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Non-stationary processing centre for small and medium-sized blueberry farms. A Review

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Abstract

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Growing blueberries on exhausted milled peat fields could be a possible solution to decrease carbon dioxide emission from these areas. To operate such crop-giving plantation manually, a lot of manpower is needed. To decrease the manpower, suitable and helpful technical solutions should be introduced. The aim of this article is to investigate different technological aspects of post-harvest processing of blueberries and to study already existing technical solutions. As a result, non-stationary processing centre for small or medium-sized blueberry farms is proposed. The proposed solution allows reducing manpower, lowering production costs and increasing the area used for growing blueberries. Also, it may encourage other farms to start growing blueberries.

Keywords: agricultural engineering; berry sorter; bilberry; post-harvest treatment

Exhausted and abandoned milled peat fields are the largest plains of denudation in Estonia that are caused by human activity (Purre 2013). In 2009, the area of such fields was about 9,400 ha from which about 2,000 ha are suitable to restart peat mining (Ramst, Orru 2009). It has been found that up to 20,000 ha of exhausted milled peat fields will be added to it in the next 10–15 years (Ilomets 2011). 1 ha of exhausted milled peat field emits approximately 4–5 t of carbon dioxide every year (Ilomets et al. 2010). Thus, in 10–15 years there will be about 29,400 ha of exhausted milled peat fields that will yearly emit up to 147,000 t of carbon dioxide. In addition, these areas are extremely inflammable during hot summer periods. Therefore, it is important to recover or recultivate these areas (Purre 2013). Mostly, this does not happen by itself and human assistance is required (Purre 2013). Also, abandoned milled peat fields are not only a problem for Estonia, it is a wider problem for all the countries with the peat deposits (Paal et al. 2007; Vahejõe et al. 2010). There are several options but Vahejõe et al. (2010) claim that lowbush blueberry growing on milled peat fields will put these areas to economically profitable use. It has been found that benefit-to-cost ratio for lowbush blueberries is 227% when they are cultivated on milled peat fields (Vahejõe et al. 2010).

Blueberry plantation profitability depends on the technology used, climatic conditions and crop yield of grown cultivar (Vahejõe et al. 2010). According to Starast et al. (2005) and Albert et al. (2010), in Estonia it is recommended to cultivate half-high blueberry varieties ‘Northblue’ and ‘Northcountry’, which have been gained by highbush blueberry and lowbush blueberry hybridization. In addition, lowbush blueberry is suitable for production plantation on abandoned milled peat fields (Starast et al. 2005). In 2010 there were about 100 blueberry growers in Estonia (Ilomets 2011). The area of exhausted milled peat fields that were used for growing blueberries was 30 ha (Ilomets 2011). One very good example in Estonia is the Marjasoo farm in Tartumaa.

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In the Marjasoo farm and also in other Estonian blueberry farms, blueberries are harvested manually at the moment (Vahejõe et al. 2010). This harvesting method is time consuming, requires lot of manpower and thus, is not economically profitable compared to mechanical harvesting (Vahejõe et al. 2010; Olt et al. 2013). One worker can pick about 40–50 kg of large blueberries in a day (Starast et al. 2005). It is essential to harvest blueberries at right time when their quality is optimal for handling and consumption because their quality cannot be improved after harvest (Forney 2009). Blueberries are ready for harvesting one week after they have reached correct and uniform colour (Starast et al. 2005). It means that increasing blueberry growing area in farms may lead to a situation where it is essential to use productive harvesting method. For example, the productivity of machine harvester is 60 times higher than handpicking (Brown et al. 1996; Käis, Olt 2010). Making such change in harvesting methods requires also productive post-harvest processing technology.

In addition to domestic market, blueberries are also sold to China. According to the Estonian Ministry of Agriculture (2015), the biggest export product from Estonia to China in 2014 in period from January to October were frozen blueberries. Percentage of frozen blueberries from all exported agricultural products and food products to China was 61%, but only 2% of it was grown in Estonia. This shows that the quantity of exported frozen blueberries that are grown in Estonia could be much larger.

The aim of this research was to study blueberries different post-harvest processing factors and existing technological solutions to propose a suitable technological solution for small or medium-sized blueberry farms located in Estonia. An indirect goal was to encourage usage of exhausted milled peat fields for growing blueberries. In the analysis, different blueberry post-harvest factors were considered and different technical solutions were investigated to estimate the most suitable method for mechanical post-harvest processing of blueberries.

Blueberry post-harvest factors

Blueberries are highly perishable and the final quality of berries depends on their cultivars (Faria et al. 2005; Sinelli et al. 2008; Eum et al. 2013). A blueberry cultivar is suitable for growing in Estonia when it is able to tolerate northern climatic conditions, for example it must be winter hardy (Albert et al. 2010). In 2014, night frosts ruined the blueberry crops; major climatic danger for blueberries in Estonia is thus night frost during the blooming season. Blueberry varieties differ from each other by taste, colour and physico-mechanical features like geometric dimensions, which is the main characteristic for sorting (Bosoi et al. 1977). The diameter of highbush blueberry *Vaccinium corymbosum* berry is 4–12 mm, lowbush blueberry *Vaccinium angustifolium* berry diameter is 3–12 mm, 'Northblue' berry diameter is up to 20 mm and 'Northcountry' berry diameter is up to 10 mm (Starast et al. 2005; Noormets 2006; Hansaplant 2013).

Blueberries can be harvested by handpicking or mechanically. The first method is blueberry-friendly and is preferred for fresh market berries. Mechanically harvested blueberries are usually processed frozen (Forney 2009). Handpicking can also be done using berry rake but it may harm blueberries (Starast et al. 2005). All harvesting methods may knead blueberries or remove wax coating (Starast et al. 2005). The most unfriendly method for berries is mechanical harvesting, but for bigger fields it is the most suitable. In Estonia, it can be done with motor-block harvester and harvesting productivity is then 300 kg/h (Käis, Olt 2010).

According to Forney (2009) the most crucial factor in the post-harvest handling of blueberries is the right storage temperature. Higher storage temperatures will result in higher firmness loss and it affects blueberries final marketing quality (NeSmith et al. 2002, 2005; Tetteh et al. 2004; Nunez-Barrios et al. 2005; Paniagua et al. 2013). Blueberry firmness is related to water loss that is measured via weight loss (Paniagua et al. 2013). Water loss is caused by a difference in vapour pressure between the fruit and the surrounding environment and is influenced by the area to volume ratio, mechanical damage of the skin, and also by the emperature at which blueberries are stored (Kays 1997; Willis et al. 1998; Eum et al. 2013). Moisture loss is predictable when tracking blueberries weight loss during the post-harvest chain (Paniagua et al. 2013). Blueberries weight loss levels must be held below 8% during the postharvest chain to minimize excessive softening (Paniagua et al. 2013). Best storage temperature for blueberries is at 0°C (Jackson et al. 1999; Forney, 2009). Literature sources claim that cooling blueberries to 5°C before packing also reduces microbial activity, especially

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when blueberries are unclean and mistreated (Jackson et al. 1999). Correct temperature management must start immediately after harvesting with removing saved field heat out of the blueberries to maintain their quality (Forney 2009). Due to the transportation limitations immediate cooling is impossible thus, it is considered optimal to cool blueberries down in the timeframe of 2 to 12 hours (Starast et al. 2005). It would be good to develop technological solution where heat removal starts already in the field. It is difficult to accomplish storage temperature of 0°C in the field because usually there is no electricity for refrigeration units. The simplest and cheapest way is to cover harvested blueberries with reflective cover to protect them from solar radiation (Forney 2009) or with light moistened fabric (Starast et al. 2005). Blueberries collecting place thus equipped should be placed near the side of the field. From the tent the blueberries can be transported to the repository periodically (Starast et al. 2005).

According to Yu et al. (2014) in harvesting, processing and handling, the drop height of berries is important to preserve their quality. When comparing short and long impacts then short impacts are more dangerous to the fruit because they create forces with high impulse (Mohsenin 1986; Yu et al. 2014). When blueberry drop height to hard surface is greater than 150 mm, extensive bruising will occur (Brown et al. 1996). Also, Yu et al. (2014) claimed that this aspect is the reason why conveyor belts should be made of plastic to lower the impact magnitude. In addition, Brown et al. (1996) claim that using cushioning materials will help prevent bruising of blueberries with drop height up to 1.2 m.

When developing machines that process food, it is important that all used materials and technological liquids are approved to be in contact with food (Food standards agency 2009). Common material that is used in food processing machines is stainless steel because it is corrosion resistant, it is easy to clean and it does not need surface finish. Stainless steel type that is recommended by Fischer et al. (2010) and by the British Stainless Steel Association (2015) to be used in food production is X2CrNiN19-11.

Technologies for post-harvest processing of blueberries

In the field, handpicked blueberries may be collected into the berries collection boxes, where they are sold (Starast et al. 2005). With this harvesting version, picker selectively picks blueberries with suitable size and colour from plant and removes additional material from berries when needed. This harvesting method is labour-intensive but it does not require blueberries cleaning and sorting. A faster harvesting method is harvesting with berry rake and blueberries may be collected into bigger collection boxes or pails. This harvesting version is less labour-intensive but requires post-harvesting cleaning and sorting. When quantities are small, cleaning and sorting might be done by hand, but with larger quantities it is reasonable to use machines. The third harvesting version, mechanical harvesting, is the least labour-intensive and has the lowest harvesting costs (Brown et al. 1996) but the harvested berry mixture contains semi-ripe berries, bruised and crushed berries, good quality berries of different size, and other additional materials (Soots et al. 2014).

In the berry mixture that is harvested with berry rake or mechanically the most valuable berries are large, good quality berries (Starast et al. 2005; Forney 2009). Second valuable fractions are middle and small size blueberries. It is essential that the post-harvest processing technology will maintain the quality of all harvested blueberries. According to Soots et al. (2014) blueberries that are harvested by machine need post-harvest processing technology that includes many different operations to achieve the desired result. All these operations may harm blueberries quality. The less blueberries are processed and the shorter the chain to the consumer is, the better it is for blueberries quality (Forney 2009).

Methods for removing additional material

Light debris can be removed from the harvested berry mixture by a blower cleaner. This method is widely used for example in grain winnowers. Initial tests have shown that the most suitable for blueberries are centrifugal fans. Such fans are already used in berry blower cleaners manufactured by the Lakewood Process Machinery (2015) and the A&B Packing Equipment (2015) and they offer berry blower cleaners where the out-going air is filtrated with mesh sieve. During the process mesh sieve collects blown-out trash and it may become clogged. To avoid clogging or turning off blower cleaner for mesh sieve cleaning, A&B Packing Equipment

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(2015) has developed a solution where tubular shape mesh sieve is constantly cleaned with a rotary head. Factors that must be considered in blower cleaner development are as follows: even airflow to ensure equal cleaning in conveyor scope, side panels should be removable for cleaning, configurable conveyor speed to ensure line speed, configurable airflow speed to ensure cleaning performance, right construction materials to ensure product quality, self-cleaning air filter to avoid clogging and turning off the blower cleaner (A&B Packing Equipment 2015; Lakewood Process Machinery 2015).

Methods for fractioning

Fractioning of the harvested berries can be achieved with various methods like video grading sorting, roll sorting, net sorting, line sorting, drum sorting and belt sorting (Recce et al. 1998; Grote, Feldhusen 2007; Kondo 2009; Cubero 2014; Soots et al. 2014). Different methods are studied to find suitable solutions for blueberries. Extracts from patents from the European Patent Office (2015) that are studied and considered in this research, are given in Table 1. Patents given in Table 1 are ordered by the year of publication.

In a method that is not described in any literature source but is used by some berry pickers an inclined sorting area is used. Inclined sorting area is formed by a moistened fabric. Harvested berries are poured into the higher part of the sorting area and berries roll along the fabric into the fruit collection box that is located at the lower part. Additional material like leaves or branches will stay on the fabric and they are removed periodically by hand. How this method affects berries quality is unknown at the moment.

According to Karolin and Pärli (1998), factors that influence sorting quality of potatoes are speed of the sorting unit, sorting area inclination angle and potatoes feed quantity. These factors must be also considered when developing sorting machine for blueberries.

Suitable technological solution for post-harvest processing

Companies like the Lakewood Process Machinery (2015) and the A&B Packing (2015) offer machines for post-harvest processing of blueberries. To use these machines, it is required to install them in a factory building. Unfortunately, this may be a problem for small or medium size farmers as it requires large investment while this factory building would be in use only about 1–2 months per year.

Machines that are important for post-harvest processing of blueberries cannot be installed on blueberries harvester because they will increase harvester weight and turf soil in bogs cannot bear heavy machinery (Olt, Arak 2012; Olt et al. 2013). One option is to develop non-stationary processing centre (NSPC) where all the necessary components are installed on a trailer. This trailer is transported onto the field by an all-terrain vehicle (ATV). While the NSPC is operating at the field, the ATV can be used for transporting harvested and processed blueberries into a repository where they are transported into the grocery stores and food industries. NSPC can be mounted to the trailer or it can be detachable. In this study, the NSPC was mounted on a trailer. The trailer should be similar to the Estonian trailer manufacturer Respo Haagised AS trailer version 750M301L150 KIOSK. The main technical parameters of this trailer are: height 1.6 m, length 3 m, width 1.5 m and load capacity 300 kg. The trailer is covered from all sides and from the top to protect devices and berries from rain and solar radiation. Still, this 4.5 m^2 size area is not sufficient and an extra area should be used next to the NSPC to store harvested and processed blueberries. This area should also be covered with solar radiation reflective tent.

Inputs for NSPC are blueberries harvested with berry rake or machine harvester. The minimum productivity of the NSPC must be equal to the productivity of blueberry machine harvester because it is greater than the productivity with berry rake. According to Käis, Olt (2010) productivity of the motor-block harvester is about 300 kg/h. If there is no electricity to run the NSPC on field, electricity can be obtained from a generator with combustion engine. NSPC should include machines to carry out post-harvest processing of blueberries according to the principle scheme given in Soots et al. (2014).

NSPC starts with a reception area where harvested berries are poured from collection boxes to bottomless downwardly tapers reception containers (A&B Packing Equipment 2015; Lakewood Process Machinery 2015). This container is installed above the feed conveyor. The main task of the conveyor is

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Table 1. Extract from relevant patents.

Patent No.	Year	The aim of patent	For which product	Reference
US 1681627 (A)	1928	ripe berries settle in the bottom of the tank, berries are removed with conveyor	berries	Sawyer (1928)
US 2018157 (A)	1935	cleaning and washing apparatus with power driven drum.	blueberries	William (1935)
US 2210486 (A)	1940	berry cleaner with fan, inclined conveyors, grading belt and automatic container filler.	dried peas, beans and berries	Ezekiel (1940)
US 2316159 (A)	1943	washing with water sprays, endless belts to carry berries, freezer, equally diverged belts.	berries and fruits	Evett (1943)
US 2591086 (A)	1952	apparatus to remove foreign particles from berries without immersing them into water	berries	McLauchlan (1952)
FR 1076299 (A)	1954	grader	fruits, tubers	Marijon (1954)
GB 745730 (A)	1956	adjustable sorter with rails and endless band with pyramid pads	potatoes, other round objects	Packman (1956)
FR 1248240 (A)	1960	manually adjustable grader	unknown	Bertz (1960)
CA 842562 (A)	1970	berry cleaner and washer	berries (raspberries)	McLauchlan (1970)
AU 5757373 (A)	1975	destemmer with rotatable drum	grapes	Dorter (1975)
US 4279346 (A)	1981	sorter with optical asynchronous detector, uses air jet sorting system	fruits (blueberries)	McClure and Rohrbach (1981)
SU 822784 (A1)	1981	grader	berries, buckthorn	Sinelnikov et al. (1981)
GB 2140712 (A)	1984	manually adjustable sorter with belts	fruits e.g. plums	Kilgour and Bruce (1984)
US 4542687 (A)	1985	washer, to remove stems it uses discs with curved slots	green peanuts	Johnson (1985)
US 5203259 (A)	1993	berry washer, to remove stems is uses destemming rollers	different types of fruit (blueberry)	Miedema (1993)
EP 0884113 (A1)	1998	method and device for sorting, adjustable slot between cords	fruit and bulbous plants	Van der Poel (1998)
WO 98 48951	1998	adjustable grader solution with ridged belts	fish	Magnusson et al. (1998)
NZ 314846 (A)	1998	adjustable grading apparatus	mussels	Yealands (1998)
DE 10359369 (A1)	2005	manually adjustable sorter	fruits	Willi and Stiefvater (2005)
US 2006 0113224 (A1)	2006	adjustable size sorting apparatus with elastic conveyor bands	blueberries, cherries and cherry tomatoes	Williamson (2006)
WO 2006 120706 (A1)	2006	solution with support members and adjusting screwing members for grading system with ridged belts.	delicate marine species and fruits	Magnusson and Ragnarsson (2006)
US 2006 0162306 (A1)	2006	non-stationary deleafer apparatus with blade assembly	vines	Schloesser (2006)
US 2009 0057208 (A1)	2009	sorting area is formed by rolls	small fruits	Pellene and Gialis (2009)
EE 05642 (B1)	2013	belt sorter with adjustable roller	berries (blueberries)	Olt and Soots (2013)

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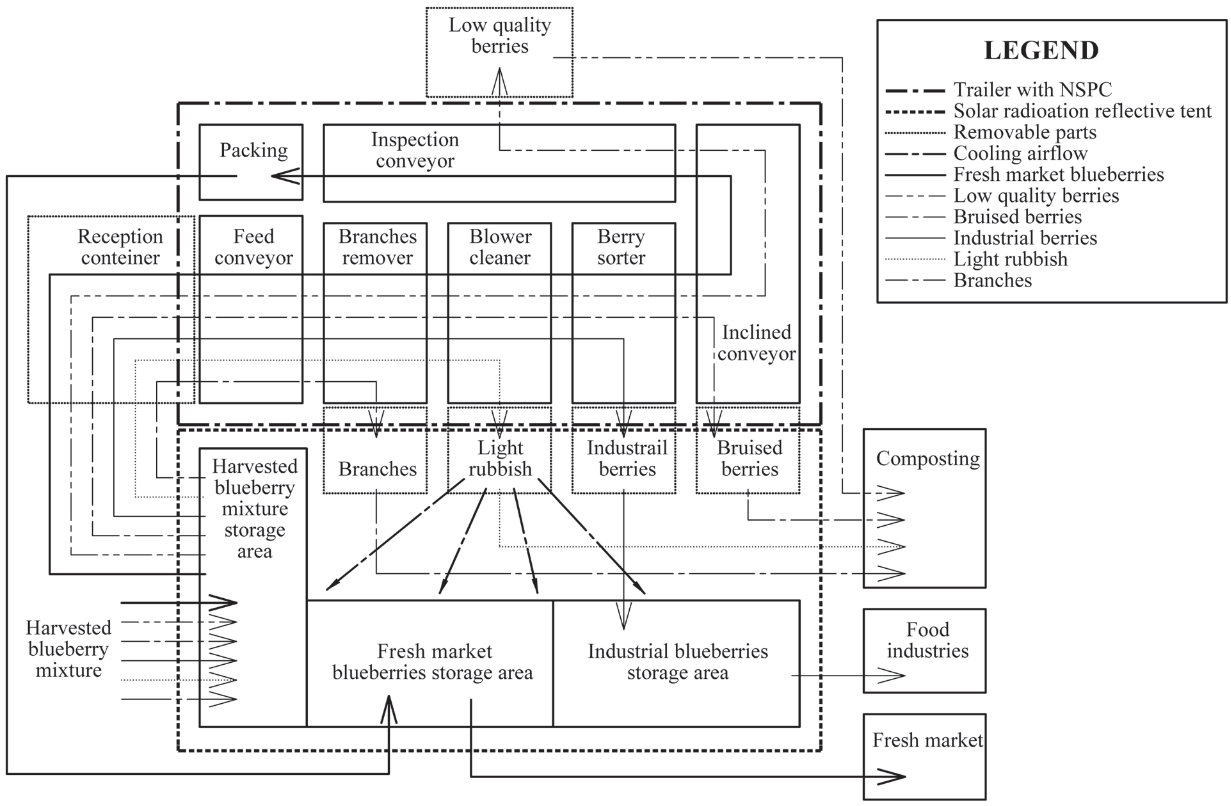

Fig. 1. Principle schematic of the NSPC

to receive harvested berry mixture from reception container and to supply following NSPC part with an even flow of berry mixture. Berry mixture layer height on feed conveyor can be controlled by slot height between reception conveyor and container. Feed speed of the berry mixture to the next NSPC step is controlled by the conveyor speed. Volume of the container should be at least double the volume of the collection box to ensure continuous berry mixture flow onto the reception conveyor.

The next NSPC part should be remover of branches. Branches may cause jams in different NSPC parts and so it is essential to remove them in the beginning of processing line. For example the Lakewood Process Machinery (2015) produces branches removers where rollers with grooves are used to form roller conveyor. Berries fall through slots between rollers grooves and branches and bigger leaves are transported over rollers to the rubbish container. A similar solution can be used in the NSPC.

In the next phase of the NSPC light rubbish is removed from the harvested berry mixture. For that, a blower cleaner is installed on the NSPC. In order to prevent damaging the blueberries, berry mixture should be transported through the blower cleaner with wire belt conveyor to avoid blueberries falling through. It is not reasonable to let the produced airflow from blower cleaner into the surrounding environment. Out-going airflow of the blower cleaner can also be used to remove the saved field heat from blueberries. Thus, air output from blower cleaner should be directed into the side area under solar radiation reflective tent, where the harvested and processed blueberries are stored. To keep already processed blueberries clean in the storage area, the airflow from blower cleaner must be filtered, for example with mesh sieve. Cleaning of the filters should be solved in such a way that there is no need to turn off the blower cleaner, similar to the solution designed by the A&B Packing Equipment (2015).

The next NSPC stage should be sorting berries by size. The sorter must be adjustable to ensure that NSPC can be used with all blueberry cultivars that can be cultivated in Estonia. Sorting method should be simple to use for blueberry growers and sorter parameters easily adjustable. Modern video grading method may be too complicated for farmers and may increase the NSPC price so much that

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blueberry growers would lose interest to buy it. In this study, the belt sorter was used. The idea of sorting is to separate bigger blueberries from the smaller ones. Blueberries could be sorted into two or three fractions by their size. Smaller blueberries are marketed in a frozen form in food industries and bigger blueberries are marketed fresh.

To decrease labour of inspection conveyor worker, the inclined conveyor should be used in the NSPC to remove bruised berries and non-round rubbish from fresh market berries. The working principle of the inclined conveyor is that round shaped objects are rolling off from conveyor to the picking table and non-round objects are transported with conveyor to the rubbish box. Conveyor and screens around the conveyor should be covered with soft material to avoid bruising of the berries.

Inspection conveyor is a part of the NSPC where remaining trash and low quality blueberries are handpicked from the fresh market berries. After inspection conveyor fresh market berries are collected in boxes and they are moved to the storing area. As the work in this part of the NSPC is performed manually by a worker, the inspection conveyor must be ergonomically built. For example, its width must be in accordance with the worker forward reach distance. If the picking table height of 100 cm above the floor is considered, the conveyor should not be wider than 37 cm (Putz-Anderson 1988; Konz, Johnson 2000). Inspection conveyor should also be provided with lighting to operate in darker conditions.

All the separate parts of the NSPC should be adjustable to ensure flexibility, to use slower line speeds at the beginning of processing in order to make fine adjustments and to ensure the NSPC max. processing quality. More specifically adjustable should be the horizontality of NSPC, berry mixture layer height on feed conveyor; feed conveyor speed, blower cleaner wire belt conveyor speed, air flow from blower cleaner, belt conveyor speed that forms belt sorter, belt sorter gap size between belts, inclined conveyor speed, inclined conveyor slope and inspection conveyor speed. The principle schema for the NSPC is given in Fig. 1.

Three workers are needed to run the NSPC and, in cases where blueberries that are marketed fresh are packed on the field, one extra worker is needed. It must also be kept in mind that the NSPC works in outdoor environment, so all electrical and mechanical systems should have protection against potential damage from moisture and water. To evaluate the water loss of harvested blueberries, the weight of processed blueberries in their collection boxes should be measured. It would be advantageous to determine a fixed weight for all boxes to simplify the monitoring of weight loss.

The main reason for developing NSPC was the lack of a suitable technological solution that could process blueberries from small or medium-size blueberry farms. Also, it helps to increase the use of machine harvesters and, which increases the productivity at farms where blueberries are normally handpicked. The expected benefits of the utilisation of the proposed NSPC in the blueberry farms are in economical savings and processing speed. If blueberries are processed on the field, the transportation chain is shorter and costs for that are lower too. Berries that are marketed fresh can be transported directly from field to the grocery store or market. Rubbish that is removed from berries can be left on the field as a fertilizer, which also helps to save money on rubbish transportation and utilisation. As the work with the NSPC is seasonal in Estonia, it is reasonable that the NSPC owner would rent it out to other blueberry growers to shorten the NSPC payback period.

CONCLUSION

In this research, the principle structure of the non-stationary processing centre (NSPC) for post-harvest processing of blueberries at small or medium-sized blueberry farms is proposed. In the development of the NSPC, various different blueberry post-harvest factors that influence berry quality have been considered, in order to find suitable technical solutions for processing blueberries. All processing operations may cause unintended harm to blueberries, so the proposed NSPC includes only essential processing operations in order to ensure quality of the blueberries. For further research, real tests with the NSPC are required to find out how much it affects blueberry quality and how large its economic gains for blueberry growers really were.

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