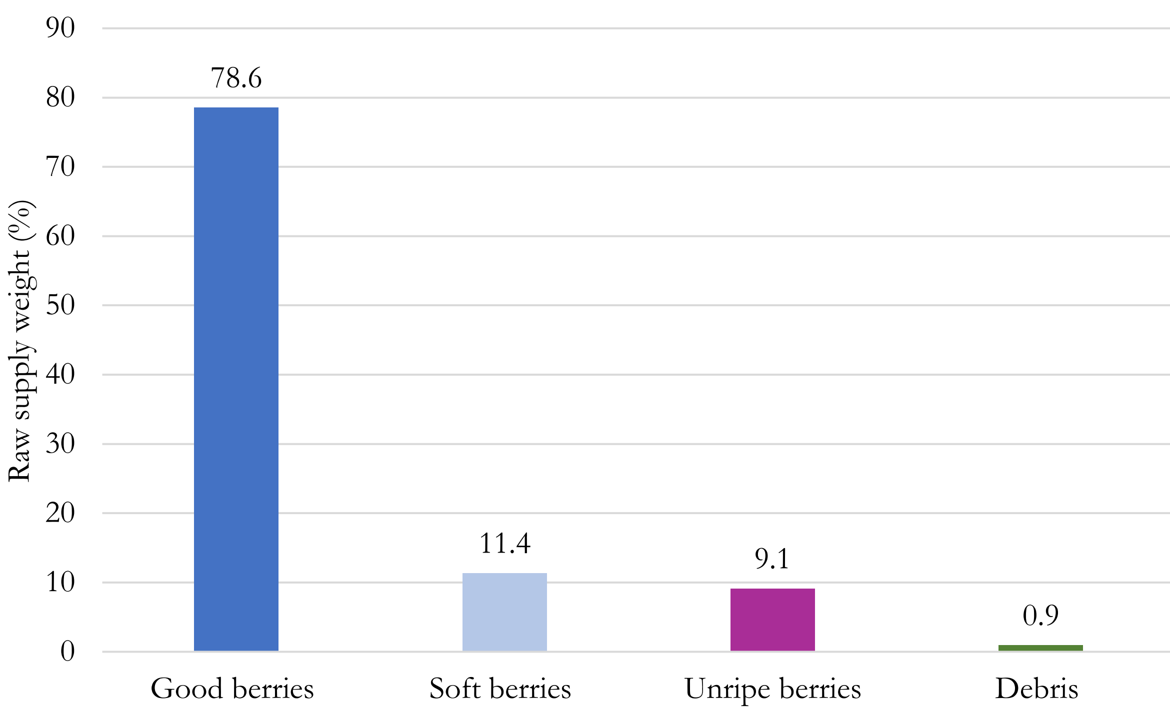


Figure 11: Components of the raw supply of berries processed at both lines. The mean values of weight samples of berries/debris have been plotted as columns.

Good quality berries remained in a similar proportion during the four weeks of the study. More unripe berries were expected in the early harvesting season and vice versa for soft berries but results suggested otherwise. The likely cause of similar weights of unripe berries in both early and late season was due to fields maturing at different intervals based on their geographical location. Fields that are ripe earlier in the season are traditionally harvested sooner than later ripening fields which is likely the cause of the unexpected results. Overall, there were no trends and the proportion of the four studied components remained inconsistent.

Another anticipated source of error with the study may have occurred due to the automated Impulse soft sorter and BerryTek color sorter system being used for the first time in this facility and workers were unfamiliar with this operation. Workers responsible for running the processing shifts were continuously adjusting the feed rate to fine tune based on input berry quality and processing performance. For example, the input conveyer belts were halted if the pick over line became overworked and backed up. Belt cleaning interval and technique of both the Impulse soft sorter and BerryTek color sorter were among the biggest challenges. The automated system malfunctioned throughout the morning of August 17th (week 1). Visual observation and video footage revealed that a significant proportion of rejected berries were mistargeted (Figure 12) and several soft and unripe berries continued through the automated system untargeted. The likely cause was the input berries were wet and caused the belts to rapidly become sticky. Visual observation and video footage suggest that berries failed to follow the same trajectory when travelling on the sticky belt surface resulting in the air blast system mistargeting and rejecting good quality berries. In order to fix this issue, the Auto-line was intermittently stopped to clean off the sticky belting surfaces as well as adding a continuous supply of clean dry air to reduce moisture. The cleaning and drying of the belts with pressurized air resulted in temporary improvement but still was cause for concern. Consensus was that the automated system was not capable of accurately processing wet harvested berries. Comparatively, dry berries were processed during the afternoon shifts (replications 3 and 4). The Impulse color sorter and BerryTek color sorter performed better during afternoon hours likely due to the conveyor belts not becoming sticky keeping the berries travelling at the proper trajectory during free falls so the air blast system could more accurately reject the targeted berries/debris.

Another instance of poor targeting performance using the automated system occurred on August 23, when the supply of input berries was hand-raked two days prior to processing. This supply contained wet berries that caused a sticky buildup on the conveyor belts. Following a supply batch change to freshly hand raked berries in the next replication the results indicated better performance from the automated system.

One consideration that could have skewed the results in favour of the Manual-line was the presence of an added rejection conveyor on the Manual pick over line. Good quality berries coming from the tilt table bounce and roll towards the center of the pick over line. Berries that don't bounce or roll further than ~7 cm mark on the pick over belt are diverted away from the boxed fruit and rejected into a separate container for disposal. It is recommended that if the automated system is used that a similar rejection channel be used for berries that don't bonce or roll towards the center of the belt after coming off the tilt table.

Figure 12: Poor targeting performance of BerryTek color sorting during week 1.

6.2 Feed, Output Rates and Shrinkage

The Auto-line berry feed rate (kg/h) was 2.5 to 5.6 times higher than that of the Manual-line during the four weeks' in operation (Table 3). However, the number of workers were only 1.1 to 2.3 times greater on the Auto-line as compared to the Manual-line (Table 1). The higher feed rate resulted in more than 2.4 to 4.9 times greater output clean berries per hour using the Auto-line (Table 3). Mean values of shrinkage (%) per week using the Manual-line ranged from 14.8 to 21%; whereas the Auto-line shrinkage values ranged from 11.9 to 30.8% during the four weeks of processing (Table 3). Other than week 1 the mean shrinkage values remained similar during weeks 2 to 4. Relatively, higher calculated value of shrinkage (30.83%) using the Auto-line in week-1 was because of poor quality of infeed berries during the first day of processing. Another reason for high shrinkage in week 1 using the Auto-line was because the automated sorters were not properly adjusted or calibrated. The Manual-line was not operated on the first day.

Table 3: Berry feed rate (kg/h), output (kg/h), shrinkage (kg/h) and percent shrinkage (%) for Manual and Auto-lines calculated during weeks 1 through 4.

Sorting type	Week	Feed rate (kg/h)	Output (kg/h)	Shrink (kg/h)	Shrink (%)
Manual-line	1	130.31	102.97	27.34	20.98
	2	277.07	230.33	46.74	16.87
	3	236.16	201.28	34.88	14.77
	4	173.53	147.14	26.39	15.21
Auto-line	1	733.48	507.35	226.13	30.83
	2	688.67	549.70	138.97	20.18
	3	767.18	645.28	121.90	15.89
	4	583.58	514.31	69.27	11.87

The Auto-line berry feed rate (kg/person-h) was 1.6 to 4.1 times higher than that of the Manual-line during the four weeks' operation (Table 4). The productivity per person increased by 154.7 to 405.3% using the Auto-line as compared to the Manual-line (Table 4). Note that feed rate (kg/person-h) used in this calculation only considered those persons working the pick over line (step 7). It was assumed that if the feed rates between the Manual and Auto-lines were matched the only difference in labor would be on the pick over lines.

Table 4: Productivity of Manual-line as compared to Auto-line.

Week	Feed rate (kg/person-h)		Auto-line productivity increase	
	Manual-line	Auto-line	Factor	Percent (%)
1	32.58	132.03	4.05	405.27
2	40.55	114.78	2.83	283.08
3	59.04	91.33	1.55	154.69
4	35.90	74.27	2.07	206.87

For the Manual-line to match the same feed rate (kg/h) as the Auto-line an additional 9 to 19 pick over line workers would be required (Table 5). This additional labor on the Manual-line results in $134.91 to $277.72 per hour to process the same quantity of berries as the Auto-line berry assuming an hourly wage per person of $15 (Table 5). On average the use of the automated sorting equipment reduced the labour requirement by approximately 56.75% on the pick over line.

Table 5: Comparison of labor required on Manual-line as compared to the Auto-line. Note: Hourly wage = $15.

Week	Pick over line workers		Additional pick over line workers needed to match Auto-line productivity	Additional pick over line labor cost ($/h)
	Manual-line	Auto-line		
1	4.00	5.56	18.51	277.72
2	6.83	6.00	10.15	152.27
3	4.00	8.40	8.99	134.91
4	4.83	7.86	11.42	171.32

6.3 Overview of Manual and Auto-line Components Feed, Output Rates and Shrinkage

A flow chart of mean values for both the Manual-line (Figure 13) and Auto-line (Figure 14) were compiled and displayed for easy visualization of processing steps for week-3. Similar flow charts for each of the 4-weeks covering the variability of early, mid and late season harvesting for both the Manual and Auto-lines can be found in the Appendix. Percent shrink (weight basis) was determined at each step throughout the fresh berry processing procedure.

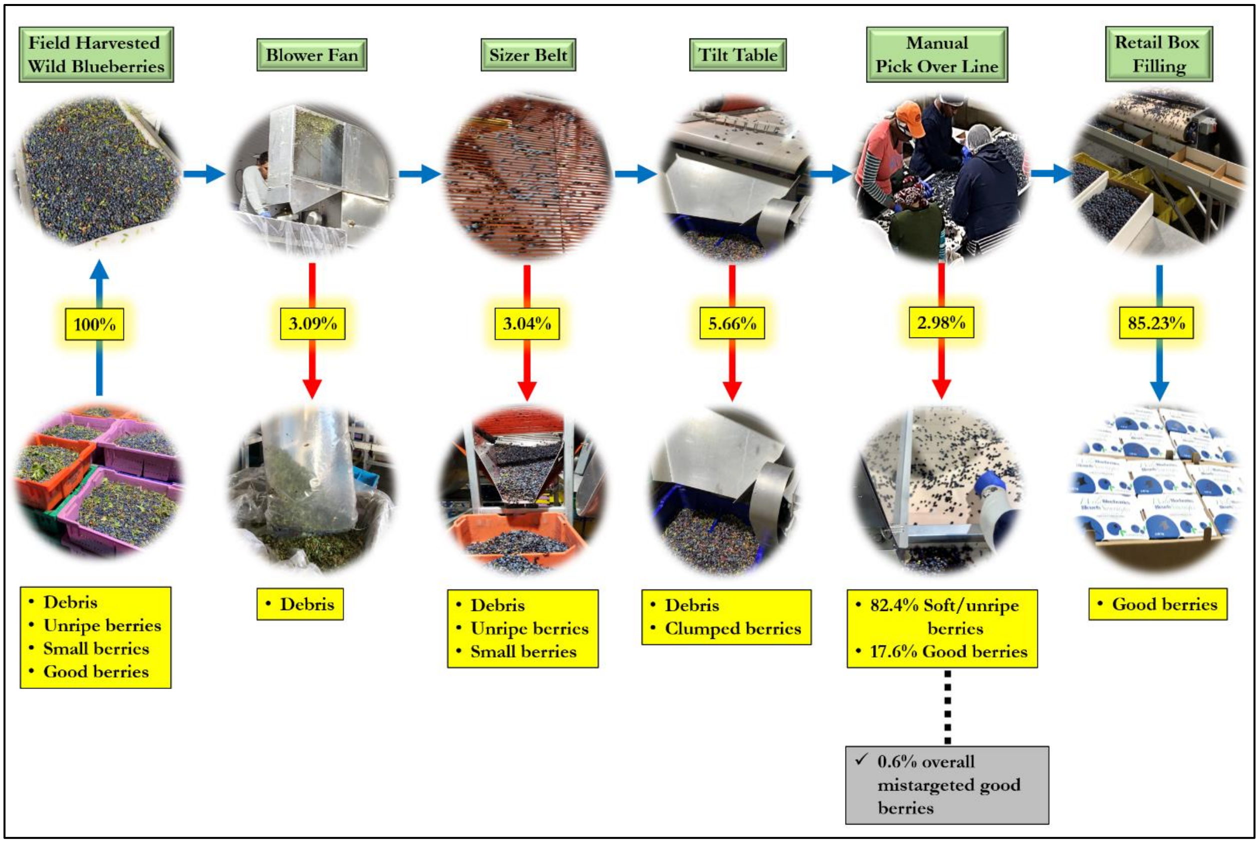


Figure 13: Flow chart showing performance of the Manual-line sorting system during week-3.

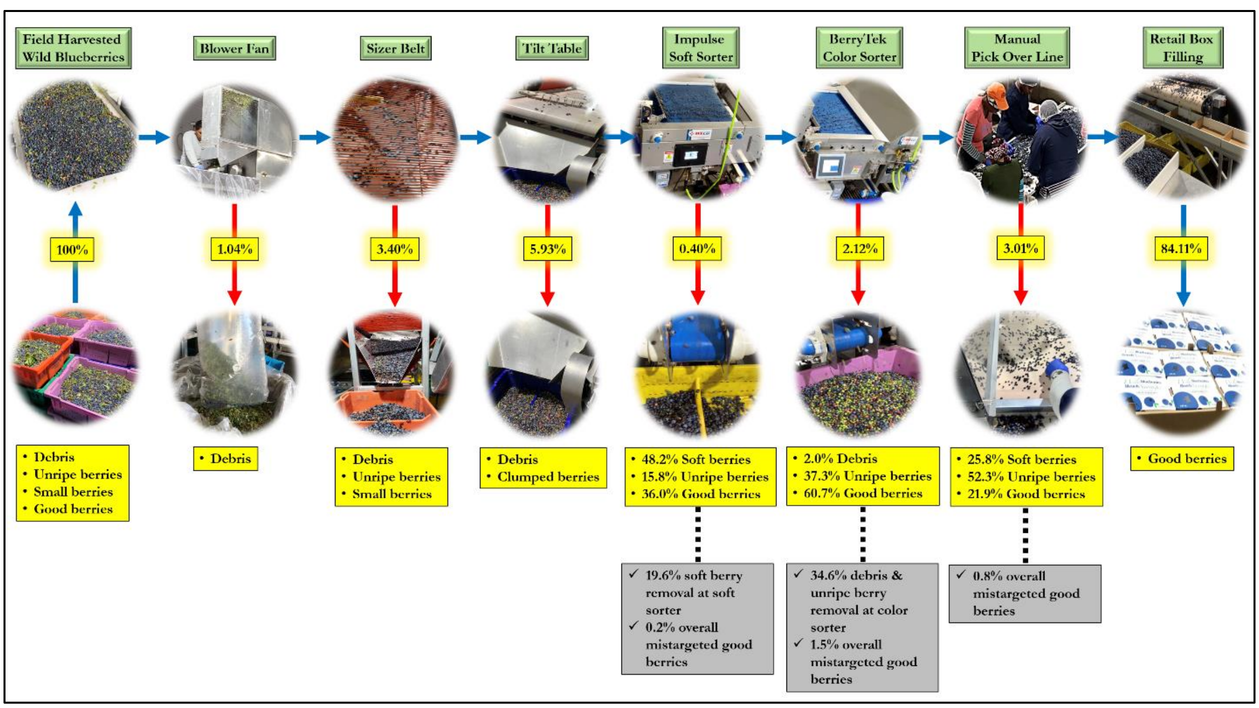


Figure 14: Flow chart showing performance of the Auto-line sorting system during week-3.

The blower fan removed 1.28 to 3.09% debris (weight-basis) on the Manual-line and 0.94 to 1.17% debris on the Auto-line (Table 6). The sizer belt removed 1.21 to 4.68% small berries and debris using the Manual-line and a comparative 0.97 to 4.27% small berries and debris using the Auto-line (Table 6). The tilt table removed 5.66 to 9.01% debris and clumped berries using the Manual-line and 0.97 to 4.27% debris and clumped berries using the Auto-line (Table 6). The Impulse soft sorter removed 0.40 to 4.03% of material on a weight basis while the BerryTek color sorter removed 0.7 to 6.22% (Table 6). The workers and the discharge chute on the Manual-line removed 2.98 to 6.12% foreign debris and damaged or unripe berries while workers on the Auto-line picked 1.73 to 3.43% (Table 6). The output from the Manual line ranged from 79.02 to 85.23% while the Auto-line ranged from 69.17 to 88.13% (Table 6). Lowest outputs (maximum shrink) was found during week-1 due to poor berry quality and the Auto-line not being properly calibrated.

Table 6: Manual and Auto-line processing component breakdown during weeks 1 to 4 showing percent material removal (weight basis).

	Week	Blower fan	Sizer belt	Tilt table	Impulse soft sorter	BerryTek color sorter	Pick over line	Output
		(%)	(%)	(%)	(%)	(%)	(%)	(%)
Manual-line	1	2.27	3.58	9.01	-	-	6.12	79.02
	2	1.28	4.68	6.85	-	-	4.05	83.13
	3	3.09	3.04	5.66	-	-	2.98	85.23
	4	1.78	1.21	6.29	-	-	5.46	84.79
Auto-line	1	1.00	4.23	13.70	4.03	6.14	1.73	69.17
	2	0.94	4.27	5.81	1.02	6.22	1.93	79.82
	3	1.04	3.40	5.93	0.40	2.12	3.01	84.11
	4	1.17	0.97	4.74	0.57	0.70	3.43	88.13

6.4 Manually Removed Berries and Debris from the Pick Over Line (Manual and Auto-lines)

Step 7 is the final processing step to remove unwanted debris prior to filling consumer retail boxes for the end user. Regardless of the nature of processing (manual vs. auto), a major percentage of the labour force was engaged at this step. In order to address a query about the workload of labor at step 7 of Manual and Auto-lines, results of the analyses of the samples collected from hand-picking labor are given in Table 7. Samples collected show a range of 80.50 to 93.00% of the components removed from the Manual-line were soft/damaged or unripe berries. To best understand the specific material remaining on the pick over belt of the Auto-line samples were separated into three classes (soft berries, unripe berries and good berries). The Auto-line sub samples contained a range of 25.80 to 72.30% soft berries and 9.60 to 52.30% unripe berries. Percent mistakenly removed good quality berries in the rejected material was consistently within the range of 0.50 to 1.30% for both the Manual and Auto-lines.

Table 7: Percent removal of good quality berries (by mistake) and rejected (soft/damaged/unripe) berries during hand-picking at the final pick over belt of the Manual and Auto-lines.

	Week	Soft berries	Unripe berries	Good berries	Overall mistargeted berries
		(%)	(%)	(%)	(%)
Manual-line	1	-		-	-
	2	80.50		26.50	1.30
	3	82.40		17.60	0.60
	4	93.00		7.00	0.50
Auto-line	1	-	-	-	-
	2	30.00	44.30	25.70	0.60
	3	25.80	52.30	21.90	0.80
	4	72.30	9.60	18.10	0.70

6.5 Performance of the Impulse Soft Sorter

The percent berries removed by the Impulse soft sorter decreased from weeks 1 through 4 (Table 6). Higher removal during week 2 was likely due to wet infeed berries or berries not processed directly after being harvested that may have increased the percentage of damaged and bruised berries. The samples collected from rejection output belt of the Impulse soft sorter contained samples ranging from 39.90 to 48.20% soft berries. Furthermore, 4.60 to 15.80% of the samples contained berries that were unripe while the remaining 36.00 to 52.40% of rejected material was good quality berries mistakenly targeted. Overall, the results suggest the Impulse soft sorter was able to remove between 9.80 and 41.50% of the soft berries from the processing line while at the same time mistargeting only 0.2 to 0.60% of good quality berries from the line.

Table 8: Auto-line Impulse soft sorter performance.

Week	Soft berries	Unripe berries	Good berries	Soft berries removed at soft sorter	Overall mistargeted good berries
	(%)	(%)	(%)	(%)	(%)
1	-	-	-	-	-
2	39.90	7.70	52.40	41.50	0.60
3	48.20	15.80	36.00	19.60	0.20
4	47.30	4.60	48.10	9.80	0.30

6.6 Performance of the BerryTek Color Sorter

The percent berries removed by the BerryTek color sorter decreased from weeks 2 through 4 (Table 6). Higher removal during week 1 and 2 could have been due to more unripe and off-color berries in the raw supply feed during earlier weeks of harvest but also from the malfunctioning of the sorter as discussed in section 6.1. During the later weeks of the harvesting season the berries matured, and a better understanding of the importance of dry input berries was recognized and adjustments made. Resultantly, lesser number of off-color berries were available for the color sorter to target in the later weeks. The overall mistargeted good berries ranged from 0.30 to 5.10% (Table 9).

Table 9: Auto-line BerryTek color sorter performance.

Week	Debris	Unripe berries	Good berries	Percent debris & unripe berries removed at color sorter	Overall mistargeted good berries
	(%)	(%)	(%)	(%)	(%)
1	-	-	-	-	-
2	0.00	29.90	70.10	68.50	5.10
3	2.00	37.30	60.70	34.60	1.50
4	21.60	34.10	44.30	54.20	0.30

6.7 Energy Requirements

Both the Impulse soft sorter and BerryTek color sorter require 110V and operate with an amperage draw of 7.5A (Table 10). The major electricity spike comes from the addition of a 220V (30A) air compressor that is needed to supply the pressurized air to redirect the targeted berries and debris. Based on a Nova Scotia electricity rate of $0.15/kWh the cost to operate either of the auto sorters is approximately $0.12 per hour while the air compressor costs approximately $0.99 per hour (Table 10). Running both the auto sorters and the air compressor will cost approximately $1.24 per hour.

Table 10: Additional electricity demand from the Auto-line as compared to the Manual-line.

Equipment	Amperage draw (A)	Voltage (V)	Wattage (W)	Electricity cost ($/kWh)	Cost to operate ($/h)
Impulse soft sorter	7.5	110	825		0.12
BerryTek optical sorter	7.5	110	825	0.15	0.12
Air compressor	30	220	6,600		0.99
				Total	1.24

6.8 The Payback Period

The breakdown of components and installation required to retrofit a Manual-line to operate using the auto sorters is displayed in Table 11. The analysis is based on the yearly reoccurring lease of both an Impulse soft sorter and a BerryTek color sorter. In the first year a freight charge of $3,340 is included but not reoccurring since the equipment is not returned until the end of the lease period. The analysis assumed that an air compressor was bought out right in year 1 without any reoccurring fee assuming negligible maintenance was required. Belting costs of approximately $20,000 are needed in year 1 to retrofit the existing Manual-line to accommodate the addition of the automated sorters. Electrical expenses of approximately $5,000 are needed to initially hookup power required by the new automated components. An additional $5,000 of fabrication costs are required to retrofit and raise the existing Manual-line (input conveyors, blower fans, sizer belts, tilt tables) to allow the retrofit of the Impulse soft sorter and BerryTek color sorter. Based on a 24-day season working a 12-hour shift each day results in an additional $356 electricity charge for operating the Auto-line as compared to the Manual-line (Table 11). The additional pick over line labor cost to operate the Manual-line to compete with the feed rate of the Auto-line (Table 5) results in a yearly cost (24-day season with 12-hours per day working shifts) of $53,008 (Table 11). The Auto-line costs $89,496 in year 1 and approximately $49,356 reoccurring yearly following that. The Auto-line has a potential payback period of ~10 years. An additional consideration is although labor is still required for the pick over line using the Auto-line it is much less than that of a comparable Manual-line. If labor is scarce it would be an added benefit to switch to an automated system to reduce the dependency on a large labor force.

Table 11: Payback period based on 12-hour shifts over a 24-day season.

Manual-line additional yearly labor cost ($)	Leased Auto-line cost				Auto-line payback period (years)
	Equipment	Year 1 ($)	Year 2 ($)	Year 3 ($)	
53,008.04	Soft & optical sorter	49,000.00	49,000.00	49,000.00	9.99
	Freight	3,340.00	0.00	0.00	
	Air compressor	6,800.00	0.00	0.00	
	Conveyor belting	20,000.00	0.00	0.00	
	Electrical install	5,000.00	0.00	0.00	
	Platform install	5,000.00	0.00	0.00	
	Electricity cost	356.40	356.40	356.40	
	Total cost	89,496.40	49,356.40	49,356.40	

When considering a fresh processing line that operates at full capacity for a 24-day season with round the clock personnel the results are substantially dissimilar as compared to the 12-hour shift. The Manual-line additional yearly labor cost doubles to $106,016 however, the only additional cost with the Auto-line is the doubling of its electricity consumption ($713). Due to fixed leased cost of the Auto-line components as compared to an hourly rate is more profitable to operate it as many days and hours as possible in one season. Using a 24-day season the Auto-line has a potential payback of less than one season (Table 12).

Table 12: Payback period based on 24-hour shifts over a 24-day season.

Manual-line additional yearly labor cost ($)	Leased Auto-line cost				Auto-line payback period (years)
	Equipment	Year 1 ($)	Year 2 ($)	Year 3 ($)	
106,016.08	Soft & optical sorter	49,000.00	49,000.00	49,000.00	0.85
	Freight	3,340.00	0.00	0.00	
	Air compressor	6,800.00	0.00	0.00	
	Conveyor belting	20,000.00	0.00	0.00	
	Electrical install	5,000.00	0.00	0.00	
	Platform install	5,000.00	0.00	0.00	
	Electricity cost	712.80	712.80	712.80	
	Total cost	89,852.80	49,712.80	49,712.80	

The Auto-line can potentially decrease the pick over line labor by \$0.16/kg to \$0.63/kg as compared to operating using a Manual-line. When factoring in the lease cost of the equipment averaged over a 10-year span when running 12-hour day shifts throughout a 24 day season the decrease in processing cost with the Auto-line was only possible using results gathered from week-1 (Table 13). Results from weeks 2 to 4 suggest that the Manual-line would still be more economical although a larger labor force would have to be readily available. When considering the lease cost of the auto sorter equipment averaged over a 10-year span when running 24-hour day shift throughout a 24 day season the decrease in processing cost with the Auto-line ranged from \$0.01/kg to \$0.45/kg (Table 13).

Table 13: Decrease in labor and processing cost per kg of processed fruit with the Auto-line as compared to operating using a Manual-line.

Week	Decrease in labor cost with Auto-line	Decrease in processing cost with Auto-line	
		10 years @ 12 h/day for 24 days	10 years @ 24h/day for 24 days
	(\$/kg)	(\$/kg)	(\$/kg)
1	0.63	0.26	0.45
2	0.28	-0.06	0.11
3	0.16	-0.13	0.01
4	0.34	-0.02	0.16

6.9 Conclusion & Recommendations

This project was performed during a 4-week period (August 15 to September 11, 2019) at the research site in Great Village, Nova Scotia. The main objective of this project was to compare the ability of an automated optical sorter to remove unripe and overripe wild blueberries and debris as compared to a traditional manually operated processing line. Results from this study suggest that the automated equipment was able to significantly reduce pick over line labor requirements by 56.75% while achieving reasonable accuracy results. On average the Impulse soft sorter removed 23.63% soft or damaged wild blueberries (weight-basis) while only mistargeting 0.37% good berries. The BerryTek color sorter removed an average of 52.43% of the foreign debris and unripe berries while mistargeting 2.3% good berries. In comparison to the automated system, manual workers on average removed the remaining 76.37% soft berries and 47.57% debris and unripe berries while also mistakenly removing 0.75% good berries.

Improvements can be made to the layout of the Auto-line that was evaluated including widening the feed belt after the tilt table and creating berry/debris ejection chutes on either side similar to the

Manual-line pick over table. Visual observation and data from selected replications suggest that infeed berries must be freshly harvested and be reasonably dry when using the Auto-line. It was also noted that excessively high feed rates using the Auto-line result in higher missed or mistargeted fruit due to the close contact of the berries travelling along the grooved belts. A 10-year payback is achievable when leasing the Impulse and BerryTek sorters by reducing the labor requirement following a 24-day season operating at 12-hour shifts per day. Additionally, a relatively large financial gain (<1-year payback) can be achieved if the Auto-line can be operated 24-hours per day throughout the harvest season which helps offset the yearly lease cost.

Further evaluation is suggested using different combinations or additional auto sorters in parallel to determine if increased labor savings can be achieved. It would be valuable to understand any potential benefits from effectively pre-cooling berries prior to sorting in conjunction with monitoring the moisture content. Other advanced systems including automated weighing and packaging could also improve efficiencies over the current labor-intensive manual process. Further research is also suggested to determine the effectiveness of the automatic sorters with berries that are mechanically harvested or raw supply (berries/debris) that were previously frozen. It was noted that manual labor was required to weigh and package the processed fruit which could potentially be reduced using an automated system.

7. Appendix

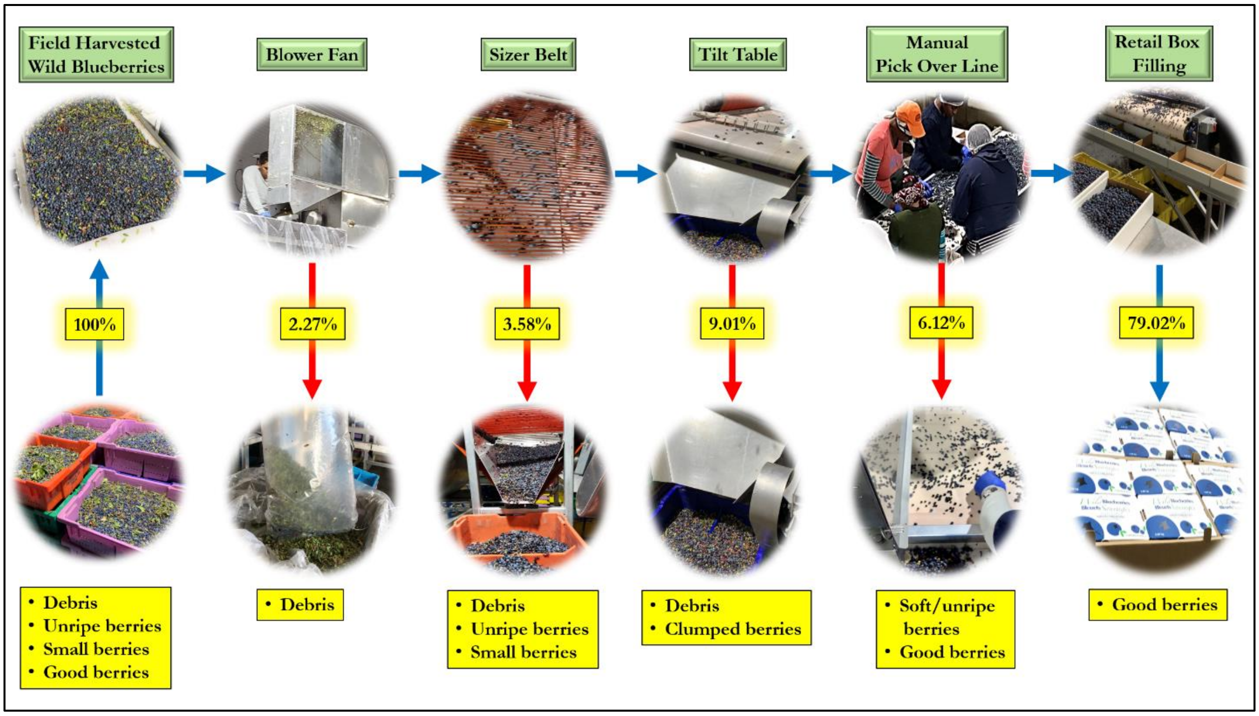


Figure 15: Performance of manual-line sorting system during week 1.

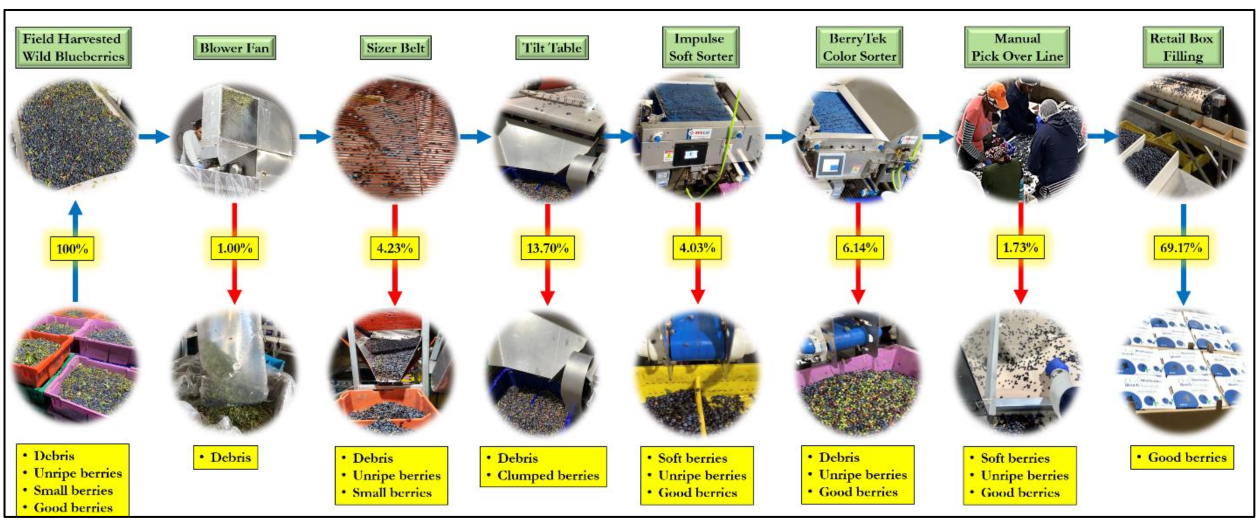


Figure 16: Performance of auto-line sorting system during week 1.

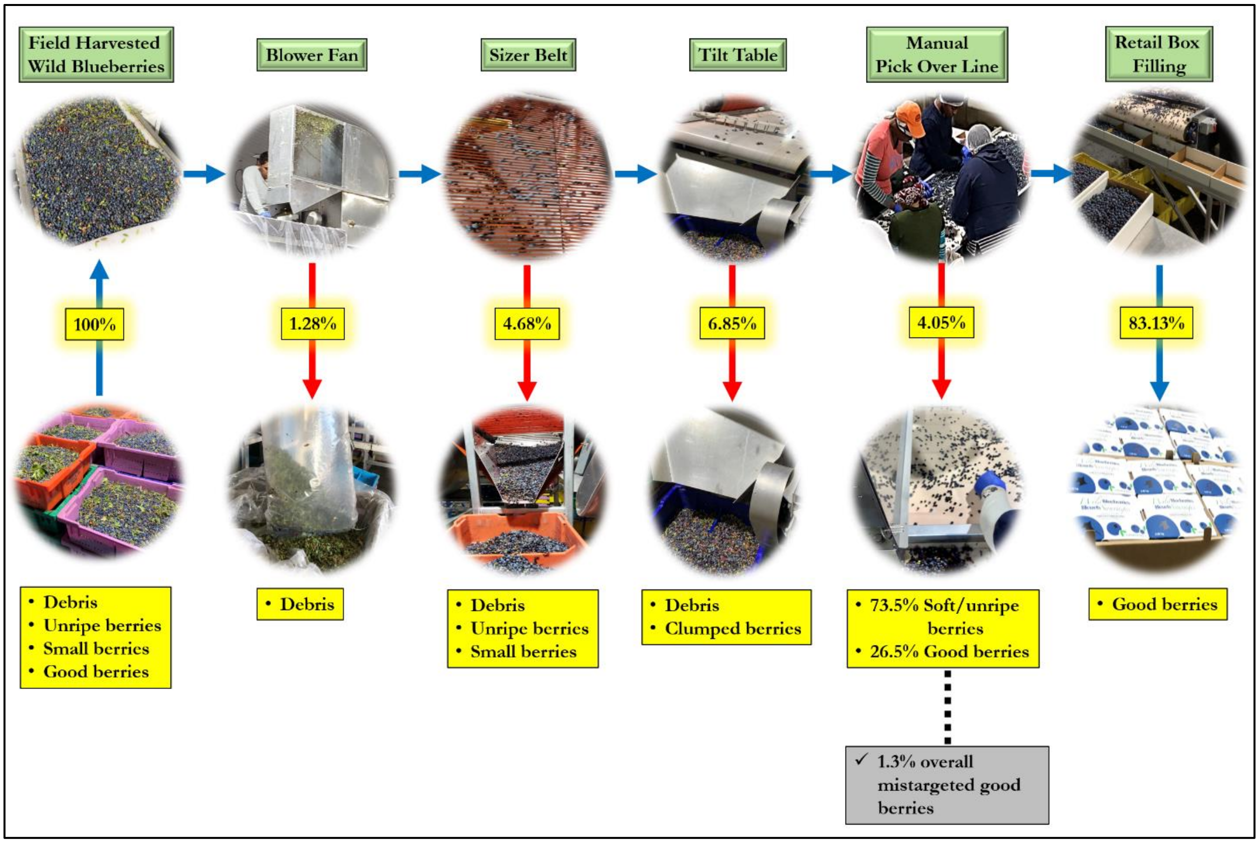


Figure 17: Performance of manual-line sorting system during week 2.

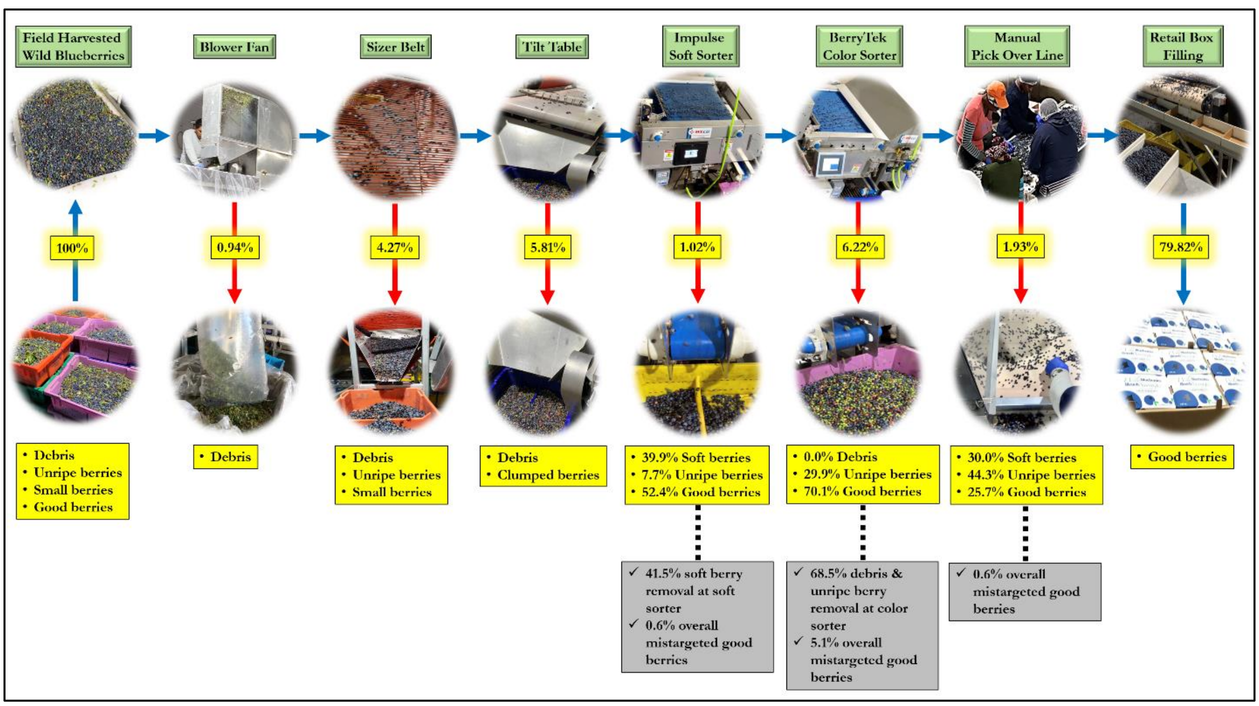


Figure 18: Performance of auto-line sorting system during week 2.

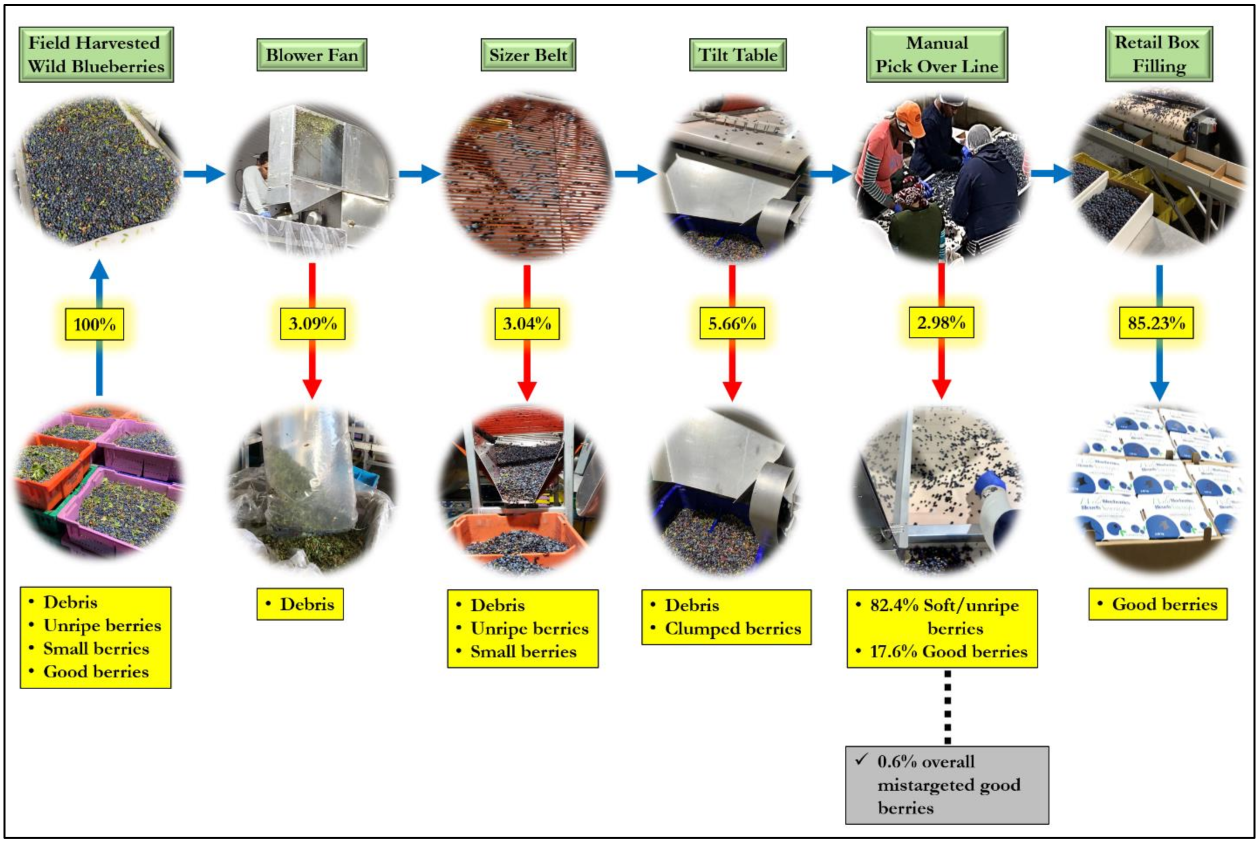


Figure 19: Performance of manual-line sorting system during week 3.

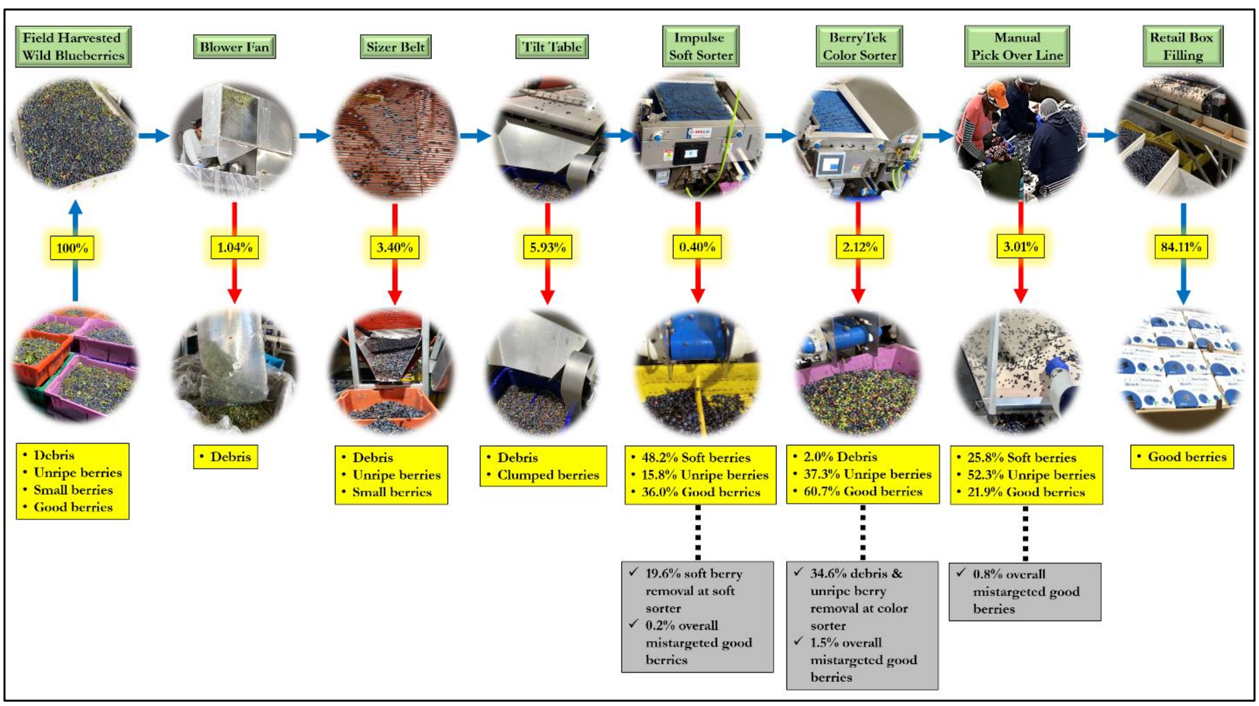


Figure 20: Performance of auto-line sorting system during week 3.

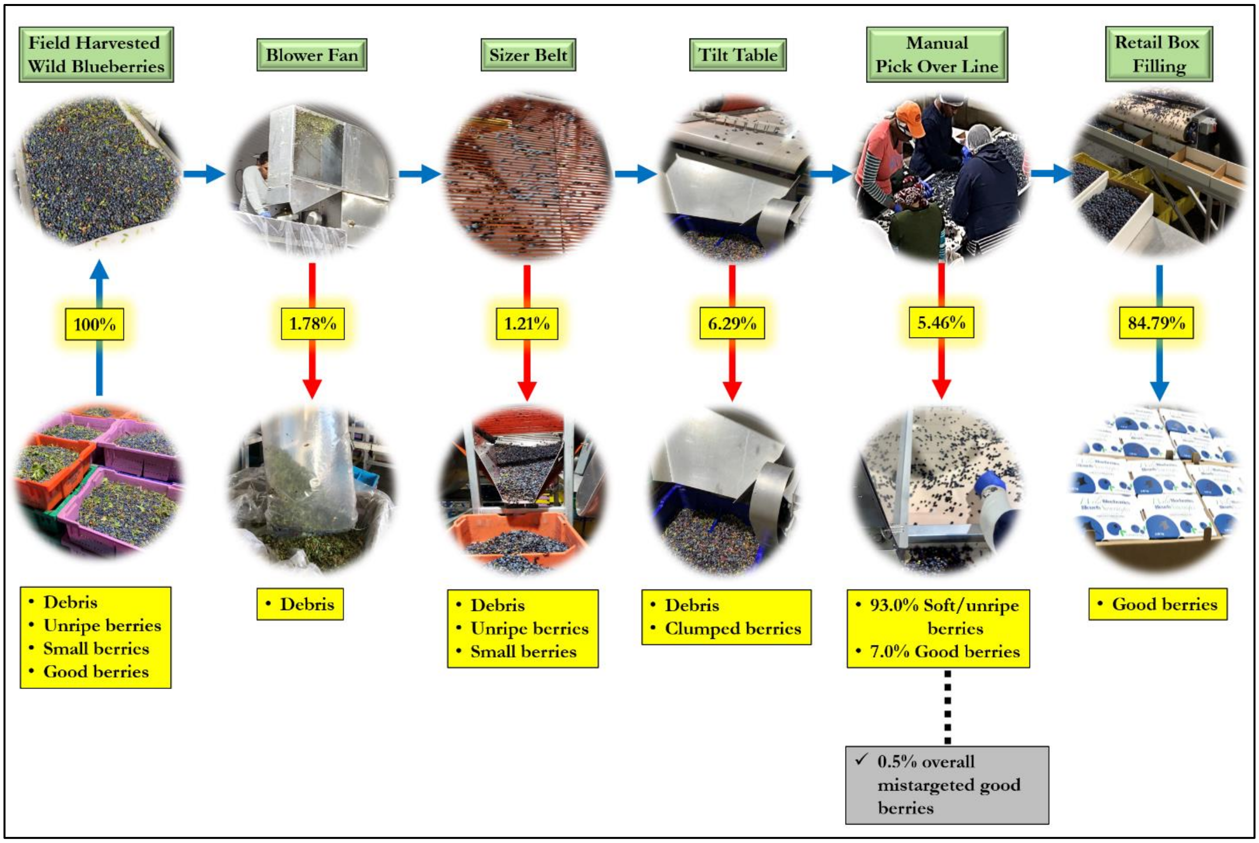


Figure 21: Performance of manual-line sorting system during week 4.

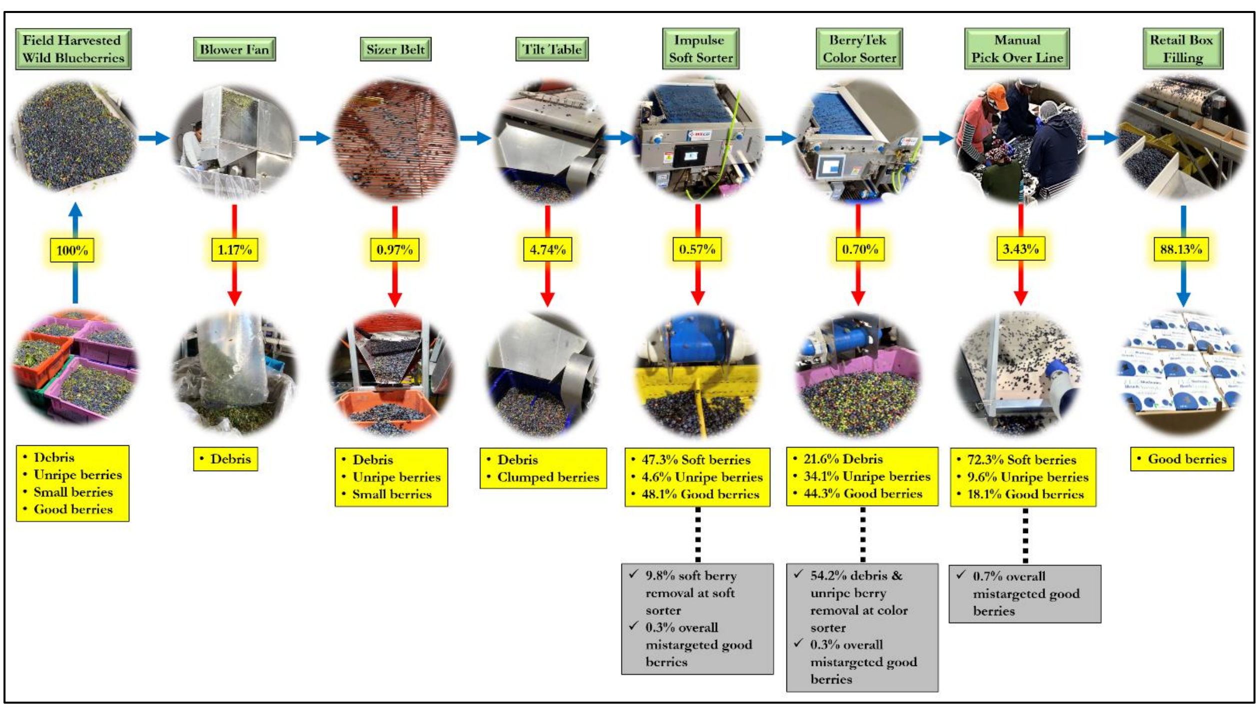


Figure 22: Performance of auto-line sorting system during week 4.