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Risk Analysis of Berry Harvesting in a Blueberry Plantation

Analiza ryzyka dotyczącego pozyskania jagód na plantacji borówki

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Abstract: The purpose of the study was to conduct a risk analysis of the operation of a highbush blueberry plantation based on the FMEA method. The research was based on the information acquired from two private blueberry plantations differing in location (Sokolniki, Dybów) and acreage size (0.45 ha and 4 ha). It was pointed out that the greatest threat to both plantations, and thus to the quality of the product, turned out to be ensuring proper fertilization and protection from diseases and pests (risk index: 126). In addition, in the case of the first plantation, the location of the plantation (147), cutting and shaping of bushes that have a significant impact on plant development (120) and protection from wild birds (112) were of great importance. Similarly, plantation location, cutting and bush formation (162), yields, commercial quality of the harvest, and plantation location (112) were diagnosed as high risks for the second plantation. The most critical risks to blueberry quality occur at the first link in the logistics chain, i.e. the agricultural producer.

Keywords: risk analysis, FMEA method, highbush blueberry.

Streszczenie: Celem pracy było przeprowadzenie analizy ryzyka funkcjonowania plantacji borówki wysokiej, z wykorzystaniem metody FMEA. Oparto się na informacjach pozyskanych z dwóch prywatnych plantacji borówki, różniących się położeniem (Sokolniki, Dybów) oraz wielkością areału (0,45 ha i 4 ha). Wskazano, że największym zagrożeniem dla plantacji pierwszej oraz drugiej, a tym samym dla jakości produktu, okazało się zapewnienie prawidło-

wego nawożenia i ochrona przed chorobami i szkodnikami (wskaźnik ryzyka: 126). Ponadto w przypadku pierwszej plantacji duże znaczenie miało położenie plantacji (wskaźnik ryzyka: 147), cięcie i formowanie krzewów mające ogromny wpływ na rozwój roślin (120) oraz ochrona przed dzikimi ptakami (112). Jako duże zagrożenie dla plantacji drugiej zdiagnozowano również położenie plantacji, cięcie i formowanie krzewów (162), plonowanie, jakość handlową zbiorów oraz położenie plantacji (112). Najważniejsze zagrożenia dla jakości borówek występują w pierwszym ogniwie łańcucha logistycznego, tj. jest u producenta rolnego.

Słowa kluczowe: analiza ryzyka, metoda FMEA, borówka wysoka.

1. Introduction

Several studies have presented the prospects of the cultivation and possible use of blueberry fruits in the fruit and vegetable processing industry, taking into account the nutritional and health benefits of blueberries as well as the economic conditions of their cultivation (Milewski, 2015; Reszka, Lesiów, and Mońka, 2017).

Attention is drawn to the variety of environmental factors and the many measures that are essential for the proper operation of the plantations and for ensuring the quality and safety of the berries of the American blueberry (Bryk, 2013; Carroll, 2016; Demchak, Harper, and Kime, 2014; Pliszka, 2010). A risk analysis for blueberry plantations should also be an essential part of these considerations.

In the available literature, risk analysis concerning any other fruits was not found. In some reviews, the potential effects of different factors on the quality of fruits can be found. For example, in Muzammil, Mudassir, Dar, and Wani (2017), the authors discussed how to prolong the postharvest shelf life of sweet cherries; among various factors that significantly influence it, they list harvest time, proper handling and cooling practices, and packaging.

Another publication (Khan, Zingh, and Ali, 2018), focused on preharvest factors affecting the postharvest handling of plums, such as soil, climate (as the adequate light intensity and air temperature), canopy position, the tree genotype (cultivars and rootstocks), cultural practices (e.g. the method of mulching or deficit irrigation), mineral nutrition, irrigation, and the application of different chemicals. In postharvest handling and storage, precooling, heat treatment, cold storage, controlled atmosphere storage, modified atmosphere packaging, and edible coating are essential.

The study aimed to conduct a risk analysis for blueberry plantations using the FMEA method.

2. Materials and methods

The authors used the FMEA method (Failure Mode and Effects Analysis) to analyse the types and effects of possible errors. The technique examines the causal relationship between potential product defects and includes the analysis' criticality factor (risk).

The aim was to consistently and systematically identify possible product or process defects during the design and manufacturing phase and eliminate or minimize the associated risks (Brayer-Marczak, 2015).

The FMEA analysis was performed in the following order (Przystupa, 2013; Wolniak, 2011):

- activities related to the establishment and operation of the plantations were identified;
- a list of possible errors for the establishment and operation of the plantations, which may lead to a possible deterioration in the quality of the blueberries, was drawn up;
- a list of the probable effects of such errors and the effects of the detected deficiencies which may impact the external and internal client was drawn up. Each result obtained was assigned a **significant factor of the defect concerned Z**, also referred to in the literature as Zn or as the probability number of the significance of the defect, i.e. the impact on the consumer, LPZ. The coefficient values range from 1 (without effects) to 10 (serious effects);
- an analysis of possible errors was carried out on the prepared list of the causes of possible errors or deficiencies. When determining the causes of the error, the probability of the influence of a given event on the occurrence of the identified error is determined. In this way, a real causal link can be established between the possible error and its cause;
- an error risk assessment was carried out, i.e. the probability of occurrence of the defect, i.e. the frequency the defect occurring. **The frequency coefficient R** is determined by a ten-step scale and is also indicated by other symbols: Cz or the probability that a defect will occur (LPW). The different values of the coefficient mean as follows: 1 – random occurrence, 2, 3 – rare, 4, 5, 6 – within acceptable limits, 7, 8 – a common occurrence, 9, 10 – very common;
- the preventive measures, the implementation of preventive measures, and the verification of their effectiveness were planned. This set out the measures currently being taken to identify the defect or the cause of the defect. The factor determined after determining the control measures is **the defect detection rate W**. Other symbols used in the literature are Wy or the number of probability that a defect is detected (LPO), which determines the probability that a specific defect is detected (1 – large/significant, 10 – very small).

The cause-deficiency-effect was assessed on a 10-point scale (integer numbers with an interval of 1-10) according to the gradation proposed by Lendzion, Batura, and Cybulski (2006) based on the three logging criteria (Wyrębek, 2012):

- risk (frequency, probability) of an error/defect/cause – **R number** (very unlikely 1, unlikely 2-3, likely 4-6, moderately likely 7-8, and highly likely 9-10);
- possibility (probability) of detecting the occurrence of a cause before it causes an error or defect – **W number** (high probability 1, moderate probability 2-5, low probability 6-8, very low probability 9, and unlikely 10);

- relevance of the defect or defect to the product or impact on the consumer – **Z number** (almost unnoticeable 1, light load 2-3, moderate 4-6, large 7-8, and very large 9-10).

Based on these figures, the so-called P-priority number, also known as the Risk Priority Number (LPR) or the Level of Risk Factor (WPR), was calculated as follows:

$$P = R \times W \times Z,$$

where R is the frequency coefficient, W is the detection factor, and Z is the factor of the importance of the defect for the customer.

The priority number (risk factor) makes it possible to identify which hazard represents the greatest (most significant) risk and to determine the order of prevention measures to be taken. Preventive measures should reduce the probability of the defect's cause or improve the visibility of a defect that has already occurred.

The number **P** can take values in the range of 1-1000. As the P-number rises, the risk of a defect increases. In most cases, a so-called critical level (acceptable level) is defined, i.e. the value of the number P, above which all deficiencies are analysed. Therefore, this makes it possible to take preventive measures, e.g. changes to the design of an existing product, to correct the technological process (Trafiałek, Kaczmarek, and Kolanowski, 2016; Zalewski, 2008). Preventive measures should aim to reduce the probability of the cause of the defect occurring (R) or to increase the visibility of a defect that has already happened (W) (Wolniak, 2011).

The main activities involved in planting and operating the plantations, harvesting, transporting, storing, and packaging the berries, and delivering them to the final consumer that affects the quality and safety of the finished product (packaged blueberry fruit), were identified based on: available literature (Pliszka, 2010; Reszka et al., 2017) and on an analysis of the operation of two blueberry plantations.

These comprise the place where to grow the blueberry, the plantation's irrigation, fertilization, and pest control, and the harvesting, transport, and storage of the final product, i.e. the blueberries.

The first blueberry plantation in Sokolniki (municipality Kąty Wrocławskie) covers the area of 0.45 ha and grows Puru, Spartan, and Duce varieties of blueberry, which are all early varieties. At the end of June, the blueberries are harvested into baskets for strawberries (approximately 2-3 kg). Harvesting is carried out by three to five pickers in the morning (from 7 am to 12 am) at two-day intervals for approximately one month. The baskets are transported by car to a cool room (approximately 1 km, temperature less than 10°C). The plantation is a cargo plantation (raw material collection on site).

The second blueberry plantation in Dybów covers an area of 4ha and the following types of blueberry varieties: Duke, Patriot, Bluecrop. The Duke variety makes up 25% of the plantation, as does the Patriot variety, while the Bluecrop variety is 50% of the crop.

The fruits of the first two varieties reach harvest capacity in the early season, while the fruits of the third one are harvested about two weeks later. The harvest period for the second plantation is about two months. Harvesting is done for final packaging, depending on the order specification. These are usually 500 g buckets or 250 g containers; 30 to 40 pickers harvest from 8 am to 5 pm, including logistic, weighing, and quality staff (another six people). After packing, weighing, and quality control, the packed fruits are placed in a refrigerated truck and transported to the producer groups.

The second plantation also sells blueberries to individual customers and small stores, while the producer groups receive the most significant part of the production. The plantation's logistic chain for small stores and individual buyers ends with the refrigeration of the fruit. In contrast, for the producer groups, the plantation must deliver the fruit to the group's headquarters, where it is stored under refrigeration. When the plantation provides a day's production to the group, the fruit is not stored on the plantation, which reduces costs and storage risks.

3. Results and discussion

The results of the FMEA analysis for the blueberry plantations and the harvesting, transportation, and storage of berries, i.e. all the potential irregularities that have a bearing on the quality and safety of the final product, namely the blueberry, and for which remedial action should be taken as a first step, are shown in Table 1. In this case, the calculated highest risk priority number ($P = R \times W \times Z$) values ($P > 100$) were used as a criterion.

The P priority indices given in Table 1 were placed in the order from the largest to the smallest value for plantation 1 and plantation 2 (Table 2).

It was indicated that the greatest threat to both plantations, and thus to the quality of the product, was ensuring proper fertilization and protection from diseases and pests (126). In addition, in the case of the first plantation, the location of the plantation (147), cutting and shaping of the bushes (120), and protection from wild birds (112) were significant. Similarly, cutting and shaping of bushes (162), having a significant impact on plant development, yield, and commercial quality of the harvest, as well as the location of the plantation (112), was diagnosed as a significant threat to the second plantation.

Plantation irrigation and water quality (84 and 108; 84/112), in an era of global warming, were of vital importance, more noticeable in the case of plantation two. The problem of irrigation in plantation one was not so substantial, which may be due to the different geographic locations of the two plantations. In the case of plantation two, the following post-harvest stages of fruit harvesting, i.e. ensuring adequate storage conditions, were critical (108).

Table 1. FMEA sheet for highbush blueberry plantation (values are for plantation 1/plantation 2)
Tabela 1. Arkusz FMEA dla plantacji borówki wysokiej (wartości dla plantacji 1/plantacji 2)

No P	Potential type of defect	Potential effects of defect	Number Z	potential cause/ mechanism of defect	Number R	Control measures used	Number W	P	Actions recommended
1	2	3	4	5	6	7	8	9	10
I a blueberry site selection	improper site (e.g. poor sunlight, little rainfall, lack of shelter from the wind, low groundwater level, too wet a place), improperly prepared substrate (inadequate acidity of the soil), unfavourable vegetation near the plantation, inadequate spacing of seedlings between rows, inadequate spacing of seedlings in the row	destruction of the plantation through frost, limited growth of bushes, poor/ little fruiting, access of pests to bushes, withering of bushes	7/7	lack of experience and competence, improper location of plantations, improper preparation of soil (replacing or mixing it with peat, adding sawdust)	3/4	interview with people who already have highbush blueberry plantations, soil pH test, soil abundance test	7/4	147/112	training, following professional literature, when establishing a plantation, preparing the soil using acid peat, seasoned sawdust, and soil in a ratio of 1:1:1
I b choice of blueberry varieties	inadequate planting, mixing late varieties with early varieties	difficult harvest, the reduced yield from plantation, difficult care of bushes	4/3	lack of knowledge, lack of planning	4/4	learning about characteristics of bushes varieties	4/5	64/60	training, following professional literature
I c irrigation of plantations	too abundant irrigation or inappropriate irrigation hours, in the case of dot installation,	development of soil pathogens due to root flooding, leaching of mineral elements from the soil, diseases	7/9	inexperience, inaccuracy of personnel. watering too much and at different times during the day, lack of irrigation	4/6	water must meet the requirements of water fit for consumption, control of irrigation system efficiency	3/2	84/108	training, correct planning of the irrigation system, in the case of drip

	improper selection of lines	resulting from not irrigating or sprinkling in the morning, poorly formed, diseased fruit, lack of irrigation of some shrubs if the dripper is not within the radius of the root ball, withering of plants							lines, it is recommended to use densely spaced drippers
I d irrigation of plantations – the quality of water	inadequate water quality, too much iron, calcium, magnesium	magnesium soil deacidification, limited development of shrubs	7/7	the water of inadequate quality in the intake that is the source for irrigation	4/4	water hardness test	3/4	84/112	use of irrigation water treatment filters
I e cutting and shaping shrubs	poor growth of shrubs, the appearance of diseased, poorly formed shoots, too many fruiting shoots, not removing old shoots (after four this year), improper shrub formation	smaller, poorly formed fruit, lower fertility, hindered harvesting, possibility of frost	8/9	lack of training and experimentation, imprecision, improperly selected pruning method for a given shrub species, inappropriate tools for cutting shrubs	5/6	observation, recording techniques of cutting and care of shrubs	3/3	120/162	training, following the professional literature, instruction videos
I f mulching	lack of mulching, inadequate mulching material, weed growth around shrubs, limited shrub development	smaller, poorly formed fruit, lower fruit yield, presence of undesirable elements in fruit and shrubs, difficult harvesting, the possibility of frost	4/4	lack of availability of mulching material, no possibility of mechanical mulching	7/9	observation and recording of shrub development, testing fruit for heavy metal content	2/2	56/72	training

Table 1/Tabela 1, cont./cd.

1	2	3	4	5	6	7	8	9	10
I g fertilization and protection against diseases and pests	inadequate dosage of fertilizer components and fertilizers not adapted to the crop year, season, inadequate and at the wrong time applied plant protection measures and protection against diseases (shoot blight, gray, mildew powdery mildew, anthracnose), and pests, which are divided into soil borers, pimples, hornets, aphids, scrolls, and beetles (such as Drosophila suzukii midge, May beetle, puffball), rodents (grubs)	disruption or inhibition of growth and development of indicator organs (leaves and young shoots), smaller fruit size, faster aging of bushes and reduced productivity, susceptibility to damage to the root system, lower resistance to diseases and pests, excessive growth of shoots from which the fruit is not durable and exposed to fungi during storage, excessive development of lateral shoots, mechanical damage to fruit caused by pests	9/9	lack of ability to calculate the balanced amount of mineral nutrients necessary for the growth and proper fruiting of blueberries, scarcity of fencing of plantations and limitation of contact with wild animals, improper storage/storage of fertilizers and plant protection products (non-separated place), increase in the number of rodents, moles, voles, and shrews as a result of not rooting the grass between the rows of bushes, lack of available effective plant protection products (e.g., for spider mites)	7/ 7	record of preparation and application of fertilizers and protection products	2/2	126/126	training on the use of fertilizers, protection products and related to microbiological risks from wild animals and birds with free access to the plantation, auditing the plantation, the need for frequent use of selective crop protection products
I h protection from wild birds	inadequate or lack of protection against wild birds (biosonic apparatus, installation of nets	destruction of fruit by foraging birds during the period of ripening and berry picking, reduction of plantation productivity	9/7	lack of experience	7/4	control of the functioning and effectiveness of electric wild bird scarecrows (hawk scream),	2/2	112/56	training on how to protect plantations from wild birds and animals

	to prevent birds from invading plantations and others),					gas cannons, construction of installed nets			
II blueberry harvesting and transportation	inappropriate timing of berry harvesting (unsuitable for the variety), harvesting wet fruit, repeated handling and shifting of berries, boxes into which berries are packed are not white, not ensuring rapid cooling after picking	fruit is not wholly discolored, crippling of fruit and spread of diseases, too high a temperature irreversibly destroys the tissues of the fruit, signs of rotting, mechanical damage pollution and foreign bodies, foreign smell, and taste	9/7	inexperience, improper habits, failure to maintain hygienic conditions, inadequate plastic packaging, shelling, baskets, the threat of mold, abrasion, crushing of berries; as a result, reducing the microbiological status and quality of the goods as well as storage life	4/4	quality control by the plantation owner, adherence to the principles of Good Agrarian Practice and Good Hygiene Practice	2/2	72/56	training, continuous inspection, preparation of a social station for people working on the plantation (possibility of washing hands, eating meals, short rest), control of the cleanliness of the lupines, bulk packaging, auditing the plantation
III storage of blueberries	inadequate air humidity, improper temperature cooling, and storage of fruit in the cold room (higher than the recommended 4°C), including during weighing and packing	deterioration of color, firmness, turgor, nutritional value of berries, the appearance of storage diseases (gray mold, anthracnose), drying of the fruit	9/9	improper cooling parameters of berries, failure to maintain hygienic conditions	3/4	record of cooling conditions	3/4	81/108	continuous control of temperature, humidity, and cleanliness of fruit storage

Table 1/Tabela 1, cont./cd.

1	2	3	4	5	6	7	8	9	10
IV packaging	packaging is not new and clean, incomplete product information on the label, improper packaging, inadequate weighing equipment, weighing errors	microbiological risk, misleading the customer	9/9	improper parameter setting of the packaging machine, failure to maintain hygienic conditions	4/4	control of the operation of the packaging machine	1/1	36/36	calibration of the packaging machine, inspection of personal hygiene of persons packing berries manually
V transport to the final customer	improper means of transportation, failure to ensure refrigeration temperature	deterioration of quality and shortening of storage life of packaged berries	9/9	Inappropriate cooling parameters, failure to maintain the cold chain after fruit harvest, picking, sorting, storage, and transport to the final customer, microbiological risk, weight loss, reduction of storage life	4/4	control of temperature and humidity in transport, control of transport time	2/2	72/72	continuous temperature control, proper handling of packaged fruit

Source/Źródło: authors' own study/badania własne.

Table 2. Priority indicators P from the largest to the smallest value for plantation one and plantation two
Tabela 2. Wskaźniki priorytetu P, uporządkowane od wartości największej do najmniejszej, dla plantacji pierwszej i plantacji drugiej

Indices of priority P for plantation one	Indices of priority P for plantation two
I a choice of location for blueberry cultivation 147	I e cutting and shaping of shrubs, mulching (peat, bark, sawdust) 162
I g fertilization and protection against diseases and pests 126	I g fertilization and protection against diseases and pests 126
I e cutting and shaping of shrubs, mulching (peat, bark, sawdust)	I a blueberry site selection 112
I h protection from wild birds 112	I d irrigation of plantations-quality of water 112
I c irrigation of plantations 84	I c irrigation of plantations 108
I d irrigation of plantations-quality of water 84	III storage of blueberries 108
III storage of blueberries 81	I f mulching 72
V transport to the final customer 72	V transport to the final customer 72
II blueberry harvesting and transportation 72	I b choice of blueberry varieties 60
I b choice of blueberry varieties 64	I h protection from wild birds 56
I f mulching 56	II blueberry harvesting and transportation 56
IV packaging	IV packaging

Source/Źródło: authors' own study/badania własne.

Significant differences were found in the assessment of plantation risk from wild birds in the two plantations (112 versus 56). This is related to the location of the plantation. On reaching the fruit's harvesting capacity and the possible foraging of wild birds, the animals leave the plantation and forage elsewhere. The second plantation has not yet decided to use nets to protect against wild birds and weather conditions due to the reduced profitability of production in recent years. However, a necessary task to be carried out in the next production year will be installing a shrub support structure to reduce the area of the bushes and prevent the shoots from breaking under the pressure of the fruit.

The remaining factors listed in Table 2 take values below 100. They are of lesser importance, however overall, they can affect the final quality of the final product.

Carrying out the recommended actions (Table 1) in the case of a risk factor taking values above 100, can change the ordering of factors affecting blueberry quality (Table 2). Conducting another FMEA-based plantation risk analysis is an improvement in plantation operation.

The risk index values should be adjusted through the recommended netting to reduce their size to an acceptable level.

4. Conclusion

The FMEA method is an effective tool for conducting a risk analysis of blueberry plantation operations.

Tracking potential risks and improving plantation operations is indispensable in minimizing risks to fruit/blueberry quality throughout the logistics chain. Mere knowledge of the factors determining product quality at both pre and post-harvest stages is insufficient. Identifying the factors that are most likely to decide about the risks to product quality is very important, as it allows, in the case of identified irregularities, to quickly take the necessary measures to minimize the risks.

As for the two plantations presented, it was found that measures should be taken to minimise the risks to the plantation, regarding ensuring proper fertilization and protection from diseases and pests (126).

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