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Hazelnut postharvest technology: A review

Tehnologija berbe, sušenja i skladištenja lješnjaka: Pregled literature

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ABSTRACT

In the Republic of Croatia, hazel (*Corylus avellana* L.) is the fruit species with the largest recorded increase in cultivation. Due to its high content of lipids and moisture (at the time of harvest) hazelnuts are susceptible to quality deterioration (rancidity development, mycotoxins contamination etc.) and therefore proper harvest and post-harvest handling is necessary to preserve their quality. Hazelnuts are most often collected from the ground by the appropriate mechanization. After harvesting, proper drying of is a crucial measure. Hazelnuts in the shell should be dried to about 7 - 10% moisture, and the kernel moisture content should be from about 4 - 6%. The maximum drying temperature should never exceed 50 °C. Regarding the storage conditions, the relative humidity is the most important factor and should never exceed 70%, while it is optimal to range from about 55 - 65%. Low temperatures (<10 °C) are effective means of prolonging hazelnut storage life because numerous negative processes (rancidity development, microbiological activity, etc.) are notably slowed down. The use of a modified atmosphere (low oxygen concentrations) has also shown to be an effective measure in prolonging storage life.

Keywords: hazel, *Corylus avellana*, hazelnut, storage, aflatoxins

SAŽETAK

U Republici Hrvatskoj lijeska (*Corylus avellana* L.) je voćna vrsta s najvećim zabilježenim porastom uzgoja. Zbog visokog sadržaja lipida i vlage (u trenutku berbe) lješnjaci su podložni kvarenju (razvoj užeglosti, kontaminacija mikotoksinima itd.) te je stoga pravilno provedena berba, sušenje i skladištenje nužno kako bi se očuvala njihova kvaliteta. Lješnjaci se najčešće skupljaju s tla pomoću odgovarajuće mehanizacije, a moguće ih je još otresati na platno ili brati sa stabla. Lješnjake u lupini je potrebno osušiti do oko 7 - 10% vlage, a sadržaj vlage u jezgri bi se trebao kretati od oko 4 - 6%. Tijekom sušenja maksimalna temperatura nikad ne bi smjela prelaziti 50 °C zbog razvoja užeglosti tijekom skladištenja. Od skladišnih uvjeta relativna vlažnost zraka je najbitnija te ona nikad ne bi trebala prelaziti 70%, a optimalno je da se kreće od oko 55 - 65%. Niske temperature (<10 °C) su učinkovito sredstvo za produljenje skladišne sposobnosti lješnjaka jer su brojni negativni procesi (razvoj užeglosti, mikrobiološka aktivnost itd.) značajno usporeni. Upotreba modificirane atmosfere (niske koncentracije kisika) se pokazala također učinkovitom mjerom u produljenju skladišne sposobnosti.

Ključne riječi: lijeska, *Corylus avellana*, lješnjak, čuvanje, aflatoksini

INTRODUCTION

Hazelnut, the fruit of the hazel (genus *Corylus*), due to its great nutritional and dietary value, a number of positive health effects on human health and great economic potential has recently experienced notable production increase (Koyuncu et al., 2005; Miljković, 2018a; Vujević et al., 2018; Şenol, 2019). Within the genus *Corylus*, the European hazel (*Corylus avellana* L.) is the main species of interest for nutritional uses (Silvestri et al., 2021), and can be grown on its own root or grafted on Turkish hazel (*Corylus colurna* L.) (Miljković and Jemrić, 1997). Hazelnut is a nut that has one seed in the wooden pericarp, and usually two to four nuts are wrapped in a common husk (Skendrović Babojelić and Fruk, 2016). The world's largest producer of hazelnuts in shell is Turkey (776,046.00 t), followed by Italy (98,530.00 t), Azerbaijan (53,793.00 t), USA (39,920.00 t), Chile (35,000.00 t), China (29,318.00 t), Georgia (24,000 t), Iran (16,121.00 t), Spain (12,370.00 t), etc. (FAOSTAT, 2019). In Southeast Europe, Serbia (4,949.00 t) has the highest recorded production of hazelnuts in the shell, followed by Croatia (1,960.00 t), while notably smaller have Bulgaria (430.00 t), Slovenia (250.00 t) and Romania (230.00 t) (FAOSTAT, 2019). In the Republic of Croatia hazel is a fruit species with a pronounced increase in cultivation (Vujević et al., 2018; Solina Međimurec et al, 2020). Most of the hazelnut production in the Republic of Croatia is located in the continental Croatia with an emphasis to the slopes of Papuk, Krndija and Bilogora; while notable plantations are also planted in Osiječko-baranjaska County and other areas (Vujević et al., 2018).

Hazelnut represents a nutrient-rich food due to its high content of fatty acids (with emphasis on unsaturated), proteins, amino acids, minerals, vitamins (B_1, B_6, niacin and alpha tocopherol), etc. (Koyuncu et al., 2005; Amaral et al., 2006a; Köksal et al., 2006; Oliveira et al., 2008). Due to the aforementioned chemical composition their positive impact on human health has been reported in numerous studies (Mercanlıgil ets al., 2007; Orem et al., 2013; Renzo et al., 2019). However, because of the high content of lipids and water (during harvest) hazelnuts (as well as other nut fruit species) are susceptible to spoilage which can lead to significant losses during storage (Bulatović, 1985; San-Martin et al., 2001; Miljković, 2018b; Turan, 2018a, 2019). Therefore, properly conducted harvest, fast post-harvest processing (especially drying) and satisfactory storage conditions are necessary for minimization of postharvest hazelnut losses (Massantini et al., 2009; Ghirardello et al., 2013; Turan, 2018a). Thanks to the continuous technology development new hazelnut storage methods have been invented that can contribute to their storage time extension and quality preservation. Although in the Republic of Croatia hazel is cultivated on relatively large area, growers still pay insufficient attention towards harvest and postharvest technology which can lead to high losses. Jemrić and Ilić (2012) stated that one of the main reasons for the high postharvest losses in the Republic of Croatia and Serbia is the lack of knowledge in the commercial practice. Therefore, the aim of this paper is to provide an overview of so far published studies on new technologies that can reduce hazelnut postharvest losses and, as well, to describe in detail harvest and all postharvest operations.

HAZELNUT QUALITY TRAITS

As Cristofori et al. (2008) assumed, nowadays due to the market expansion there has been an increase in competitiveness among hazelnut producers and in the importance of high quality products. Achieving satisfactory hazelnut quality traits is extremely important since acquired hazelnut price will to a significant extent depend on it (Zinnanti et al., 2019). In general, about 90% of the produced hazelnuts are destined for processing (Garrone and Vacchetti, 1994 cited in Cristofori et al., 2008, p.1091), which means that only about 10% is used for fresh consumption. Similarly Altundag (1989, cited in Özdemir and Devres, 1999, p.310) and Anonymous (1995 cited in Özdemir and Devres, 1999, p.310) state that of the total amount of produced hazelnut kernels, about 80% is used in chocolate manufacture, 15% in confectionery, biscuit, and pastry manufacture, and the other 5% are consumed without any further processing (fresh consumption). The main reasons for hazelnut usage are adding flavour and texture to various products (Özdemir and Devres, 1999; Ozdemir and Akinci, 2004; Köksal et al., 2006; Belviso et al., 2017). Butter and hazelnut oil are especially valued, while the oil is also high in demand in the pharmaceutical and cosmetic industry (Modic et al., 1975; Miljković, 2018b; Sun et al., 2022b). They can also be regularly consumed due to their health benefits (Köksal et al., 2006; Orem et al., 2013; Renzo et al., 2019). In the market hazelnuts can be categorized as those in which the shell is intact (in-shell hazelnuts or unshelled hazelnuts) and those in which the shell has been removed and only the kernel remains (kernels or shelled hazelnuts) (Özdemir and Devres, 1999; Ozdemir and Akinci, 2004). Hazelnut kernels can be further categorized as: natural, blanched and roasted or their products, such as sliced, chopped, flour, oil, roasted paste and hazelnut butter (Özdemir and Devres, 1999; Köksal et al., 2006). In the food industry shelled hazelnuts or hazelnut kernels are most often used (Ozdemir and Akinci, 2004). Quality parameters are most often viewed in relation to the first two main categories and are summarized in Table 1.

Since in the Table 1. only the most important hazelnut quality traits were listed, some factors need to be further emphasized and explained. The desired size depends on the intended hazelnut usage, so hazelnuts intended for the food industry should be small and medium (from 13 - 13.5 to about 17 mm in diameter), while for fresh consumption large hazelnut are preferred (diameter from 18, or even 16 mm) (Modic et al., 1975; Miljković, 2018b). The desired shape also depends on the ultimate hazelnut purpose. According to Modic et al. (1975) food industry hazelnut shape preferences are as follows (5 - most desirable shape, 1 - least desirable shape): round - 5, round - oval to oval - 4, slightly elongated or flattened - 3, elongated or flattened - 2, very elongated -1; while fresh consumption preferences are as follows: elongated to very long - 5, flattened and oval - 4, slightly oval to round - 3, very flattened - 2, elongated and very pointed - 1. According to İslam (2018) most markets mostly prefer round kernels, while long-shaped hazelnuts are consumed fresh. Fruit sphericity is also important because it affects how easily hazelnuts can be processed by the food industry, and spherical hazelnuts are preferred (Ozdemir and Akinci, 2004). Shell thickens also has certain importance, and in the food industry the fruits of thin to medium thin shell are preferred (Miljković, 2018b). Kernel/nut weight ratio is the main determinant of quality and price of hazelnuts (Liu et al., 2012). Modic et al. (1975) ranked kernel/nut weight ratio as follows (5 - most desirable, 1 - worst): > 49% - 5, 46 to 49% - 4, 43 to 46% -3, 40 to 43% - 2, <40% - 1. Mehlenbacher and Olsen (1997) stated that in the US for hazelnuts that have kernel/nut weight ratio above 50% a premium price is achieved. In addition to hazelnuts with satisfactory shell-kernel ratio, there are also those in which kernel fills shell poorly and there is a need further terminology clarification. Blank nuts describe a hazelnut shell that does not contain kernel or has an undeveloped kernel which according to Redpath (2016) fills less than 25% of the shell cavity, while according to Liu et al. (2012) and Olsen et al. (2013) less than 20%. Poorly filled nuts have kernels that fill more than 25% but less than 50% of the shell cavity (Redpath, 2016). Shrivelled kernels have wrinkling over more than 50% of the surface of the kernel, while shrunken nuts have sunken areas in the kernel. According to the same publication kernels with minor shrivelling or poor fill can be used for paste or oil provided the flesh is not tough and leathery (Redpath, 2016).

There are also some additional quality parameters that are important to the food industry and need to be taken into account. These include various texture attributes such as crispness and chewiness, which are according to Kader and Thompson (2002) influenced by the degree and uniformity of drying within and between nuts. Since the distribution of moisture in the raw material plays an important role during roasting (Fontana et al., 2014), homogeneous distribution of moisture can be considered as a positive quality trait. According to Giacosa et al. (2016) the instrumental joint mechanical-acoustic test can aid, in a future perspective, in the evaluation of instrumental-sensory correlations, particularly for the hazelnut kernel crispness-crunchiness perceptions assessment. The ease of kernel pellicle removal during the blanching and roasting is also appreciated in the confectionery industry

Table 1. Most important hazelnut quality parameters according to various sources (stated inside the table) and some minimal requirements in international trade defined by the United Nations Economic Commission for Europe (United Nations Economic Commission for Europe, 2007, 2010)

Part of the nut	Quality parameters and some minimal requirements	Sources
Shell	Cleanliness – absence of any foreign material, including insects (at any development stage) and the presence of mold (often begins to appear at the shell tips) and residues of adhered husk (maximally is allowed up to 5% of the total shell surface). The presence of foreign odors is also not allowed. Size – in accordance with the class defined by international criteria. It is determined on the basis of diameter, and is especially established for varieties of round and oblong fruits. Shape – well formed (not noticeably misshapen), for in-shell market round shape is preferred. Colour – it is desirable to be in accordance with variety characteristic. The presence of blemishes, colourless areas and stains that are in contrast with the rest of the shell surface is not allowed if they cover more than 25% of the surface. Moisture – without abnormal external moisture. Damages – without damage, including broken or detached (cracked) shells and other noticeable mechanical damage (slight superficial damage is not considered as a defect if the kernel is physically protected). The presence of bacterial blight scars is considered undesirable, but not an impermissible defect. Other defects – empty shells (kernel absence), brown stains on shell and other physiological diseases are not desirable.	Bulatović (1985); United Nations Economic Commission for Europe (2007); Kader (2013); Olsen (2013); Olsen et al. (2013); Fontana et al. (2014); Maness (2016); Redpath (2016);
Kernel	Cleanliness – absence of any foreign material (shells, stones, metals, etc.), live or dead insects (as well as their secretions) and mold. The presence of foreign odors and tastes is also not allowed. Size – in accordance with the class defined by international criteria, while market preferences depend on the kernel intended final destination. It is determined on the basis of diameter, and is especially established for varieties of round and oblong fruits. Shape – all underdeveloped and irregularly shaped kernels are undesirable, while in the shelled hazelnut market both rounded and oblong types are preferred. Colour – the presence of blemishes, colourless areas and stains that are in contrast with the rest of the kernel surface is not allowed if they cover more than 25% of the surface in total. The presence of brown or dark brown spots in the kernel cavity is not desirable, but is not considered impermissible if does not affect taste or smell. Kernel/nut ratio - kernel must fill more than 50% of the shell cavity. Pellicle – it should be smooth and without remnants of adhered shell. Moisture – total moisture content of in-shell hazelnuts must not exceed 12%, kernels of in-shell hazelnuts 7%, while shelled hazelnut kernels 6%. On the other hand, kernels with dried out or tough portions affecting more than 25% of the surface are to be excluded. Damages – without mechanical damage, including the absence of a part of the pellicle, scratch or cut (if they are less than 3 mm in diameter and 1.5 mm deep they are not considered as a defect), insect injuries, etc. However, pest damage caused by cimiciato is allowed, provided that there is only one spot on the kernel that does not exceed 3 mm in diameter by 3 mm in depth. Other defects and deterioration symptoms – shrivelled (usually due to moisture loss), rancid, rotten and mouldy kernels are not allowed.	Bulatović (1985); Kader (2013); United Nations Economic Commission for Europe (2010, 2007); Olsen et al. (2013); Fontana et al. (2014); Maness (2016); Redpath (2016);

(Silvestri et al., 2021), and is therefore considered as desirable attribute. It is also genetically determined, and our (Croatian) native variety ´Istarski duguljasti´ has very good ability of pellicle remove by blanching (Thompson et al., 1978). Kernel aroma and taste are of special importance (Miljković, 2018b). Sweetness, oiliness and roasted taste are generally among the positive taste attributes, while rancidity is a major poor quality factor of nut fruit (Kader and Thompson, 2002). In a study of the effect of hazelnut storage on oil oxidation Zhang et al. (2019) proposed that due to the existence of a significant negative correlation between linoleic acid content and oxidation indicators, linoleic acid could be used to evaluate the oxidation degree of hazelnut oil. For the same purpose they proposed volatile oxides, such as hexanal, 2-octenal, 2-decenal and 3-octene-2-one. Sun et al. (2022a) reported that 51 lipids were significantly different between fresh and oxidized hazelnut oil, which could be used as biomarkers to distinguish fresh and oxidized hazelnut oil. In accordance with the main quality traits hazelnuts are consequently classified into different classes. There are various ways for determination of hazelnut classes (e.g. depending on the country) and it would take up too much space to list them all. Some of them are listed in the following publications (Bulatović, 1985; Maness, 2016; Redpath, 2016). It should be noted that there is an international system for grading in-shell and shelled hazelnuts (United Nations Economic Commission for Europe, 2007, 2010).

HAZELNUT HARVEST

Harvest is an extremely delicate operation in hazelnut production because, as Wells (2013) states, the greatest risk of crop contamination theoretically comes with the harvest process. In addition, proper harvest time determination is necessary to maintain hazelnut high quality and safety during postharvest handling (Fontana et al., 2014). Considering the intended hazelnut usage, they can be harvested in two harvest periods: for the consumption of fresh hazelnuts when they are not fully ripe and at the time of their physiological maturity when they are used for storage and further processing. Moscettia et al. (2012) stated that harvest period of fresh hazelnuts (unripe) is defined as the stage in which hazelnuts are still on the tree when they have reached their full size, are not very firm and the seed (kernel) has begun detaching from the pericarp. Above mentioned authors also stated that the preliminary organoleptic analysis indicated that in agroecological conditions of central Italy the ´Tonda Gentile Romana´ hazelnuts harvested 8 weeks before physiological maturity (late July/early August) had the best quality level. However, hazelnuts are usually harvested when they are physiologically ripe, respectively when they are intended for longer storage and processing (which is discussed in this publication). In that case, hazelnuts are considered ripe when they will rattle inside the husk, indicating detachment of the nut from the base of the husk (Maness, 2016). Bulatović (1985) states that hazelnuts are ripe when they change colour to yellow-brown and when, in varieties where it is possible, easily fall out of the shell. Premature hazelnut harvest has a negative quality effect, which is reflected through the kernel shrivelling during the drying process, kernel toughness etc. (Bulatović, 1985; Fontana et al., 2014). In Turkey properly timed harvest of ´Tombul´ hazelnuts, in comparison with earlier harvest, caused an increase in yield from 46 to 58%, pellicle removal ability after roasting from 56 to 93% and reduction in the proportion of shrivelled kernels from 9.5 to about 1% (Cakirmelikoglu and Caliskan, 1993 cited in Özdemir and Devres, 1999, p.312). Miljković (2018b) emphasizes that the hazelnut harvest at the moment of their physiological maturity is of great importance because it reduces the oxidation of fatty acids (rancidity formation) and enables possibility for good and long storage. It is also essential for hazelnuts to be harvested immediately after they reach proper maturity in order to avoid quality reduction and to minimize potential fungi and insect problems (Kader and Thompson, 2002).

The most common hazelnut harvest methods include: early hand picking (picking from a tree), usage of canvas, plastic nets or some other material (placing material under hazel, shaking branches and picking nuts from material) and manual or mechanized harvest from the ground (with or without shaking) (Bulatović, 1985; Mehlenbacher and Olsen, 1997; Farinelli et al., 2001; Ozdemir and Akinci, 2004; Ozay et al., 2008; Olsen and Peachey, 2013; İslam, 2018; Miljković, 2018b; Turan, 2018a, 2018b). Early hand picking from the tree is most common for hazelnut cultivars in which husk is longer than the nut and is narrowed at the top, thus preventing nut from falling out of the husk when mature. In the Republic of Croatia, this harvest method is sometimes used for our native and most often cultivated variety 'Istarski duguljasti'. Also, smaller growers in the Republic of Croatia who do not own mechanization usually use this harvest method in order to prevent rodents and other animals that can cause notable damage after the fruits fall to the ground. Farinelli et al. (2001) stated that in this case harvest must be done before hazelnuts fall to the ground from the husk, but not too early because the fruits will be insufficiently ripe. The main drawback with this harvest method is the high labour cost, while others are: harvest of insufficiently mature hazelnuts and consequently higher moisture content and reduced quality, occurrence of mechanical damage due to picking nuts from the shoots, etc. Farinelli et al. (2001) also reported that hazelnuts harvested in this way have lower kernel/nut ratio and reduced polyphenol stability than those that fell naturally from the tree. The next harvest method is the utilization of canvas or tarpaulin, polyethylene net or some other material during harvest (Modic, 1985; Ozay et al., 2008; Miljković, 2018b). In that case a certain material is being developed under the hazel canopy and afterwards hazelnuts are shaken and collected from that material. Since hazelnuts do not ripen at the same time (Bulatović, 1985; Farinelli et al., 2001; Fontana et al., 2014; Miljković, 2018b), it is necessary to conduct harvest frequently in order to avoid their contact with the ground, but it is unquestionable that one proportion of them will end up on the ground. However, the great advantage of this method is in areas where access to mechanization is limited, so according to Miljković (2018b) this method is usually used there. The advantage of the first two methods, compared to the third, is notably lower foreign material contamination possibility, while the main disadvantage is decreased efficiency. Nearly all commercially harvested tree nuts are shaken from the tree or naturally fall to the ground where they are mechanically harvested directly from the ground surface and are then dumped into a harvest wagon (Wells, 2013). In recent years in Turkey this harvest method has on flat terrains become widespread (İslam, 2018). In addition to the mechanized ground harvest, it is also possible to collect hazelnuts by hand, but according to Bulatović (1985) it is applied only on small areas due to low efficiency. Machine efficiency amounts around 100 kg/hour according to Miljković (2018b) or from 120 to 500 kg/hour according to Modic (1985), while for comparison by means of manual harvest one worker can, according to Bulatović (1985), collect about 50 kg of hazelnuts in one day. On the other hand, manual hazelnut picking from the ground is still common in Turkey (Ozdemir and Akinci, 2004; İslam, 2018), and this is very likely due to cheap and available labour as well as the presence of large natural (wild) hazel population. The possibility of mechanical harvesting also depends on the hazel training system, and Mehlenbacher and Olsen (1997) state that in the United States (federal state Oregon) hazelnuts are mostly grown as the single-trunk tree to facilitate mechanical harvest. Proper soil preparation prior to harvest is crucial for mechanized harvest and insurance of good hazelnut quality. One of the main reasons is to avoid contamination with excessive amounts of foreign material (Kader and Thompson, 2002) and nut contamination with aflatoxins. Generally, it is recommended to try to avoid conditions that promote premature leaf fall (in order not to interfere with mechanized harvesting), which is the case in orchards that are deficient in potassium or due to water stress, frost damage and severe aphid infection (Olsen and Peachey, 2013). Prior to harvest soil must be free of weeds, firm and smooth (Olsen and Peachey, 2013; İslam, 2018), and satisfactorily firm and smooth soil will allow to adjust the height of the sweeper for maximum efficiency and consequently help minimize the amount of debris that ends up in the tote bins (Olsen and Peachey, 2013). Firstly, it is necessary to break the soil surface layer with a rotary cutter, and then level it with a roller (Bulatović, 1985; Modic, 1985). Although the soil needs to be kept as dry as possible to prevent the development of microorganisms that prefer a warm and humid environment (Wells, 2013), light rain before harvest can help reduce dust and harden the soil for harvest (Olsen and Peachey, 2013). Since blank nuts fall before the accurate ones, it is recommended that after their fall (and prior to fall of correct ones, usually before the end of August) growers do the final landscaping to fill small depressions in the soil (Olsen and Peachey, 2013) or perform one "pre-collection" to eliminate nuts with empty shells. The operation of the hazelnut vacuum harvester with long and flexible intake tubes of a diameter from 10 to 12 cm was described in detail by Modic (1985). Strong intake air steam is created by fans mounted on the trailer behind the tractor or are self-movable. Suction openings - tubes, which are manually directed over the hazelnuts on the floor, suck hazelnuts together with leaves, garbage and even small pieces of earth and sand. Due to the strong air flow, hazelnuts which are heavier fall into a special collection chamber while garbage and leaves are being removed (Modic, 1985). On the other hand, in the USA in the federal state of Oregon, mechanized hazelnut harvesting is done somewhat differently. Most growers have a sweeper with an attached leaf blower that moves the nuts away from the trees (into one or two windrows, each 0.6–1.2 m wide), while the other machine (harvester) picks up the row of nuts and places them in tote boxes (Mehlenbacher and Olsen, 1997; Olsen and Peachey, 2013). Since hazelnuts fall over a period of time (20 to 30 days) and due to variability of weather conditions, it is recommended to conduct harvest two or more times to avoid long stay of hazelnuts on the ground, which due to contamination and other processes can negatively affect quality (Bulatović, 1985; Farinelli et al., 2001; Massantini et al., 2009; Olsen and Peachey, 2013; Fontana et al., 2014; Miljković, 2018b). If hazelnuts are harvested twice, then the first harvest is done when 40 to 45% of the nuts have fallen to the ground, and the second at the end of physiological nut drop (Massantini et al., 2009). As only one step is not enough to remove all physical contaminations (stones, pieces of soil, pieces of wood, empty hazelnuts and generally foreign material), using cleaning equipment is recommended (Fontana et al., 2014). Olsen and Peachey (2013) state that in the USA (federal state of Oregon) in most years before October all of the hazelnuts will fall naturally, and if they do not rain and windy weather will bring down the last nuts, but also create muddy conditions. It is also similar in the agro-ecological conditions of Croatia. If hazelnuts are harvested with the husk then it needs to be removed after harvest (İslam, 2018).

For all harvest methods, harvest bins or wagons should be free of excess moisture and should not be used for transport of chemicals, fertilizers, toxic substances, or even debris from the orchard or cleaning plant (Wells, 2013). After the harvest begins, all steps (shaking, drying, transport, etc.) must be managed efficiently to ensure optimal fruit quality (Kader and Thompson, 2002). After the end of harvest all equipment should be cleaned and stored to protect from animal infestations and contamination with animal faeces (Wells, 2013). Nut reception from harvest is fundamentally a cleaning process (involving the use of high capacity machines processing about 1,000 kg/hour) and grading (according to cultivar and quality traits) (Tous, 2005). Afterwards, according to the same author, quality (based on the moisture content, kernel size, kernel/nut ratio and sometimes on the degree of mouldiness and rottenness) of the consignments is being determined and those receiving a negative evaluation are generally penalized.

HAZELNUT DRYING

The drying process must be started as soon as possible after harvest (within 24 hours) (Olsen and Raab, 2013; Turan, 2018a; Turan and İslam, 2018). Since hazelnuts at the time of harvest have higher water content, mostly in free form (high water activity) (San-Martin et al., 2001), drying of hazelnuts is a necessary measure to prevent processes related to quality reduction or fruit decay. Moisture content in hazelnuts during harvest is up to about 30% (Bulatović, 1985; López et al., 1997c; López et al., 1998; Turan, 2018a; Turan and İslam, 2018; Turan and Karaosmanoğlu, 2019). Miljković (2018b) states that hazelnuts, when climatic conditions are favourable during ripening, can contain less than 20% moisture. Enzymatic activity accelerates with increasing water activity, and undesirable hydrolase activity can lead to changes in texture, flavour, colour, and odor, resulting in undesirable quality traits, including spoilage (López et al., 1997a). Therefore, the main objective of drying hazelnuts is to inactivate the enzymes to avoid their degradation during storage, hence to increase their stability (López et al., 1997a; San-Martin et al., 2001). When hazelnuts are properly dried, they can be stored for a very long period with minimal changes (Ebraheim et al., 1994). In-shell hazelnuts should be dried to: 10-12% (Maness, 2016), 10% (Bulatović, 1985), 8-9% (San-Martin et al., 2001), 7-8% (López et al., 1997b; López et al., 1998), or about 7% moisture (Tous, 2005). The moisture content of the hazelnut kernel (in shelled hazelnuts) should amount from: 3.5 to 5% (Richardson, 1988 cited in Ghirardello et al., 2013, p.38), 4 to 5% (López et al., 1998), or according to Olsen and Raab (2013) should not exceed 5%, and according to Maness (2016) 6-7%. On the other hand, the moisture content should not be too low, because Ghirardello et al. (2013) state that too low moisture content in the hazelnut kernel leads to shrivelling, discoloration and rancidity occurrence. During the drying process various physicochemical changes occur in the fruit. Olsen and Raab (2013) state that kernel is firm at first, becomes spongy during the drying process and becomes firm again when approaching the dryness. According to the same authors, the internal colour of the kernel gradually changes from white to cream, starting at the outside.

Air temperature is one of the most important factor during the drying process since in long term it affects hazelnut quality during storage (non-enzymatic browning, degree of oxidation e.g. rancidity occurrence), as well as the drying rate (López et al., 1997c; López et al., 1998; Mousadoost et al., 2018). According to a study conducted by López et al. (1998), the drying rate of in-shell and shelled hazelnuts grows with temperature increase and in-shell hazelnuts dry more slowly due to slower moisture migration compared to the shelled ones. López et al. (1997a, 1997b) state that it is not recommended to dry hazelnuts at a temperature higher than 50 °C because lipid oxidation (formation of rancidity) and nonenzymatic browning increase with further temperature rise. The authors state that the optimal temperature for drying hazelnuts is between 40 and 50 °C, as lower temperatures require longer drying time, which is not compensated by the commercial product quality. Olsen and Raab (2013) state that the optimal drying temperature is from 35 to 40.6 °C. In Spain, Tous (2005) states a drying temperature of 40 °C, while in a studies conducted in Turkey Turan (2018a) and Turan (2019) dried hazelnuts at 45 and 50 °C. Based on a sensory analysis of hazelnuts conducted after 6 months of storage, Mousadoost et al. (2018) stated that consumers prefer in-shell and shelled hazelnuts dried at 50 °C compared to those dried at 40 or 60 °C.

Hazelnuts can be dried in different ways. Nowadays, hazelnuts are usually dried in large dryers with forced air circulation, i.e., when hazelnuts are exposed to the blasts of hot air (López et al., 1997c; Tous, 2005). The dryers can be constructed in different ways. Turan and Karaosmanoğlu (2019) described and illustrated a dryer in which drying is accomplished by the forced ventilation of hot air, which the heat-exchanger sends to the ventilator, which at the same time pushes it inside the body of the dryer. During drying, the hazelnuts are continuously mixed by means of a central Archimedean screw. The average drying time in large dryers, where the hazelnuts are exposed to hot air, depends on the drying temperature and it can take up to 48 hours at room temperature or to about 18 hours if the air is heated to 40 °C (Tous, 2005). Turan (2018a) reported that in a drier at a temperature of 45 °C it took for 23 hours to reduce the moisture content of in-shell hazelnuts from 27.25 to 8.10%. In Croatia some producers dry hazelnuts by room heating. Sun-drying is a drying method usually practised by smallholders because it can handle small quantities of hazelnuts and the method is cheap and simple (López et al., 1997c). This type of drying is still traditionally done in Turkey on concrete and/or grass ground (Turan, 2017 cited in Turan and Karaosmanoğlu, 2019, p.1). Modic (1985) states that when hazelnuts are dried in the sun, they should be spread on a clean and flat surface (cement or wooden floor) in a layer of 10 to 15 cm and stirred several times a day in order to evenly dry. At night, they should be covered with plastic material as a prevention from getting wet (dew) (Turan, 2018a). Sun drying requires a continuous period of dry and sunny weather, which after harvest is quite difficult to achieve, hence this drying method is only possible in areas with satisfactory ecological conditions (Modic, 1985; López et al., 1997c; Turan, 2018b; Turan and Islam, 2018; Turan and Karaosmanoğlu, 2019). Therefore, the average drying time cannot be accurately determined. Turan (2018a) reported that in Turkey it took 39 hours of sun drying (including the active drying time, i.e. from 8:00 a.m. to 8:00 pm) to reduce the in-shell hazelnut moisture content of from 27.25 to 7.89% (dried on concrete floor) and 9.11% (dried on grass floor), respectively. Also in Turkey, Turan (2019) reported that it took 156 and 165 of sun drying hours (including the active drying time, i.e., from 8:00 a.m. to 8:00 pm) were required to reduce the in-shell hazelnut moisture content from 28.36 to 8.73% (dried on a concrete floor) and 6.82% (dried on a grass floor), respectively. The main disadvantage of this drying method, besides the uncertainty of weather conditions, is the high labour cost and drying time (López et al., 1997c; Turan and Karaosmanoğlu, 2019). Therefore, this method cannot be practised by estates and medium-scale processors (López et al., 1997c). Smaller quantities of hazelnuts can also be dried in the warm air stream above a furnace or radiator, and then it takes 2 to 3 days to dry them (Olsen and Raab, 2013). Drying method can also affect the hazelnut storage efficiency. Hazelnuts dried in dryers, in comparison with those dried on concrete and grassy ground, exhibited better oxidative stability during 12 months of storage at ambient temperature (20-25 °C) and relative humidity from 70 to 80% (Turan, 2018a).

HAZELNUT STORAGE

Since the hazelnut marketing is generally distributed for a period of over one year after harvest, the role of storage conditions, due to their quality influence, is of extreme importance for both food industry and direct consumption (Ghirardello et al., 2013, 2014). Hazelnuts are mainly composed of lipids (about 64%) (Amaral et al., 2006a), and therefore one of the main storage objective is to prevent (or slow down) their oxidation (Fontana et al., 2014; Ghirardello et al., 2014). In hazelnuts, unsaturated fatty acids are predominant in relation to saturated fatty acids (ratio 13.1) (Köksal et al., 2006), which is the reason for their beneficial effect on human health (Garcia et al., 1994; Orem et al., 2013), but also makes them highly susceptible to oxidation (Koyuncu et al., 2005; Mousadoost et al., 2018). During hazelnut storage acidity, peroxide value and content of total saturated fatty acids increases, while total phenolic content, antioxidant capacity, content of total unsaturated fatty acids and unsaturated/saturated fatty acids ratio decreases (Ghirardello et al., 2013). In comprehensive lipidomics analysis of the lipids in hazelnut oil during storage Sun et al. (2022a) reported that after 24 storage days the content of triacylglycerol, diacylglycerol, phosphatidic acid, phosphatidylethanolamine, phosphatidylethanol, ceramide, and total lipids decreased significantly. Hydrolysis and oxidation of lipid fraction during the storage will result in undesirable odors and flavours, and in the reduction of the nutritional value of the kernels (Ghirardello et al. 2014). Secondary oxidation products (such as peroxides and free lipid radicals) can react with proteins and vitamins and cause nutrient losses (San-Martin et al., 2001). Therefore, the exceptional importance of proper storage of hazelnuts is evident. Hazelnuts can be stored as in-shell or shelled (Fontana et al., 2014). Hazelnut kernels are more difficult to preserve due to her inherent softness and fragility (Mousadoost et al., 2018). San-Martin et al. (2001) reported that hazelnut shell is effective mean in protecting kernel against lipid oxidation, i.e. rancidity (provided they are stored at low temperatures). Hence, it is recommended to remove the shell only prior to their commercial utilization.

During hazelnut storage, humidity and then temperature present crucial parameters (San-Martin et al., 2001; Ghirardello et al., 2013, 2014). Since hazelnuts have low moisture content, unlike most of other commercial fruits, control of moisture content is necessary. In humid storage facilities, hazelnuts quickly decay and become moldy, while at too low humidity levels they dry out, lose weight and quality (Bulatović, 1985). During storage relative humidity should never exceed 70% (Tombesi, 1985 cited in Ghirardello et al., 2013, p.38), while Redpath (2016) recommends storage at humidity levels lower than 65%. Massantini et al. (2009) states that producers in Italy mainly store hazelnuts at a relative humidity from 60 to 70%, while Mumelaš and Gobec (1985) recommend from 50 to 60%. Moscetti et al. (2012) stored hazelnuts harvested for fresh consumption (which are not physiologically ripe) at a relative humidity of 80%.

Since many negative processes are associated not only with high humidity but also with temperature, temperature also presents an important parameter in the storage of hazelnuts. Enzymatic and chemical rancidification processes, and vitamin E degradation, are considerably retarded at low temperature, while mold and insect activity is virtually eliminated near freezing temperatures (Ghirardello et al., 2013). According to Gvozdenović and Davidović (1990), the recommended storage temperature for hazelnuts is between 0 and 5 °C, while according to Mumelaš and Gobec (1985) between 5 and 10 °C. Maness (2016) states that if temperature is below 10 °C than in-shell hazelnuts can be stored up to 24 months with minimal quality reduction. Fontana et al. (2014) recommend storing shelled hazelnuts at a temperature of 5 °C and a relative humidity of 60%. Ghirardello et al. (2013) reported that when shelled hazelnuts were stored at 4 °C and 55% of relative humidity, their quality was maintained for up to one year. Ebraheim et al. (1994) reported that during two-year storage of shelled hazelnuts, the peroxide content was highest in hazelnuts stored at 10 °C, followed by 5 °C and lowest at 0 °C. Maness (2016) states that roasted hazelnuts can be stored at 0, 5, or 10 °C for up to 6 months before development of noticeable rancidity symptoms. Although low temperatures are recognized as effective means of prolonging hazelnut storage time, usually the nuts are stored at ambient temperature because of the high energy cost for refrigeration (Ghirardello et al., 2013). This type of storage is still common in Turkey (Turan, 2017 cited in Turan and Karaosmanoğlu, 2019, p.1), as well as in the Republic of Croatia, especially among small producers. Since hazelnut storage at room temperature is not as adequate as at low temperatures, special care must be taken to ensure that other storage factors are satisfactory. In Italy, this type of storage is applied during the winter period, but at adequate humidity (60-70%) and in a ventilated environment (Massantini et al., 2009). It has been reported that in-shell hazelnuts can be stored at room temperature up to 8 months (Ghirardello et al., 2013). Mousadoost et al. (2018) state that if the ambient temperature does not exceed 21 °C in-shell hazelnuts can be stored up to one year without any change in flavour quality, provided that if they are kept in silos, their ventilation must be perfect and constantly controlled.

Recently, the storage of hazelnuts in controlled atmosphere has been intensively researched. Hazelnuts can be stored prolonged periods of time at ambient temperature under nitrogen (2: 99.5kPa) with a loss of quality that is comparable to that resulting from storage conditions at low temperatures and controlled relative humidity (3 - 6 °C, 50 - 60% relative humidity) (Keme et al., 1983 cited in Johnson et al., 2009, p.521). San-Martin et al. (2001) studied the quality of in-shell and shelled hazelnuts after storage in modified atmosphere with different oxygen concentrations (1, 5, 10 and 20%) and two different temperatures (7 and 25 °C). After one year of storage neither treatment exhibited significant rancidity development in hazelnuts. However, it was confirmed that at oxygen concentrations below 10%, autoxidation was reduced. Ghirardello et al. (2014, 2013) reported that shelled hazelnuts had significantly lower acidity and peroxide values after 12 months of storage at 4 °C in a controlled atmosphere (1% oxygen, 99% nitrogen) than those stored under the same conditions but in a normal atmosphere. Ghirardello et al. (2013) also reported that lower oxygen levels had a positive effect on the long-term storage of roasted kernels. In an atmosphere with almost 100% of nitrogen shelled hazelnuts can be stored for up to two years if their water content is less than 10% (Gvozdenović and Davidović, 1990). Silvestri et al. (2021) conclude that lower temperatures with oxygen concentration below 10% are the best solution for postponement of the rancidity occurrence. In addition to the storage of standardly harvested hazelnuts, Moscettia et al. (2012) studied the storage of hazelnuts harvested for fresh consumption (not physiologically ripe) at 4 and 10 °C and relative humidity of 80% with normal atmosphere and under the same conditions but with two different modified atmospheres: 100 ± 1 kPa CO_2 and 100 ± 1 kPa N_2. Based on measurements and organoleptic analysis after 12 days, hazelnuts stored in normal atmosphere were inferior to those stored in modified atmosphere (except for a slight aroma loss). The storage temperature of 4°C (compared to 10 °C) proved to be the best for all treatments. A possible satisfactory alternative to modified atmosphere storage is storage for up to 8 days in normal atmosphere at 4 °C. Belviso et al. (2017) recommended the storage time of six months at 4 °C of roasted hazelnuts placed in non-permeable polypropylene/aluminium/polyethylene bags under vacuum for the maintenance of a high antioxidant capacity.

Light, along with temperature, humidity and oxygen availability, is also a very important factor in maintaining quality during storage. Light, depending on its intensity, wavelength, duration of exposure, absorbability of the product, presence of senitizers, temperature, and amount of available oxygen may induce oxidative rancidity (Özdemir and Devres, 1999). Odor is the next very important factor, because according to Bulatović (1985) hazelnuts can absorb smell very easily and therefore are not stored in the same rooms as other products (fresh fruit, onions, etc.). In practice, to meet all the above conditions, hazelnuts can be successfully stored in silos or storage facilities of the classical type. Mumelaš and Gobec (1985) state that hazelnut storage in steel or concrete silos is the most suitable since nuts are protected from mechanical damage and monitor of storage parameters with a precise measuring system is ensured. In traditional warehouses, hazelnuts can be packed in jute (through which air can circulate) or polyethylene bags, or be scattered (Modic, 1985; Ozay et al., 2008; İslam, 2018; Turan, 2018a, 2019; Turan and Islam, 2018; Turan and Karaosmanoğlu, 2019). Manufacturers can also store hazelnuts in net bags. Hazelnut bags are stacked on pallets, and the stacking must be done clearly, sorted by variety and calibration and with sufficient amount of space for passage between pallets (Mumelaš and Gobec, 1985). It should also be mentioned that currently there is an ongoing development of postharvest hazelnut treatments. Güler et al. (2017) reported that hazelnuts exposed to gamma radiation of 0.5 kGy had quite good quality after storage (based on the content of free fatty acids, peroxides and vitamin e) and hence recommend this treatment compared to other with 1 and 1.5 kGy.

FINAL PROCEDURES BEFORE HAZELNUT COMMERCIALIZATION OR USAGE

If hazelnuts are to be commercialized or used as a kernel, it is necessary to approach shelling. After calibration, the separation of the shell from the kernel is done by machines that crush the shell on rotating plates with special serrations, between which the hazelnut passes (Mumelaš and Gobec, 1985). The shelling operation leads to damaged, broken and hidden-damaged kernels due mechanical forces applied to the nut during the shelling operation (Özdemir, 1999). As the hazelnut skin protects the hazelnut oil from oxidation, mechanical damage during cracking has to be averted (Fontana et al., 2014). The percentage of the damage depends on the mechanical force applied to the hazelnut, rotational speed of the cracker, thickness of shell and shape of the hazelnuts, number of sizing grades and efficiency of sizing (Özdemir and Özilgen, 1997). Therefore, proper calibration of the hazelnuts is extremely important so that the shelling machine can remove the shell with as little damage as possible, and Fontana et al. (2014) recommend that it should be conducted at 0.5 mm. The separation of the shell from the kernel is done in a pneumatic rotary cleaning device, where the shell, which has a lower specific mass, is carried away by air currents (Mumelaš and Gobec, 1985). Damaged and broken kernels, and any remaining unbroken nuts are usually separated by hand picking (Özdemir, 1999). The advantage of manual sorting is low initial costs and high efficiency without false waste (which can be about 5-10% in machine sorting), while the advantage of machine sorting is high production rate (up to 6 t/hour) and consistent rate of efficacy (Fontana et al., 2014). Today, most European processors use integrated mechanical and manual sorting (Fontana et al., 2014). Hazelnuts are also often subjected to heat treatment (mainly roasting) mainly to promote flavour and texture, which will ultimately improve the overall taste of the product (Özdemir et al., 2001; Saklar et al., 2001; Amaral et al., 2006b). In fact, during the roasting of hazelnuts, a complex mixture of more than 20 different substances is formed (Saklar et al., 2001).

After shelling and sorting by size, diameter, and health safety, hazelnuts are packed in bags or smaller packages (Modic, 1985). The choice of packaging also has a notable impact on maintaining the quality of hazelnuts (shelf life), since packaging material influences internal conditions (gas composition, humidity and light availability), which are important for the stability of the product. Dark cellophane packaging successfully protects the product from light-induced rancidity (Bulatović, 1985). According to the same author, the best results were obtained with thin parchment paper, because then the light has no effect on the oil changes in the kernel. In addition to the above mentioned conditions for optimal shelf life insurance, according to Özdemir and Devres (1999) control of the oxygen content in the packaging is also crucial, since many changes depend on the redox potential and the available oxygen in the packaging. This can be ensured by vacuum packaging.

ALFATOXINS IN HAZELNUTS

Nowadays in the global market, special attention is dedicated to safety of food of plant and animal origin. Among the various contaminants of plant products, during last 30 years special attention has been paid to mycotoxins (Kuiper-Goodman, 2004; Reddy et al., 2010; Marin et al., 2013). Hazelnuts, as well as fruit of some other fruit nut species, are considered a suitable substrate for mycotoxin production (Sanchis et al., 1988; Ozay et al., 2008; Battilani, 2010). Among mycotoxins that contaminate hazelnuts, aflatoxins are considered the most common and the most health-hazardous (Reddy et al., 2010; Marín and Ramos, 2016; EFSA CONTAM Panel et al., 2020). Aflatoxins are secondary metabolites produced by fungi of the genus *Aspergillus*, section *Flavi* (Cary and Ehrlich, 2006), out of which the most important are *Aspergillus flavus* and *A. parasiticus* (Yu et al., 2004; Klich, 2007; EFSA CONTAM Panel et al., 2020). Aflatoxins are among the most potent mycotoxins, are responsible for acute and chronic aflatoxicosis, and show severe teratogenic, mutagenic and carcinogenic effects in humans and warm-blooded animals (Marin et al., 2013; Peraica et al., 2014; Šapina et al., 2014; EFSA CONTAM Panel et al., 2020). Due to their potential effect on human health, in many countries the maximum permitted aflatoxins level in plant products is regulated. In the European Union, aflatoxins are regulated by Commission Regulation (EC) 1881/2006 from 19 December 2006 setting maximum levels for certain contaminants in foodstuffs (Commission Regulation (EC) 1881/2006). According to the mentioned regulation, the maximum permitted amount of aflatoxin B_1 in "nuts to be subjected to sorting, or other physical treatment, before human consumption or use as an ingredient in foodstuffs" is 5.0 µg/kg, and in "nuts and processed products thereof, intended for direct human consumption or use as an ingredient in foodstuffs" is 2.0 µg/kg. In both categories maximum tolerable sum levels of aflatoxins B_1, B_2, G_1 and G_2 are also defined.

Regulation and control of the maximum permitted aflatoxins levels in hazelnuts can have a notable impact on hazelnut exports for certain countries. For example, due to the relatively frequent interceptions of these mycotoxins in exceeded maximum permitted levels, the European Union has set more frequent controls on hazelnuts and hazelnut products imports from Turkey, Georgia and Azerbaijan (Commission Implementing Regulation (EU) 2019/1793). Such stricter controls on imports into the EU are regulated by Commission implementing Regulation (EU) 2019/1793 of 22 October 2019 on the temporary increase of official controls and emergency measures governing the entry into the Union of certain goods from certain third countries. Turkey, as one of the world's largest hazelnut producer, systematically invests in risk reduction and control of the aflatoxins presence in hazelnuts and hazelnut products. This problem is approached in a planned, systematic and institutional manner (European Commission, 2008).

The presence of mycotoxins on plant products depends on the presence of toxigenic fungi ("molds") on them. Colonization and toxigenic activity of *Aspergillus* species on hazelnuts depend on a number of factors (Klich, 2007; Yu, 2012; Marín and Ramos, 2016; EFSA CONTAM Panel et al., 2020). *Aspergillus* species are not pathogenic to hazelnuts and do not cause symptoms on fruit in the form of necrosis, lesions or rot. The most important aflatoxins producers, *Aspergillus flavus* and *A. parasiticus*, are cosmopolitan saprophytic species naturally living and persisting in the soil, on the soil surface and on the surface of plant organs (Cary and Ehrlich, 2006; Klich, 2007; Battilani, 2010). Colonization of hazelnuts by these fungi occurs during the vegetation period, but primarily in the period prior and during the harvest (Ozay et al., 2008). Such contaminated hazelnuts can be transferred into storage facilities. In a study conducted in Turkey, Gürses (2006) identified species *Aspergillus flavus* in all nine out of 28 analysed hazelnut samples containing aflatoxins. During three-year study, Ozay et al. (2008) found the presence of *A. flavus* and *A. parasiticus* in 47 - 79% of hazelnut samples from 72 orchards in different areas of Turkey. In another study from Turkey, fungi of the genus *Aspergillus* were dominant among fungi found on raw and roasted hazelnuts and accounted for 45–80% of all fungal isolates (Keskin and Gursoy, 2019). Relatively frequent presence of *Aspergillus* species on hazelnuts has also been confirmed in studies carried out in other countries, such as the USA (Pscheidt et al., 2019), Egypt (Abdel-Hafez and Saber, 1993), Iran (Khosravi et al., 2007) or Saudi Arabia (Abdel-Gawad and Zohri, 1993). On the other hand, toxic *Aspergillus* species in certain hazelnut cultivation areas in the world may not be present, or the conditions for their development and fruit colonization are not favourable. *Aspergillus flavus* and *A. parasiticus* are thermophilic fungi and as mycotoxin producers may present a problem in cultivation of some crops in areas with tropical, subtropical or Mediterranean climate (Kuiper-Goodman, 2004; Xu et al., 2011; Marin et al., 2013). In this context, Magan et al. (2011) and Medina et al. (2014) pointed out that global warming could lead to more intense aflatoxins occurrence in areas where these contaminants have not been common so far. In addition to the presence of toxigenic *Aspergillus* species, strains and isolates, the production of aflatoxins on hazelnuts is also influenced by many other factors. Aflatoxin production is very complex, and is conditioned by numerous interactions between substrate, toxigenic fungus and the environment (Battilani, 2010; Marin et al., 2013; EFSA CONTAM Panel et al., 2020). The presence and the content of aflatoxins in hazelnuts are primarily influenced by strains (isolates) of *Aspergillus* species present on fruits (Yu, 2012; Ortega et al., 2020), moisture (Marín and Ramos, 2016; Pscheidt et al., 2019; Valente et al., 2020), temperature (Sanchis et al., 1988; Marín and Ramos, 2016) and storage duration (Magan and Aldred, 2007). Variation in aflatoxin levels found in hazelnut and hazelnut product samples is evident in different studies. Analysis of hazelnuts from Italian stores revealed that 35 of 93 hazelnut samples were contaminated by aflatoxins, with a higher percentage of contaminated nuts originating from Turkey than from Italy (Prelle et al., 2012). Kabak (2016) determined aflatoxins in 12% of raw hazelnut samples with the content ranging from 0.09 to 11.3 µg/kg. Baltaci et al. (2012) reported that aflatoxin content in raw hazelnuts ranged between 0.02 and 78.98 µg/kg, while Gürses (2006) reported levels between 1 and 113 µg/kg. Shapina et al. (2014) demonstrated a notable variability in aflatoxin content in hazelnut samples collected on the Croatian market, with three of the 19 samples containing amounts of more than 4 µg/kg.

The variability of factors influencing aflatoxin production makes contamination control measures relatively difficult to conduct (Kuiper-Goodman, 2004; Magan and Aldred, 2007; Ozay et al., 2008). Nevertheless, certain important findings and some scientific evidence can provide appropriate guidelines to the manufacturers. The production of aflatoxins is directly related to the development of toxigenic *Aspergillus* species on fruit, for which optimal development conditions are temperature from 25 to 30 °C and relative humidity from 97 to 99%

(Klich, 2007; Yu, 2012). The first step in preventing aflatoxin contamination is the prevention of fruit colonization by *Aspergillus* species. As noted, the critical period for hazelnuts contamination with aflatoxins is the period prior and during the harvest (Ozay et al., 2008). As hazelnut harvest usually involves gathering nuts from the ground, it is advisable to keep the ground as dry as possible. It is reported that soil moisture and the contact period of hazelnuts with the soil are directly related to the fungal colonization and contamination levels of nuts (Ozay et al., 2008; Pscheidt et al., 2019). In a three-year study, Ozay et al. (2008) reported that the orchard, environmental moisture and temperature conditions, season and hazelnut drying method did not have a significant impact on aflatoxin content. The only significant difference was found between nuts that were in contact with the soil and those that were not. Significant differences in fungal colonization of hazelnuts on moist and on dried soil were also confirmed by Pscheidt et al. (2019). Therefore, nut contact with the soil should be reduced to a minimum during the harvest. Another crucial measure in risk management of aflatoxin contamination is rapid and efficient nut drying and their storage in dry conditions. As mentioned, toxigenic *Aspergillus* species require moisture for their development on fruits. Rapid hazelnut drying to 6% moisture and their storage in dry conditions reduce, or prevent the development of fungi on them (Magan and Aldred, 2007; Ozay et al., 2008; Fontana et al., 2014). In a study conducted by Valente et al. (2020), the effect of five different drying temperatures on the development of *A. flavus* and aflatoxin production on artificially inoculated hazelnuts was studied. Aflatoxin was formed when drying temperatures were 30 and 35 °C, while *A. flavus* developed even when drying temperature was 40 °C. Fungal development was significantly lower, and aflatoxins were not formed after drying at 45 and 50 °C. The authors recommended a temperature of 45 °C as the minimal for drying hazelnuts. In Turkey, Ozay et al. (2008) recommended that during the harvest and drying period hazelnuts are to be collected in jute instead of nylon bags. In jute bags the airiness is better, which can affect fungal development on fruit. Except during the harvest and sorting period, the effect of moisture on aflatoxin production may be also significant during the storage (Magan and Aldred, 2007). Gurses et al. (2001) reported notably lower aflatoxin contamination on hazelnuts stored at 85% of relative humidity compared to those stored at 95% of relative humidity. Similar significant effect of moisture on hazelnut aflatoxin levels during the storage was reported by Sanchis et al. (1988). Hazelnut storage facilities should be dry, and it would be preferable to store them in controlled atmosphere in order to preserve all quality traits. The third measure in preventing aflatoxin contamination would be the efficient nut sorting before storage, which separates damaged fruits and nuts contaminated by fungi ("moldy" fruits). In the study of Şen (2021), whole and visually intact hazelnuts contained aflatoxins only in traces, while those "moldy" contained levels up to 433 μg/kg. Indirectly, any measure taken during the vegetation period intended for prevention of hazelnut damage, such as pest and disease control, may have an effect on aflatoxin contamination (Fontana et al., 2014).

In addition to preventive measures aiming to reduce aflatoxin occurrence and development, the possibilities of detoxification and removal of mycotoxins on plant products are being intensively investigated nowadays. On hazelnuts, very good aflatoxin detoxification results have been achieved by treatment with “cold atmospheric plasma”, an ionizing mixture of nitrogen and hydrogen under voltage (Siciliano et al., 2016; Sen et al., 2019). Ozone treatment proved to be effective in reduction of aflatoxins content in peanut seeds (Proctor et al., 2004), and the similar has been achieved in hazelnuts by gamma radiation (Sen et al., 2019). There is a rapid development of new technology which could efficiently reduce, or eliminate, aflatoxin occurrence by using environmentally and economically acceptable methods. Such technologies will certainly gradually find an application in practice, and may present a major step in solving the problem of mycotoxin food contamination.

CONCLUSION

Since hazel is being increasingly cultivated in the Republic of Croatia, and the world is paying more attention to the health safety and quality of nuts, producers are forced to master technologies related to harvest and post-harvest procedures. Throughout this process, adequately timed harvest, proper drying, satisfactory storage conditions and prevention procedures related to the mycotoxin contamination are necessary to achieve (maintain) satisfactory hazelnut quality. Recently, new methods have been invented that contribute to the better hazelnut quality preservation, e.g. storage in controlled atmosphere or application of new technologies for mycotoxins reduction, which will notably contribute hazelnut quality insurance, provided they are cost-effective.

Tehnologija berbe, sušenja i skladištenja lješnjaka: Pregled literature

UVOD

Lješnjak, plod lijeske (rod *Corylus*), zbog velike hranjive i dijetne vrijednosti, niza pozitivnih zdravstvenih utjecaja na ljudsko zdravlje te velikog ekonomskog potencijala se u posljednje vrijeme sve više proizvodi (Koyuncu et al., 2005; Miljković, 2018a; Vujević et al., 2018; Şenol, 2019). Unutar roda *Corylus*, europska lijeska (*Corylus avellana* L.) je glavna vrsta od interesa za prehrambene potrebe (Silvestri et al., 2021), a može se uzgajati na vlastitom korijenu ili na podlozi medvjeđoj lijesci (*Corylus colurna* L.) (Miljković i Jemrić, 1997). Plod lijeske je orah koji u drvenastom usplođu ima jednu sjemenku, a obično su po dva do četiri ploda obavijena zajedničkim ovojem (kupola ili komušina) (Skendrović Babojelić i Fruk, 2016). Najveći svjetski proizvođač lješnjaka u lupini je Turska (776.046,00 t), nakon čega slijedi Italija (98.530,00 t), Azerbajdžan (53.793,00 t), SAD (39.920,00 t), Čile (35.000,00 t), Kina (29.318,00 t), Gruzija (24.000 t), Iran (16.121,00 t), Španjolska (12.370,00 t) itd. (FAOSTAT, 2019). U jugoistočnoj Europi Srbija (4.949,00 t) ima najveću zabilježenu proizvodnju lješnjaka u lupini, nakon čega slijedi Hrvatska (1.960,00 t), a značajno manje imaju Bugarska (430,00 t), Slovenija (250,00 t) i Rumunjska (230,00 t) (FAOSTAT, 2019). U Republici Hrvatskoj lijeska je voćna vrsta s izrazito izraženim porastom uzgoja (Vujević et al., 2018; Solina Međimurec et al, 2020). Većina proizvodnje u Republici Hrvatskoj je smještena na području kontinentalne Hrvatske s naglaskom na obronke Papuka, Krndije i Bilogore; a podignuti su značajniji nasadi i u Osječko – baranjskoj županiji te drugim predjelima (Vujević et al., 2018).

Plod lijeske predstavlja nutritivno bogatu hranu, uslijed velikog sadržaja masnih kiselina (sa naglaskom na nezasićene), bjelančevina, amino kiselinama, mineralnih tvari, vitaminima (B_1, B_6, niacin i alfa tokoferol) itd. (Koyuncu et al., 2005; Amaral et al., 2006a; Köksal et al., 2006; Oliveira et al., 2008). Uslijed navedenog kemijskog sastava, pozitivan utjecaj lješnjaka na ljudsko zdravlje je zabilježen u brojnim istraživanjima (MercanlIgil ets al., 2007; Orem et al., 2013; Renzo et al., 2019). Međutim zbog visokog sadržaja lipida te vode (za vrijeme berbe) lješnjaci (kao i plodovi ostalih lupinastih voćnih vrsta) su podložni kvarenju što može dovesti do značajnih gubitaka tijekom skladištenja (Bulatović, 1985; San-Martin et al., 2001; Miljković, 2018b; Turan, 2018a, 2019). Stoga pravilno provedena berba, brza obrada nakon berbe (posebno sušenje) kao i zadovoljavajući uvjeti tijekom skladištenja su nužni ukoliko se žele minimizirati gubitci lješnjaka nakon berbe (Massantini et al., 2009; Ghirardello et al., 2013; Turan, 2018a). S razvojem tehnologije dolazi do novih metoda čuvanja lješnjaka, koji potencijalno mogu produžiti mogućnost njegovog skladištenja i bolje očuvati njegove karakteristike. Iako u Republici Hrvatskoj ima relativno dosta površina pod lijeskom, nedovoljno se pažnje posvećuje tehnologiji berbe i čuvanja lješnjaka nakon berbe, zbog čega mogu nastati visoki gubitci. Jemrić i Ilić (2012) navode da je jedan od glavnih razloga nastanka velikih gubitaka plodova nakon berbe u Republici Hrvatskoj i Srbiji nedovoljna količine znanja u komercijalnoj praksi. Stoga cilj ovog rada je dati pregled dosadašnjih istraživanja o novim tehnologijama koje mogu reducirati gubitke lješnjaka nakon berbe, kao i detaljno opisati berbu i sve operacije koje slijede nakon berbe.

PARAMETRI KAKVOĆE LJEŠNJAKA

Kao što su pretpostavili Cristofori et al. (2008), u današnje vrijeme je uslijed širenja tržišta došlo do povećanja kompetitivnosti među proizvođačima lješnjaka te značaja proizvoda visoke kakvoće. Postizanje zadovoljavajućih parametara kakvoće lješnjaka je iznimno bitno jer će o njima u značajnoj mjeri ovisiti postignuta cijena lješnjaka (Zinnanti et al., 2019). Generalno oko 90% proizvedenih lješnjaka se koristi u prerađivačkoj industriji (Garrone i Vacchetti, 1994 citiran u Cristofori et al., 2008, p.1091), što znači da svega oko 10% otpada na stolnu potrošnju. Slično Altundag (1989, citiran u Özdemir & Devres, 1999, p.310) i Anonymous (1995 citiran u Özdemir & Devres, 1999, p.310) navode da od ukupne proizvedene količine jezgre lješnjaka oko 80% se koristi u čokoladnoj prerađivačkoj industriji, 15% u slastičarstvu, proizvodnji biskvita i kolača, a ostalih 5% se konzumira bez ikakve prerade (stolna potrošnja). Glavni razlog korištenja lješnjaka je u svrhu dodavanja okusa i teksture raznim proizvodima (Özdemir i Devres, 1999; Ozdemir i Akinci, 2004; Köksal et al., 2006; Belviso et al., 2017). Osobito su cijenjeni i maslac i ulje od lješnjaka, a ulje je veoma traženo i u farmaceutskoj i kozmetičkoj industriji (Modic et al., 1975; Miljković, 2018b; Sun et al., 2022b). Također se mogu regularno konzumirati zbog njihovog pozitivnog učinka na zdravlje (Köksal et al., 2006; Orem et al., 2013; Renzo et al., 2019). Lješnjaci se na tržištu mogu kategorizirati kao oni kod kojih je lupina netaknuta (lješnjaci u lupini) te oni kod kojih je lupina uklonjena te je ostala samo jezgra (jezgra lješnjaka) (Özdemir i Devres, 1999; Ozdemir i Akinci, 2004). Jezgre lješnjaka se mogu dalje kategorizirati kao: prirodne (neobrađene), blanširane i pržene, a njihovi proizvodi kao našnitani, nasjeckani, izrezan u obliku kockica te kao brašno, pržena pasta, ulje ili maslac (Özdemir i Devres, 1999; Köksal et al., 2006). U prehrambenoj industriji najčešće se koriste lješnjaci sa uklonjenom lupinom, odnosno jezgre lješnjaka (Ozdemir i Akinci, 2004). Parametri kakvoće se najčešće gledaju u odnosu na prve dvije glavne kategorije te su sažeti u Tablici 1.

S obzirom da su u prethodnoj tablici navedene samo najvažniji parametri kakvoće lješnjaka, potrebno je neke čimbenike dodatno naglasiti i objasniti. Željena veličina ploda ovisi o namjeni korištenja ploda, tako plodovi namijeni za prehrambenu industriju trebaju biti sitni i srednje veliki (promjera od 13 - 13,5 do oko 17 mm), a za upotrebu u svježem stanju prednost imaju veliki plodovi (promjera od 18, pa čak i 16 mm na više) (Modic et al., 1975; Miljković, 2018b). Poželjan oblik ploda također ovisi o krajnjoj namjeni ploda. Prema Modicu et al. (1975) preferencije prehrambene industrije za oblik ploda su sljedeće (5 – najpoželjniji oblik, 1 – najmanje poželjan oblik): okrugao – 5, okrugao - ovalan do ovalan – 4, slabo izdužen ili spljošten – 3, izdužen ili spljošten – 2, jako izdužen -1; dok za upotrebu u svježem stanju sljedeće: izdužen do jako dug – 5, spljošten i ovalan – 4, slabo ovalan do okrugao – 3, jako spljošten – 2, izdužen i jako šiljat – 1. İslam (2018) navodi da danas većina tržišta uglavnom preferira okrugle jezgre, a da se lješnjaci duguljastog oblika konzumiraju svježi. Sferičnost ploda je također bitna jer utječe na to kako lagano se lješnjaci mogu u prehrambenoj industriji preraditi, a preferiraju se sferični lješnjaci (Ozdemir i Akinci, 2004). Debljina lupine isto ima određenu važnost, a u prehrambenoj industriji se preferiraju plodovi tanke do srednje tanke lupine (Miljković, 2018b). Randman je jedna od glavnih odrednica kakvoće i cijene lješnjaka (Liu et al., 2012). Modic et al. (1975) su na sljedeći način rangirali randman jezgre (5 – najpoželjniji, 1 – najlošiji): > 49% - 5, od 46 do 49% - 4, od 43 do 46% -3, od 40 do 43% - 2, < 40% - 1. Mehlenbacher i Olsen (1997) navode da se u SAD-u za lješnjake koji imaju randman jezgre iznad 50% postiže „premium“ cijena. Osim lješnjaka sa dobrim randmanom, postoje i oni kod kojih jezgra slabo ispunjava lupinu, a tu je potrebno dodatno razjasniti terminologiju. Prazne lupine opisuju lješnjak koji ne sadrži jezgru ili kada jezgra, prema Redpath (2016) ispunjava manje od 25% kapaciteta lupine, dok prema Liu et al. (2012) i Olsen et al. (2013) manje od 20% kapaciteta lupine. Slabo popunjene lupine uključuju jezgre koje su popunile šupljinu lupine sa više od 25%, a manje od 50% (Redpath, 2016). Smežurane jezgre imaju smežuranost na više od 50% površine jezgre, dok djelomično smežurani lješnjaci imaju smežurane manje dijelove na jezgri (Redpath, 2016). Prema istom autoru jezgre koje su blago smežurane te koje slabo popune lupinu se mogu koristiti za proizvodnju paste ili ulja, pod uvjetom da meso nije žilavo (tvrdo) i kožasto (Redpath, 2016).

Postoje još neki dodatni parametri kakvoće koji su bitni prehrambenoj industriji, a koje je potrebno uzeti u obzir. Tu spadaju razni atributi teksture kao hrskavost i žvakavost, koji su prema Kader i Thompson (2002) pod utjecajem stupnja i uniformnosti sušenja unutar i između lupinastih plodova. S obzirom da distribucija vlage u sirovom materijalu ima bitnu ulogu tijekom

Table 1. Najvažniji parametri kakvoće lješnjaka prema raznim publikacijama (prikazani unutar tablice) te neki minimalni zahtjevi u međunarodnoj trgovini definirani od Ekonomske komisije Ujedinjenih naroda za Europu (United Nations Economic Commission for Europe, 2007, 2010)

Dio ploda	Parametri kakvoće i neki minimalni zahtjevi	Izvori
Lupina / Shell	Čistoća – izostanak bilo kakvog stranog materijala, uključujući insekte (bilo kojeg stadija razvoja) i prisutnosti plijesni (često se počinje javljati pri vrhu lupine) te rezidua prilijepljenog ovoja (kupole) (maksimalno dozvoljeno do 5% cjelokupne površine lupine). Prisustvo stranog mirisa također nije dozvoljeno. Veličina – sukladno klasi prema međunarodnim kriterijima. Određuje se na temelju promjera, a posebno se utvrđuje za sorte okruglih i duguljastih plodova. Oblik – dobro oblikovana lupina (bez značajnih nepravilnih oblika), na tržištu lješnjaka u lupini okrugli oblik se preferira. Boja – poželjno je da je karakteristična za sortu. Nije dopušteno prisustvo bezbojnih područja te mrlja koje su u suprotnosti s ostatkom površine lupine ukoliko ukupno prekrivaju više od 25% površine. Vlaga – bez prisustva abnormalne vanjske vlage. Oštećenja – bez oštećenja, uključujući polomljene ili razdvojene (napuknute) lupine te ostale uočljive mehaničke štete (blago površinsko oštećenje se ne smatra štetom dok je jezgra zaštićena). Prisutnost ožiljaka od bakterioza se smatra nepoželjnim, ali ne i nedopuštenim defektom. Ostali defekti – nisu poželjne prazne lupine (izostanak jezgre), smeđe mrlje na lupini te ostali fiziološki poremećaji.	Bulatović (1985); United Nations Economic Commission for Europe (2007); Kader (2013); Olsen (2013); Olsen et al. (2013); Fontana et al. (2014); Maness (2016); Redpath (2016);
Jezgra / Kernel	Čistoća – izostanak bilo kakvog stranog materijala (lupina, kamenje, metal itd.), živih ili mrtvih insekata i njihovih izlučevina te plijesni. Prisustvo stranog mirisa i okusa također nije dozvoljeno. Veličina – sukladno klasi prema međunarodnim kriterijima, a preferencije tržišta ovise o krajnjoj namijeni sirovine. Određuju se na temelju promjera, a posebno se utvrđuje za sorte okruglih i duguljastih plodova. Oblik – nepoželjne su jezgre svih nepravilnih oblika i nedovoljno razvijenih jezgri, a u tržištu oljuštenih lješnjaka preferiraju se i okrugli i duguljasti oblici. Boja – nije dopušteno prisutnosti bezbojnih područja te mrlja koje su u suprotnosti s ostatkom površine jezgre ukoliko ukupno prekrivaju više od 25% površine. Prisustvo smeđih ili tamno smeđih mrlja u šupljini se ne smatra nedopuštenim defektom ako ne utječe na okus ili miris, ali nije poželjno. Randman - jezgra mora popuniti više od 50% šupljine lupine. Pelikula – trebala bi biti glatka i bez ostataka prilijepljene lupine Vlaga – ukupan udio vlage kod cjelovitih lješnjaka u lupini ne smije biti veći od 12%, jezgre lješnjaka u lupini 7%, dok jezgre lješnjaka (kod kojih je lupina uklonjena) 6%. S druge strane jezgre s isušenim ili tvrdim dijelom koji zahvaća ukupno više od 25% površine trebaju biti isključene. Oštećenja – bez mehaničkih oštećenja, uključujući odsustvo dijela pelikule, ogrebotine ili izrezotine (ukoliko su promjera manjeg od 3 mm i dubine od 1,5 mm ne smatraju se defektom), ozljede od insekata itd. Međutim, štete od stjenica su dozvoljene ukoliko je prisutno samo jedno mjesto na jezgri koje ne prelazi 3 mm u promjeru i 3 mm u dubini. Ostali defekti i simptomi propadanja – smežurane (najčešće uslijed gubitka vlage), užegle, trule i pljesnive (bez prisustva aflatoksina) jezgre nisu dopuštene.	Bulatović (1985); Kader (2013); United Nations Economic Commission for Europe (2010, 2007); Olsen et al. (2013); Fontana et al. (2014); Maness (2016); Redpath (2016);

prženja (Fontana et al., 2014), homogena distribucija vlage se može smatrati pozitivnim čimbenikom kakvoće. Giacosa et al. (2016) navode da bi u budućoj perspektivi zajednički mehaničko-akustični test mogao pomoći u evaluaciji instrumentalno-senzornih korelacija, posebno pri procjeni percepcije hrskavosti jezgre lješnjaka. Lakoća uklanjanja pelikule jezgre tijekom procesa blanširanja i prženja je također cijenjena u slastičarskoj industriji (Silvestri et al., 2021), te stoga spada pod poželjne atribute. Ona je i genetski uvjetovana, a naša autohtona sorta lijeske ´Istarski duguljasti´ ima iznimno dobru mogućnost uklanjanja pelikule blanširajem (Thompson et al., 1978). Posebno značenje imaju aroma i okus jezgre (Miljković, 2018b). Slatkoća, uljnost i prženi okus uglavnom spadaju pod dobre atribute okusa, dok je užeglost glavni faktor loše kakvoće lupinastih plodova (Kader i Thompson, 2002). Zhang et al. (2019) su u istraživanju učinka skladištenja lješnjaka na oksidaciju ulja ustanovili da se uslijed postojanja signifikantne negativne korelacije između sadržaja linolne kiselina i indikatora oksidacije, upravo sadržaj linolne kiseline može koristiti kao pokazatelj procjene stupnja oksidacije ulja. Za istu svrhu predložili su neke hlapljive okside (engl. hexanal, 2-octenal, 2-decenal i 3-octene-2-one). Sun et al. (2022a) su zabilježili da je 51 lipid bio signifikantno različit između svježeg i oksidiranog ulja lješnjaka, što bi se moglo koristiti kao biomarkeri za razlikovanje svježeg od oksidiranog ulja lješnjaka. Sukladno glavnim parametrima kakvoće lješnjaci se posljedično svrstavaju u različite klase. Postoje različiti načini određivanja klasa lješnjaka (npr. u ovisnosti o državi) te bi previše mjesta zauzelo da se svi navedu, a neki od njih su navedeni u sljedećim publikacijama (Bulatović, 1985; Maness, 2016; Redpath, 2016). Potrebno je napomenuti da postoji međunarodni sustav klasiranja lješnjaka u lupini i jezgri lješnjaka (United Nations Economic Commission for Europe, 2007, 2010).

BERBA LJEŠNJAKA

Berba plodova predstavlja iznimno delikatnu operaciju u proizvodnji jer, kako navodi Wells (2013), najveći rizik kontaminacije plodova dolazi sa procesom berbe. Osim toga pravilno određivanje roka berbe je nužno kako bi se održala visoka kakvoća plodova (Fontana et al., 2014). Lješnjaci se mogu u ovisnosti o namjeni brati u dva roka berbe: za potrošnju svježih lješnjaka kada nisu skroz zreli te u vrijeme fiziološke zrelosti kada se beru za čuvanje i dulju preradu. Prema Moscettia et al. (2012) berba lješnjaka za potrošnju u svježem stanju (nezrelih lješnjaka) se obavlja kada su lješnjaci i dalje na stablu ali su postigli svoju punu veličinu, nisu jako tvrdi, a jezgra se počela odvajati od perikarpa. Navedeni autori su na temelju organoleptičkih analiza utvrdili da je u agroekološkim uvjetima srednje Italije za sortu ´Tonda Gentile Romana´ to bilo 8 tjedana prije fiziološke zrelosti (kraj srpnja, početak kolovoza). Međutim lješnjaci se uglavnom beru kada su fiziološki zreli, odnosno kad su namijenjeni za dulje čuvanje i preradu (što je i problematika o kojoj se raspravlja u ovom radu). U navedenom slučaju lješnjaci se smatraju zrelima kada klepeću unutar lupine, što indicira odvajanje jezgre od hiluma lupine (Maness, 2016). Bulatović (1985) navodi da su lješnjaci zreli kada promijene boju u žuto-smeđu i kada, kod sorata kod kojih je to moguće, lako ispadaju iz ovoja. Prerana berba lješnjaka negativno djeluje na kakvoću koja se ogleda kroz pojavu smežurane jezgre tijekom procesa sušenja, žilavosti jezgre itd. (Bulatović, 1985; Fontana et al., 2014). U Turskoj berba lješnjaka sorte ´Tombul´ u pravo vrijeme, a u odnosu na raniju berbu, je uzrokovala povećanje randmana sa 46 na 58%, mogućnost uklanjanja pelikule nakon prženja sa 56 na 93 % i smanjenje udjela smežuranih jezgri sa 9,5 na oko 1% (Cakirmelikoglu i Caliskan, 1993 citirano u Özdemir i Devres, 1999, p.312). Miljković (2018b) naglašava da berba lješnjaka u trenutku fiziološke zrelosti ima veliko značenje jer se smanjuje oksidacija masnih kiselina (nastanak užeglosti) i omogućuje dobra i duga skladišna sposobnost. Također bitno je da se berba plodova lupinastih voćnih vrsta izvrši odmah nakon što dozriju kako bi se izbjegla redukcija kakvoće i minimizirali problemi sa gljivama i insektima (Kader i Thompson, 2002).

Najčešći načini berbe lješnjaka su: rana ručna berba (branje s stabla), korištenje platna, plastične mreže ili nekog drugog materijala (postavljanje materijala ispod lijeske, trešnja i skupljanje plodova s platna) te ručno ili mehanizirano skupljanje lješnjaka s tla (sa ili bez trešnje)

(Bulatović, 1985; Mehlenbacher i Olsen, 1997; Farinelli et al., 2001; Ozdemir i Akinci, 2004; Ozay et al., 2008; Olsen i Peachey, 2013; İslam, 2018; Miljković, 2018b; Turan, 2018a, 2018b). Ručna berba s stabla je najčešća kod sorata lijeske kod kojih je ovoj dulji od ploda i sužen pri vrhu te ne dopušta ispadanje plodova iz ovoja kad su zreli. U Republici Hrvatskoj ovakav način berbe je čest slučaj kod naše najčešće zastupljene i autohtone sorte 'Istarski Duguljasti'. Također manji uzgajivači u Republici Hrvatskoj koji ne posjeduju mehanizaciju znaju brati plodove sa stabla (neovisno o sortimentu) kako bi preduhitrili glodavce i ostale životinje (divlje svinje) koje nakon padanja plodova na tlo rade velike štete. Farinelli et al. (2001) navode da se u tom slučaju berba mora obaviti prije nego lješnjaci otpadnu na tlo iz ovoja, ali ne prerano jer će plodovi biti nedovoljno zreli. Glavni problem ovakvog načina berbe je veliki utrošak radne snage, a ostali su: berba nezrelih lješnjaka te posljedično veći sadržaj vlage u plodovima i reducirana kakvoća, nastanak mehaničke štete na stablima uslijed trganja plodova sa rodnih izbojaka itd. Farinelli et al. (2001) su također zabilježili da plodovi ubrani na ovakav način imanju manji randman i manju stabilnost sadržaja polifenola od onih koji su prirodno pali sa stabla. Sljedeći način berbe je korištenje platna ili cerade, polietilenske mreže ili nekog drugog materijala pri berbi (Modic, 1985; Ozay et al., 2008; Miljković, 2018b). Tada se određeni materijal razvije ispod krošnje lijeske nakon čega se lješnjaci tresu i sa platna skupljaju. S obzirom da lješnjaci ne dozrijevaju istovremeno (Bulatović, 1985; Farinelli et al., 2001; Fontana et al., 2014; Miljković, 2018b), potrebno je učestalo provoditi berbu kako bi se izbjegao kontakt lješnjaka s tlom te je neupitno da će dio lješnjaka završiti na tlu. Međutim velika prednost navedene metode je u područjima gdje nije moguć pristup mehanizaciji, te se prema Miljkoviću (2018b) ona tamo obično i koristi. Prednost prve dvije metode, u odnosu na treću, je značajna manja mogućnost kontaminacije stranim materijalom, dok je glavni nedostatak manja efikasnost. Većina plodova lupinastih voćnih vrsta se bere tako da ih se trese sa stabala (ili ih se pusti da prirodno padnu na tlo), te se potom mehanički skupljaju pomoću strojeva direktno sa površine tla i prebacuje u vagone ili ostale privremene spremnike (Wells, 2013). İslam (2018) navodi da je posljednjih godina u Turskoj na ravnim terenima takav način berbe postao raširen. Osim korištenja mehanizacije moguće je plodove skupljati i ručno, ali prema Bulatoviću (1985) ono se primjenjuje samo na manjim površinama zbog malog učinka. Učinak strojeva može iznosit oko 100 kg / sat prema Miljkoviću (2018b) ili od 120 do 500 kg/sat prema Modicu (1985), dok za usporedbu ručnom berbom jedan radnik u jednom danu može prema Bulatoviću (1985) sakupiti otprilike oko 50 kg plodova. S druge strane u Turskoj je i dalje ručno skupljanje lješnjaka čest slučaj (Ozdemir i Akinci, 2004; İslam, 2018), a navedeno je vrlo vjerojatno uslijed jeftine i dostupne radne snage kao i zbog prisutnosti velike prirodne (samonikle) populacija lijeske. Mogućnost mehaničke berbe ovisi i o uzgojnom obliku te Mehlenbacher i Olsen (1997) navode da se u SAD-u u saveznoj državi Oregon lijeske uglavnom uzgajaju u obliku stabla kako bi se upravo omogućila mehanička berba. Pravilna priprema tla pred samu berbu je krucijalna za pravilno provođenje mehanizirane berbe i osiguranje dobre kakvoće lješnjaka. Jedan od glavnih razloga je kako bi se izbjegla kontaminacija prevelikom količinom stranog materijala (Kader i Thompson, 2002) te kontaminacija plodova aflatoksinima. Generalno preporučuje se pokušati izbjeći uvjete koji promoviraju prerano otpadane listova (kako ne bi smetali pri mehaniziranoj berbi), što je slučaj u voćnjacima koji su deficitarni kalijem te uslijed vodnog stresa, šteta od mraza i jakog napad lisnih ušiju (Olsen i Peachey, 2013). Tlo pred berbu mora biti bez korova, čvrsto i glatko (Olsen i Peachey, 2013; İslam, 2018), a zadovoljavajuće čvrsto i glatko tlo će omogućiti prilagođavanje visine usisavača za skupljanje lješnjaka na maksimalnu efikasnost te posljedično minimizirati kontaminaciju stranim materijalom (Olsen i Peachey, 2013). Prvo je potrebno površinski sloj razbiti rotacijskom sitnilicom, a zatim valjkom poravnati (Bulatović, 1985; Modic, 1985). Iako je tlo potrebno održavati što šušlje kako bi se onemogućio razvoj mikroorganizama koji preferiraju topao i vlažan okoliš (Wells, 2013), blaga kiša prije berbe može pomoći u reduciranju prašine i očvrsnuti tlo za berbu (Olsen i Peachey, 2013). S obzirom da lješnjaci s praznim lupinama padaju prije ispravnih plodova, preporuča se da nakon što oni popadaju (a prije opadanja ispravnih plodova, obično pred kraj kolovoza) odradi završno uređivanje tla kako bi se popunile male depresije u tlu (Olsen i Peachey, 2013) ili da se obavi jedno „pred skupljanje“ kako bi se eliminirali navedeni plodovi. Način rada usisivača za skupljanje lješnjaka s usisnim dugim i fleksibilnim cijevima promjera od 10 do 12 cm je detaljno opisao Modic (1985). Jaki usisni mlaz zraka stvaraju ventilatori montirani na prikolici iza traktora ili su samohodni. Usisnim otvorima – cijevima, koji se ručno usmjeravaju preko lješnjaka na podu, usisavaju se lješnjaci zajedno s lišćem, smećem pa i sitnim dijelovima zemlje i pijeska. Zahvaljujući jakom toku zraka teži lješnjaci padaju u posebnu sabirnu komoru a smeće i lišće odstranjuje se (Modic, 1985). S druge strane u SADU-u u saveznoj državi Oregon se nešto drugačije obavlja mehanizirana berba lješnjaka. Sam postupak berbe može se obavljati pomoću dva stroja. Jedan stroj (sabirnik) premješta (sabire) lješnjake dalje od stabla (prostor između redova) u jednu ili dvije linije (svaka širine 0,6 - 1,2 m), dok ih drugi stroj sakuplja i smješta u sabirnu ambalažu (Mehlenbacher i Olsen, 1997; Olsen i Peachey, 2013). Pošto lješnjaci padaju tijekom duljeg perioda (od 20 do 30 dana) te uslijed promjenjivosti vremenskih uvjeta, preporuča se da se berba obavi u dva ili više navrata kako bi se izbjegao dugi boravak lješnjaka na tlu, što uslijed kontaminacije i drugih procesa može negativno djelovati na kakvoću (Bulatović, 1985; Farinelli et al., 2001; Massantini et al., 2009; Olsen i Peachey, 2013; Fontana et al., 2014; Miljković, 2018b). Ukoliko se plodovi beru u dva navrata, tada se prva berba obavi kada je 40 do 45% plodova opalo na tlo, a druga na kraju fiziološkog opadanja plodova (Massantini et al., 2009). Pošto u jednom koraku nije moguće eliminirati sva fizička onečišćenja (kamenje, zemlja, komadići drveta, prazni lješnjaci i generalno strani materijal), korištenje opreme za čišćenje prije sušenja se preporuča (Fontana et al., 2014). Olsen i Peachey (2013) navode da će u SAD-u u saveznoj državi Oregon u većini godina do listopada svi lješnjaci prirodno pasti, a ako ne padnu vjetrovito i kišovito vrijeme će ubrzati padanje, ali i stvoriti nepovoljne uvjete za berbu. Slično je i u uvjetima Hrvatske. Ukoliko su plodovi ubrani s ovojem tada ju je potrebno nakon berbe ukloniti (İslam, 2018).

Kod svih načina berbe ne smiju se zanemariti ni vagoni i ostalim spremnici za berbu gdje je potrebno eliminirati višak vlage, a osim toga oni se ne bi smjeli prethodno koristiti za transport kemikalija, gnojiva, toksičnih tvari ili čak ostataka iz voćnjaka (Wells, 2013). Nakon što berba počne svi koraci (trešnja, sušenje, transport itd.) moraju biti efikasno vođeni kako bi se osigurala optimalna kakvoća plodova (Kader i Thompson, 2002). Kada završi berba sva oprema se treba očistiti i pravilno uskladištiti kako bi se spriječilo nakupljanje životinja i kontaminacija životinjskim fekalijama (Wells, 2013). Prijem lješnjaka nakon berbe uglavnom se sastoji od čišćenja (uključujući primjenu strojeva velikog kapaciteta procesiranja od oko 1000 kg/sat) te klasiranja (na temelju sorte i parametara kakvoće) (Tous, 2005). Potom se prema istom autoru određuje kvaliteta cijele pošiljke (na temelju sadržaja vlage, randmana i veličine jezgre, a nekada i razine prisutnosti plijesni i truleži) te se po potrebi penalizira kooperante sa loše ocijenjenom pošiljkom.

SUŠENJE LJEŠNJAKA

Što prije nakon berbe (unutar 24 sata) potrebno je započeti postupak sušenja (Olsen i Raab, 2013; Turan, 2018a; Turan i İslam, 2018). S obzirom da u vrijeme berbe lješnjaci sadrže veću količinu vode, uglavnom u slobodnom obliku (visoka aktivnost vode) (San-Martin et al., 2001), sušenje lješnjaka je neophodna mjera kako bi se spriječili procesi povezani s degradacijom kakvoće, odnosno propadanja plodova. Tijekom berbe sadržaj vlage u lješnjacima se kreće otprilike do 30% (Bulatović, 1985; López et al., 1997c; Löpez et al., 1998; Turan, 2018a; Turan i İslam, 2018; Turan i Karaosmanoğlu, 2019). Miljković (2018b) navodi da ukoliko su klimatske prilike povoljne tijekom dozrijevanja lješnjaci mogu sadržavati i manje od 20% vlage. Enzimska aktivnost se ubrzava sa povećanjem aktivnosti vode, a neželjena aktivnost hidrolaza može dovesti do promjena u teksturi, boji, mirisu i boji te posljedično nastanka nepoželjnih atributa kvalitete, uključujući i kvarenje (López et al., 1997a). Stoga, cilj sušenja lješnjaka je inaktivacija enzima kako bi se izbjeglo njihovo propadanje tijekom skladištenja, odnosno povećala njihova stabilnost (López et al., 1997a; San-Martin et al., 2001). Ukoliko su lješnjaci pravilno osušeni, tada se oni mogu skladištiti jako dugi period sa minimalnim promjenama (Ebraheim et al., 1994). Lješnjaci u lupini bi se trebali osušiti do: 10-12% (Maness, 2016), 10% (Bulatović, 1985), 8-9% (San-Martin et al., 2001), 7-8% (López et al., 1997b; López et al., 1998) ili oko 7% vlage (Tous, 2005). Sadržaj vlage u jezgri lješnjaka (kod kojih je lupina uklonjena) bi se trebao kretati od: 3,5 do 5% (Richardson, 1988 citirano u Ghirardello et al., 2013, p.38), 4 do 5% (Löpez et al., 1998), odnosno prema Olsen i Raab (2013) ne bi trebao prelaziti 5%, a prema Maness (2016) 6 do 7%. S druge strane sadržaj vlage ne smije biti ni previše nizak, jer Ghirardello et al. (2013) navode da prenizak sadržaj vlage u jezgri lješnjaka dovodi do pojave smežuranosti, promjene boje i nastanka užeglosti. Tijekom postupka sušenja događaju se fizikalno-kemijske promjene u plodu. Olsen & Raab (2013) navode da je u početku sušenja jezgra čvrsta, tijekom procesa sušenja postaje spužvasta, a kako se približava suhom stanju opet postaje čvrsta. Prema istim autorima unutarnja boja jezgre se postepeno mijenja od bijele do krem boje.

Temperatura zraka je jedan od najbitnijih faktora tijekom postupka sušenja jer dugoročno utječe na kvalitetu lješnjaka tijekom skladištenja (ne-enzimatsko posmeđenje, razina oksidacije tj. nastanak užeglosti) kao i na brzinu sušenja (López et al., 1997c; Löpez et al., 1998; Mousadoost et al., 2018). Prema studiji Löpez et al. (1998) brzina sušenja lješnjaka u lupini i jezgri lješnjaka je veća s porastom temperature, a lješnjaci u lupini se sporije suše uslijed sporije migracije vlage u odnosu na jezgre. López et al. (1997a, 1997b) navode da nije preporučljivo sušiti lješnjake na temperaturi iznad 50 °C jer se oksidacija lipida (nastanak užeglosti) i ne-enzimatsko posmeđenje povećava sa daljnjim povećanjem temperature. Autori stoga navode da se optimalna temperatura za sušenje lješnjaka kreću od 40 do 50 °C, jer niže temperature zahtijevaju dulje vrijeme sušenja, a što se ne kompenzira sa komercijalnom kvalitetom proizvoda. Olsen & Raab (2013) navode da su optimalne temperature sušenja od 35 do 40,6 °C. Tous (2005) u Španjolskoj navodi temperaturu od 40 °C, a Turan (2018a) i Turan (2019) su u istraživanju u Turskoj sušili lješnjake na 45 i 50°C (respektivno). Na temelju senzoričke analize lješnjaka provedene nakon 6 mjeseci skladištenja Mousadoost et al. (2018) navode da potrošači preferiraju lješnjake u lupini i jezgre lješnjaka sušene na 50 °C, u odnosu na one sušene na 40 °C i 60 °C.

Lješnjaci se mogu sušiti na razne načine. Danas se lješnjaci uglavnom suše u velikim sušarama s prisilnom cirkulacijom zraka, odnosno kada su lješnjaci izloženi udarima vrućeg zraka (López et al., 1997c; Tous, 2005). Sušare mogu biti različite izvedbe. Turan i Karaosmanoğlu (2019) su opisali i ilustracijski demonstrirali sušaru gdje se sušenje postiže prisilnom ventilacijom vrućeg zraka, kojeg izmjenjivač topline šalje ventilatoru, a koji ga istodobno šalje u tijelo sušilice. Za vrijeme sušenja lješnjaci se kontinuirano miješaju pomoću centralnog Arhimedovog vijka. Prosječno vrijeme sušenja u velikim sušarama gdje su lješnjaci izloženi udarima vrućeg zraka ovisi o temperaturi sušenja, a postupak može trajati do 48 sati na sobnoj temperaturi ili oko 18 sati ako se zrak zagrije na 40 °C (Tous, 2005). Turan (2018a) navodi da je bilo potrebno 23 sata sušenja u sušari na temperaturi od 45 °C da se sadržaj vlage lješnjaka u lupini smanji sa 27,25 na 8,10%. Neki proizvođači u Hrvatskoj suše lješnjake i zagrijavanjem prostorija. Manji proizvođači zbog jednostavnosti i niskih troškova znaju lješnjake sušiti na tradicionalan način, odnosno na suncu (López et al., 1997c). Ovakav način sušenja se i dalje tradicionalno provodi u Turskoj na betonskom i/ili travnatom podu (Turan, 2017 citirano u Turan i Karaosmanoğlu, 2019, p.1). Modic (1985) navodi da prilikom sušenja na suncu lješnjaci trebaju biti razvučeni na čistoj i ravnoj površini (cementni ili drveni pod) u sloju od 10 do 15 cm te ih je potrebno svaki dan više puta miješati kako bi se ujednačeno sušili. Po noći bi ih trebalo prekriti plastičnim materijalom kako se ne bi smočili (rosa) (Turan, 2018a). Za sušenje na suncu potreban je kontinuirani period sa suhim i sunčanim vremenom, što je nakon berbe dosta teško postići te je stoga ovakav način sušenja moguć samo u krajevima s zadovoljavajućim ekološkim uvjetima (Modic, 1985; López et al., 1997c; Turan, 2018b; Turan i İslam, 2018; Turan i Karaosmanoğlu, 2019). Zbog toga i prosječno vrijeme sušenja nije moguće točno odrediti. Turan (2018a) navodi da je u Turskoj bilo potrebno 39 sati sušenja na suncu (uključujući samo aktivno vrijeme sušenja tj. od 08 do 20 sati) kako bi se kod lješnjaka u lupini smanjio sadržaj vlage sa 27,25 na 7,89% (sušeni na betonskom podu) i 9.11% (sušeni na travnatom podu) (respektivno). S druge strane isto u Turskoj, Turan (2019) navodi da je bilo potrebno 156 i 165 sati sušenja na suncu (uključujući samo aktivno vrijeme sušenja tj. od 08 do 20 sati) kako bi se kod lješnjaka u lupini smanjio sadržaj vlage sa 28.36 na 8,73% (sušeni na betonskom podu) i 6,82% (sušeni na travnatom podu) (respektivno). Glavni nedostatak ovakvog načina sušenja lješnjaka je, osim nesigurnosti vremenskih uvjeta, i veliki utrošak radne snage te trajanje sušenja (López et al., 1997c; Turan i Karaosmanoğlu, 2019). Stoga ovakav način sušenja nije interesantan za srednje velike i velike proizvođače (López et al., 1997c). Manje količine lješnjake je moguće sušiti i iznad peći ili radijatora uslijed strujanja toplog zraka, a tada je potrebno 2 do 3 dana da se osuše (Olsen i Raab, 2013). Način sušenja može utjecati na uspješnost skladištenja lješnjaka. Lješnjaci sušeni u sušarama, u usporedbi sa onima sušenima na betonskom tlu i travnatom terenu, su imali bolju oksidativnu stabilnost tijekom 12-mjesečnog skladištenja na temperaturi okoline (20-25 °C) i relativnoj vlažnosti zraka od 70 do 80% (Turan, 2018a).

SKLADIŠTENJE LJEŠNJAKA

S obzirom da je tržište lješnjaka generalno raspoređeno tijekom cijele godine nakon berbe, uloga skladišnih uvjeta zbog njihova značajnog utjecaja na kvalitetu lješnjaka je od krucijalne važnosti i za prerađivačku industriju i za stolnu potrošnju (Ghirardello et al., 2013, 2014). Pošto se lješnjaci uglavnom sastoje od lipida (oko 64%) (Amaral et al., 2006a), jedan od glavnih ciljeva skladištenja je spriječiti (ili usporiti) njihovu oksidaciju (Fontana et al., 2014; Ghirardello et al., 2014). U lješnjacima su nezasićene masne kiseline dominanto zastupljene u odnosu na zasićene (omjer 13.1) (Köksal et al., 2006), što je uzrok njihovog pozitivnog djelovanja na ljudsko zdravlje (Garcia et al., 1994, Orem et al., 2013), ali ih čini i jako osjetljivima na oksidaciju (Koyuncu et al., 2005, Mousadoost et al., 2018). Tijekom skladištenja lješnjaka kiselost, peroksidna vrijednost i sadržaj ukupnih zasićenih masnih kiselina se povećava, dok se ukupan sadržaj fenola, antioksidacijski kapacitet, sadržaj nezasićenih masnih kiselina i omjer nezasićenih/zasićenih masnih kiselina smanjuje (Ghirardello et al., 2013). U sveobuhvatnoj analizi lipida u ulju lješnjaka tijekom skladištenja Sun et al. (2022a) su zabilježili da je nakon 24 dana skladištenja sadržaj triacilglicerola, diacilglicerola, fosfatidinske kiseline, fosfatidiletanolamina, fosfatidiletanola, ceramida i ukupnih lipida bio smanjen signifikantno. Hidroliza i oksidacija lipidne frakcije tijekom skladištenja rezultirat će nepoželjnim mirisima i okusima, te smanjenjem nutritivne vrijednosti jezgri (Ghirardello i sur. 2014.). Sekundarni produkti oksidacije (kao i peroksidi i slobodni radikali lipida) mogu reagirati s proteinima i vitaminima uzrokujući gubitke u hranjivoj vrijednosti (San-Martin et al., 2001). Iz svega navedenoga vidljiva je iznimna bitnost pravilnog skladištenja lješnjaka. Skladištiti se mogu lješnjaci u lupini te jezgre lješnjaka (Fontana et al., 2014). Jezgre lješnjaka je teže očuvati uslijed njihove svojstvene mekoće i povredljivosti (Mousadoost et al., 2018). San-Martin et al. (2001) su zabilježili da lupina lješnjaka predstavlja učinkovitu zaštitu protiv oksidacije lipida tj. užeglosti (uz uvjet skladištenja na niskim temperaturama). Uslijed navedenoga preporučuje se uklanjanje lupine tek uslijed komercijalne potrebe.

Tijekom skladištenja lješnjaka vlaga, a potom temperatura predstavljaju krucijalne parametre (San-Martin et al., 2001; Ghirardello et al., 2013, 2014). S obzirom da lješnjaci sadrže nizak udio vlage, za razliku od većine drugih komercijalnih voćnih vrsta, kontrola sadržaja vlage je nužna. U vlažnim prostorijama plodovi lješnjaka brzo propadaju i pljesnive, a pri nižoj vlažnosti dolazi do isušivanja, gubitka na težini i kvaliteti (Bulatović, 1985). Relativna vlažnost zraka tijekom skladištenja nikada ne smije prelaziti 70% (Tombesi, 1985 citirano u Ghirardello et al., 2013, p.38), dok Redpath (2016) preporuča skladištenje pri vlazi manjoj od 65%. Massantini et al. (2009) navodi da proizvođači u Italiji uglavnom skladište lješnjake pri relativnoj vlažnosti od 60 do 70%, dok Mumelaš i Gobec (1985) preporučuju skladištenje pri relativnoj vlažnosti od 50 do 60%. Moscetti et al. (2012) su skladištili lješnjake ubrane za potrošnju u svježem stanju (koji nisu fiziološki zreli) pri relativnoj vlažnosti zraka od 80%. S obzirom da su mnogi negativni procesi povezani osim sa povišenom vlagom i sa temperaturom, i ona predstavlja bitan parametar u skladištenju lješnjaka. Skladištenjem na niskim temperaturama procesi užeglosti i razgradnja vitamina E su znatno usporeni, dok je razvoj plijesni i insekata gotovo eliminiran blizu temperatura smrzavanja (Ghirardello et al., 2013). Prema Gvozdenović i Davidović (1990) preporučena temperatura za čuvanje lješnjaka se kreće od 0 do 5 °C, a prema Mumelaš i Gobec (1985) od 5 do 10 °C. Maness (2016) navodi da ukoliko je temperatura manja od 10 °C, tada se sa minimalnim gubitkom kvalitete lješnjaci u lupini mogu čuvati do 24 mjeseca. Fontana et al. (2014) preporučuju skladištenje jezgri lješnjaka pri temperaturi od 5 °C i relativnoj vlažnosti 60%. Ghirardello et al. (2013) su zabilježili da se skladištenjem jezgri lješnjaka na 4 °C i 55% relativne vlage zraka kvaliteta održala do jedne godine. Ebraheim et al. (1994) su zabilježili da je tijekom dvogodišnjeg skladištenja jezgre lješnjaka razina perodiksida bila najveća u lješnjacima skladištenima pri 10 °C, te potom pri 5 °C, a najmanja pri 0 °C. Maness (2016) navodi da se prženi lješnjak može čuvati do 6 mjeseci na 0, 5, ili 10 °C prije razvoja uočljivih simptoma užeglosti. Iako su niske temperature prepoznate kao učinkovito sredstvo za produljenje skladišne sposobnosti, lješnjaci se obično čuvaju na sobnoj temperaturi zbog visokih troškova energije za hlađenje (Ghirardello et al., 2013). Navedeni način skladištenja je i dalje uobičajen u Turskoj (Turan, 2017 citirano u Turan i Karaosmanoğlu, 2019, p.1), kao i u Republici Hrvatskoj, posebno kod malih proizvođača. S obzirom da skladištenje lješnjaka na sobnoj temperaturi nije jednako dobro kao ono na niskim temperaturama, u tom slučaju potrebno je paziti da su ostali čimbenici čuvanja budu zadovoljavajući. Sukladno navedenome u Italiji ovakav način skladištenja se koristi za vrijeme zimskog perioda, ali sa odgovarajućom vlažnosti (60 – 70%) i u ventiliranom okolišu te bez ikakvog kemijskog tretmana (Massantini et al., 2009). Zabilježeno je da mogućnost čuvanja lješnjaka u lupini na sobnoj temperaturi može trajati 8 mjeseci (Ghirardello et al., 2013). Mousadoost et al. (2018) navodi da se lješnjaci u lupini bez promjene kvalitete okusa mogu čuvati do jedne godine ukoliko temperatura okoline ne prelazi 21 °C, ali uz uvjet prozračivanja silosa i zadovoljavajuće vlažnosti zraka.

U posljednje vrijeme intenzivno se istraživalo i čuvanje lješnjaka u kontroliranoj atmosferi. Lješnjaci se mogu dugi period čuvati pri sobnoj temperaturi u atmosferi dušika (:2:99.5kPa) sa gubitkom kvalitete koja je usporediva sa uvjetima skladištenja pri niskoj temperaturi i kontroliranoj relativnoj vlažnosti (3 – 6 °C, 50% - 60% relativne vlažnosti) (Keme et al., 1983 citirano u Johnson et al., 2009, p.521). San-Martin et al. (2001) su proučavali kvalitetu lješnjaka u lupini i jezgri lješnjaka nakon skladištenja u uvjetima modificirane atmosfere s različitim koncentracijama kisika (1%, 5%, 10% i 20%) te dvije različite temperature (7 i 25 °C). Uočeno je da nakon jednogodišnjeg razdoblja čuvanja niti kod jednog tretmana nije došlo do signifikantnog razvoja užeglosti. Ipak, potvrđeno je da kod koncentracije kisika ispod 10% autooksidacija je bila smanjena. Ghirardello et al. (2014, 2013) su zabilježili da su jezgre lješnjaka nakon 12 mjeseci skladištenja pri 4 °C u kontroliranoj atmosferi (1% kisik, 99% dušik) imale istaknuto manju kiselost i peroksidni broj od onih skladištenih u istim uvjetima, ali sa normalnom atmosferom. Ghirardello et al. (2013) također navode da smanjena razina kisika pozitivno utječe na dugoročno skladištenje prženih lješnjaka. U atmosferi sa skoro 100% dušika jezgre se mogu se čuvati do dvije godine ako je količina vode u plodovima manja od 10% (Gvozdenović i Davidović, 1990). Silvestri et al. (2021) zaključuju da niže temperature uz koncentraciju kisika ispod 10% predstavljaju najbolje rješenje za odgađanje pojave užeglosti. Osim skladištenja standardnih lješnjaka, Moscettia et al. (2012) su istraživali skladištenje lješnjaka ubranih za potrošnju u svježem stanju (koji nisu fiziološki zreli) pri 4 °C i 10 °C te 80% RH sa normalnom atmosferom, kao i pri istim uvjetima ali dvije različite modificirane atmosfere: 100 ± 1 kPa CO_2 i 100 ± 1 kPa N_2. Na temelju provedenih mjerenja i organoleptičke analize nakon 12 dana, lješnjaci skladišteni u normalnoj atmosferi su bili inferiorni u usporedbi sa onima u modificiranoj atmosferi (s izuzetkom blagog gubitka arome). Temperatura čuvanja pri 4 °C (u odnosu na onu od 10 °C) se pokazala najbolja kod svih tretmana. Kao moguća zadovoljavajuća alternativa skladištenju u modificiranoj atmosferi je skladištenje do maksimalno 8 dana u normalnoj atmosferi pri 4 °C. Belviso i sur. (2017.) preporučili su za očuvanje visokog antioksidacijskog kapaciteta prženih lješnjaka pakiranih u nepropusne polipropilenske/aluminijske/polietilenske vreće pod vakuumom vrijeme skladištenja od šest mjeseci na 4 °C.

Svjetlost uz temperaturu, vlagu i dostupnost kisika je vrlo bitan faktor za očuvanje kvalitete tokom skladištenja. Ovisno o intenzitetu, valnoj duljini, trajanju izloženosti i apsorpciji proizvoda te temperaturi i količini dostupnog kisika, svjetlost može izazvati fotooksidacijsku užeglost (Özdemir i Devres, 1999). Miris je sljedeći jako bitan faktor, jer prema Bulatoviću (1985) lješnjaci vrlo lako mogu apsorbirati miris te se stoga ne čuvaju u istim prostorijama u kojima se nalaze drugi proizvodi (svježe voće, luk itd.).

Kako bi se zadovoljili svi gore navedeni uvjeti lješnjaci se u praksi mogu uspješno skladištiti u silosima ili u skladištima klasičnog tipa. Mumelaš & Gobec (1985) navode da je skladištenje u silosima od čelika ili betona najbolji način jer čuvaju lješnjake od mehaničkog oštećenja i osiguran je nadzor parametara skladištenja preciznim mjernim sistemom. U skladištima klasičnog tipa lješnjaci se mogu ambalažirati u jutene (kroz koje može zrak cirkulirati) ili polietilenske vreće, a mogu se i razasuti širom (Modic, 1985; Ozay et al., 2008; İslam, 2018; Turan, 2018a, 2019; Turan i İslam, 2018; Turan i Karaosmanoğlu, 2019). Također proizvođači skladište i u mrežastim vrećama. Vreće s lješnjakom se slažu na palete, a slaganje mora biti izvršeno pregledno, razvrstano po sortama i kalibraži s dovoljno prostora za prolazak između paleta (Mumelaš i Gobec, 1985). U zadnje vrijeme se razvijaju i tretmani kojima se lješnjaci podvrgnu prije skladištenja. Güler et al. (2017) su zabilježili da su lješnjaci izloženi gama zračenju od 0,5 kGy imali dosta dobru kvalitetu nakon skladištenja (na temelju sadržaja slobodnih masnih kiselina, peroksida te vitamina e) te ga stoga preporučuju u odnosu na tretman sa 1 i 1,5 kGy.

ZAVRŠNI POSTUPCI PRIJE KOMERCIJALIZACIJE ILI UPOTREBE LJEŠNJAKA

Ukoliko se lješnjak komercijalizira ili namjerava koristiti kao jezgra tada je potrebno pristupiti uklanjanju lupine. Nakon kalibriranja, odvajanje lupine od jezgre se obavlja strojevima koji drobe lupinu na rotirajućim pločama sa specijalnim nazubljenima između kojih prolazi lješnjak (Mumelaš i Gobec, 1985). Operacija uklanjanja lupine (drobljenje) dovodi do oštećenih i polomljenih jezgri lješnjaka te onih sa skrivenim oštećenjima (Özdemir, 1999). Mehanička oštećenja kožice koja obavija jezgru se trebaju spriječiti jer ona štiti od oksidacije masti te posljedično umanjuje kvalitetu jezgre i skladišnu sposobnost (Fontana et al., 2014). Udio oštećenja ovisi o mehaničkoj sili primijenjenoj na lješnjak, rotacijskoj brzini drobilice, debljini lupine i obliku lješnjaka, broju klasa veličine lješnjaka i efikasnosti kalibriranja (Özdemir i Özilgen, 1997). Upravo zbog toga pravilno provedeno kalibriranje lješnjaka je iznimno bitno kako bi drobilica mogla sa što manjim oštećenjem ukloniti lupinu, a Fontana et al. (2014) preporučuju da ono bude na 0,5 mm. Separacija lupine od jezgre vrši se u pneumatskom rotacionom uređaju za čišćenje gdje ljusku koja ima manju specifičnu težinu odnosi struja zraka (Mumelaš i Gobec, 1985). Manja količina neobrađenog lješnjaka u lupini, veći komadi lupine, pljesnive i oštećene jezgre odvajaju se ručno na pomičnim trakama (Özdemir, 1999). Prednost ručnog odvajanja je niska inicijalna cijena i visoka učinkovitost bez lažnog otpada (koji kod mehaničkih razvrstavanja može iznositi oko 5 - 10%), a prednost mehaničkog sortiranja je visoka učinkovitost (do 6 t/sat) i konstanta razina efikasnosti (Fontana et al., 2014). Danas većina europskih prerađivača koriste integrirano mehaničko i ručno sortiranje (Fontana et al., 2014). Lješnjaci su često i izloženi termičkoj obradi (uglavnom prženju), a glavni razlog je promoviranje okusa i teksture koja će u konačnici povećati ukupnu ukusnost proizvoda (Özdemir et al., 2001; Saklar et al., 2001; Amaral et al., 2006b). Naime tijekom prženja lješnjaka formira kompleksna mješavina od preko 20 različitih tvari (Saklar et al., 2001).

Nakon uklanjanja lupine i sortiranja po veličini, odnosno promjeru i zdravstvenoj ispravnosti, ambalažira se u vreće ili manju ambalažu (Modic, 1985). Izbor ambalaže ima također bitan utjecaj na očuvanje kvalitete lješnjaka (život na polici) jer o materijalu pakiranja ovise unutarnji uvjeti (sastav plinova, vlažnost i prisutnost svjetlosti) koji su važni za stabilnost proizvoda. Utvrđeno je da ambalaža od celofana tamne boje uspješno štititi proizvod od užeglosti koju izaziva svjetlost (Bulatović, 1985.). Prema istom autoru najbolje rezultate dao je tanak pergamentni papir, jer tada svjetlost nema nikakvog utjecaja na promjene ulja u jezgri. Uz navedene uvjete za osiguranje optimalnog roka života na polici prema Özdemir & Devres (1999) krucijalna je i kontrola razine kisika u pakiranju s obzirom da mnoge promjene ovise o redoks potencijalu i dostupnom kisiku unutar pakiranja. Upravo vakuum ambalaža može navedeno osigurati.

AFLATOKSINI U LJEŠNJACIMA

Na globalnom tržištu danas se osobita pažnja posvećuje sigurnosti hrane biljnog i životinjskog podrijetla. Među različitim kontaminantima biljnih proizvoda, osobita pažnja u posljednjih tridesetak godina pridaje se mikotoksinima (Kuiper-Goodman, 2004; Reddy et al., 2010; Marin et al., 2013). Lješnjaci, kao i plodovi nekih drugih lupinastih voćnih vrsta smatraju se pogodnim supstratom za proizvodnju mikotoksina (Sanchis et al., 1988; Ozay et al., 2008; Battilani, 2010). Među mikotoksinima koji kontaminiraju lješnjake, najčešćima i najrizičnijima smatraju se aflatoksini (Reddy et al., 2010; Marín i Ramos, 2016; EFSA CONTAM Panel et al., 2020). Aflatoksini su sekundarni metaboliti koje stvaraju gljive iz roda *Aspergillus*, sekcije *Flavi* (Cary i Ehrlich, 2006), među kojima su najvažniji *Aspergillus flavus* i *A. parasiticus* (Yu et al., 2004; Klich, 2007; EFSA CONTAM Panel et al., 2020). Aflatoksini se ubrajaju u najpotentnije mikotoksine, uzrokuju akutne i kronične aflatoksikoze te pokazuju snažne teratogene, mutagene i kancerogene učinke kod ljudi i toplokrvnih životinja (Marin et al., 2013; Peraica et al., 2014; Šapina et al., 2014; EFSA CONTAM Panel et al., 2020). Zbog njihovog potencijalnog učinka na zdravlje ljudi, u velikom broju zemalja regulirana je maksimalno dozvoljena količina aflatoksina u biljnim proizvodima. U Europskoj uniji, aflatoksini su regulirani Uredbom Komisije (EZ) 1881/2006 od 19. prosinca 2006 o utvrđivanju najvećih dopuštenih količina određenih kontaminanata u hrani (Commission Regulation (EC) 1881/2006). Prema spomenutom propisu, najveća dopuštena količina aflatoksina B_1 u „orašastim plodovima koji se sortiraju ili drukčije fizikalno obrađuju prije uporabe za prehranu ljudi ili kao sastojak hrane“ iznosi 5,0 µg/kg, a u „orašastim plodovima i njihovim prerađenim proizvodima za izravnu prehranu ljudi ili uporabu kao sastojak hrane“ iznosi 2,0 µg/kg. U obje navedene kategorije hrane regulirana je i maksimalna dopuštena količina zbroja aflatoksina B_1, B_2, G_1 i G_2.

Reguliranje i kontrola maksimalnih dopuštenih količina aflatoksina u lješnjacima može imati značajan utjecaj na izvoz lijeske iz pojedinih zemalja. Primjerice, zbog nalaza premašenih maksimalnih količina tih mikotoksina, Europska unija propisala je češće kontrole pri uvozu lješnjaka i proizvoda od lješnjaka iz Turske, Gruzije i Azerbajdžana (Provedbena uredba Commission Implementing Regulation (EU) 2019/1793). Takve strože kontrole pri uvozu u Uniju propisane su Provedbenom odlukom komisije (EU) 2019/1793 od 22. listopada 2019. o privremenom povećanju službenih kontrola i hitnim mjerama kojima se uređuje ulazak određene robe iz određenih trećih zemalja u Uniju (Commission Implementing Regulation (EU) 2019/1793). Turska, kao jedan od najvećih svjetskih proizvođača lijeske, sustavno ulaže u smanjenje rizika i kontrolu prisutnosti aflatoksina u lješnjacima i proizvodima od lješnjaka. Tom problemu pristupa se planski, sustavno i pod institucionalnim nadzorom (European Commission, 2008).

Prisutnost mikotoksina na biljnim proizvodima ovisi o prisutnosti toksigenih gljiva („plijesni“) na njima. Naseljavanje plodova lijeske i toksigena aktivnost

Aspergillus vrsta na lješnjacima ovisi o brojnim čimbenicima (Klich, 2007; Yu, 2012; Marín i Ramos, 2016; EFSA CONTAM Panel et al., 2020). *Aspergillus* vrste nisu patogene za lijesku te ne uzrokuju simptome na plodovima u vidu nekroza, lezija ili truleži. Najvažniji proizvođači aflatoksina, *Aspergillus flavus* i *A. parasiticus* kozmopolitske su saprofitske vrste koje prirodno žive u tlu, na površini tla i na površini biljnih organa (Cary i Ehrlich, 2006; Klich, 2007; Battilani, 2010). Kolonizacija lješnjaka tim gljivama dešava se tijekom vegetacije, a ponajprije u razdoblju pred berbu i tijekom berbe (Ozay et al., 2008). Na taj način, lješnjaci u skladište mogu doći kontaminirani. U istraživanju provedenome u Turskoj, Gürses (2006) je utvrdio vrstu *Aspergillus flavus* u svih devet od 28 analiziranih uzoraka lješnjaka koji su sadržavali aflatoksine. Ozay et al. (2008) su tijekom tri godine utvrdili su prisutnost *A. flavus* i *A. parasiticus* u 47 – 79% uzoraka lješnjaka iz 72 voćnjaka u različitim područjima Turske. U drugom istraživanju u Turskoj, gljive iz roda *Aspergillus* bile su dominantne među gljivama utvrđenima na sirovim i prženim lješnjacima te su činile 45 – 80% izolata svih gljiva (Keskin i Gursoy, 2019). Relativno česta zastupljenost *Aspergillus* vrsta na lješnjacima potvrđena je i u istraživanjima provedenima u drugim zemljama, poput SAD-a (Pscheidt et al., 2019), Egipta (Abdel-Hafez i Saber, 1993), Irana (Khosravi et al., 2007) ili Saudijske Arabije (Abdel-Gawad i Zohri, 1993). S druge strane, toksigene *Aspergillus* vrste u pojedinim područjima uzgoja lijeske u svijetu ne moraju biti zastupljene, ili uvjeti za njihov razvoj i kolonizaciju plodova nisu povoljni. *Aspergillus flavus* i *A. parasiticus* termifilne su gljive te kao proizvođači mikotoksina mogu predstavljati problem u uzgoju nekih kultura u područjima s tropskom, suptropskom ili mediteranskom klimom (Kuiper-Goodman, 2004; Xu et al., 2011; Marin et al., 2013). U tom kontekstu, Magan et al. (2011) i Medina et al. (2014) ističu da bi globalno zatopljenje moglo dovesti do jače pojave aflatoksina i u područjima gdje ti kontaminanti do sada nisu bili česti. Osim prisutnosti toksigenih *Aspergillus* vrsta, sojeva i izolata, na proizvodnju aflatoksina na lješnjacima utječu i mnogi drugi čimbenici. Stvaranje aflatoksina je vrlo kompleksno i uvjetovano je brojnim interakcijama između supstrata, toksigene gljive i okoline (Battilani, 2010; Marin et al., 2013; EFSA CONTAM Panel et al., 2020). Na prisutnost i količinu aflatoksina u lješnjacima utjecaj imaju ponajprije sojevi (izolati) *Aspergillus* vrsta prisutni na plodovima (Yu, 2012; Ortega et al., 2020), vlaga (Marín i Ramos, 2016; Pscheidt et al., 2019; Valente et al., 2020), temperatura (Sanchis et al., 1988; Marín i Ramos, 2016) i dužina skladištenja (Magan i Aldred, 2007). Velika varijabilnost u stvaranju aflatoksina očituje se u nalazima tih spojeva na uzorcima lješnjaka i proizvoda od lješnjaka. Analiza lješnjaka iz talijanskih trgovina pokazala je kontaminaciju aflatoksinima u 35 od 93 uzoraka, s višim postotkom kontaminiranih plodova porijeklom iz Turske u odnosu na one porijeklom iz Italije (Prelle et al., 2012). Kabak (2016) nalazi aflatoksine u 12% uzoraka sirovih lješnjaka, pri čemu su se nađene količine kretale od 0,09 do 11,3 µg/kg. Baltaci et al. (2012) u sirovim lješnjacima nalaze aflatoksine u količinama između 0,02 i 78,98 µg/kg, a Gürses (2006) u količinama od 1 do 113 µg/kg. Šapina et al. (2014) dokazali su značajnu varijabilnost količina aflatoksina u uzorcima lješnjaka sakupljenih na hrvatskom tržištu, pri čemu je tri od 19 uzoraka sadržavalo količine više od 4 µg/kg.

Izražena varijabilnost čimbenika koji utječu na stvaranje aflatoksina otežava mjere kontrole kontaminacije lješnjaka tim mikotoksinima (Kuiper-Goodman, 2004; Magan i Aldred, 2007; Ozay et al., 2008). Ipak, određena ključna saznanja i pojedini znanstveni dokazi mogu pružiti odgovarajuće smjernice proizvođačima. Stvaranje aflatoksina u izravnoj je vezi s razvojem toksigenih *Aspergillus* vrsta na plodovima, čiji su optimalni uvjeti za razvoj temperature 25 – 30 °C te relativna vlažnost 97-99% (Klich, 2007; Yu, 2012). Prvi korak u sprječavanju stvaranja aflatoksina je sprječavanje naseljavanja i razvoja gljiva iz roda *Aspergillus* na plodovima. Kako je napomenuto, kritično razdoblje za kontaminaciju lješnjaka aflatoksinima je razdoblje pred berbu i sama berba (Ozay et al., 2008). Kako berba lješnjaka najčešće podrazumijeva skupljanje s tla, tlo je preporučljivo održavati što je više moguće sušlje. Utvrđeno je da vlažnost tla i razdoblje kontakta lješnjaka s tlom imaju izravnu vezu s naseljavanjem gljiva na plodove i razinom kontaminacije plodova (Ozay et al., 2008; Pscheidt et al., 2019). Ozay et al. (2008) u trogodišnjoj su studiji pokazali da voćnjak, okolišni uvjeti vlage i temperature, sezona i način sušenja lješnjaka nisu imali značajan utjecaj na količinu aflatoksina. Jedini značajna razlika utvrđena je između plodova koji su bili u kontaktu s tlom i onih koji nisu. Značajne razlike u naseljavanju gljiva na lješnjake na vlažnom tlu i prosušenom tlu potvrdili su i Pscheidt et al. (2019). Kontakt plodova s tlom potrebno je tijekom berbe smanjiti na najmanju moguću mjeru. Druga ključna mjera u upravljanju rizikom od kontaminacije aflatoksinima je brzo i učinkovito sušenje plodova te njihovo skladištenje u suhim uvjetima. Kako je spomenuto, toksigene *Aspergillus* vrste zahtijevaju vlagu za svoj razvoj na plodovima. Brzo sušenje lješnjaka na 6% vlage te njihovo uskladištenje u suhim uvjetima smanjuju ili onemogućavaju razvoj gljiva na njima (Magan i Aldred, 2007; Ozay et al., 2008; Fontana et al., 2014). U istraživanju Valente et al. (2020) istraživan je učinak pet različitih temperatura sušenja na razvoj *A. flavus* i stvaranje aflatoksina na umjetno inokuliranim plodovima. Aflatoksin se stvarao u slučajevima sušenja pri temperaturama od 30 °C i 35 °C, dok se *A. flavus* razvijao još i nakon temperature sušenja od 40 °C. Razvoj gljive bio je značajno manji, a aflatoksini se nisu stvarali nakon sušenja na 45 °C i 50 °C. Autori preporučuju temperaturu od 45 °C kao minimalnu preporučenu za sušenje lješnjaka. U Turskoj, Ozay et al. (2008) preporučuju sakupljanje plodova u jutene umjesto u najlonske vreće tijekom berbe i za vrijeme sušenja. U jutenim vrećama prozračnost je veća, što može utjecati na razvoj gljiva na plodovima. Osim tijekom berbe i sortiranja, učinak vlažnosti na stvaranje aflatoksina može biti značaja i tijekom skladištenja (Magan i Aldred, 2007). Gurses et al. (2001) utvrdili su značajno slabije stvaranje aflatoksina na lješnjacima uskladištenima na 85% relativne vlažnosti u odnosu na one uskladištene na 95% relativne vlažnosti. Sličan značajan učinak vlažnosti tijekom skladištenja na stvaranje aflatoksina na lješnjacima zabilježili su i Sanchis et al. (1988).s Skladišta lješnjaka trebala bi biti suha, pri čemu je plodove zbog očuvanja svih parametara kvalitete svakako najbolje skladištiti u skladištima s kontroliranom atmosferom. Treća preventivna mjera u sprječavanju kontaminacije aflatoksinima je učinkovito sortiranje plodova prije skladištenja, kojom se odvajaju oštećeni plodovi i plodovi napadnuti gljivama („pljesnivi“ plodovi). U istraživanju Şen (2021), čitavi i vizualno neoštećeni plodovi sadržavali su samo tragove aflatoksina, dok su oni „pljesnivi“ sadržavali količine do čak 433 µg/kg. Neizravno, sve mjere koje se poduzimaju tijekom vegetacije da bi se spriječilo oštećenje plodova, kao što su suzbijanje štetnika i bolesti, mogu imati učinak na kontaminaciju aflatoksinima (Fontana et al., 2014).

Osim preventivnih mjera sprječavanja pojave i razvoj aflatoksina, danas se intenzivno istražuju i mogućnosti detoksifikacije, odnosno uklanjanja mikotoksina na biljnim proizvodima. Na lješnjacima, vrlo dobri rezultati uklanjanja aflatoksina postignuti su tretiranjem „hladnom atmosferskom plazmom“, ionizirajućom mješavinom dušika i vodika pod naponom (Siciliano et al., 2016; Sen et al., 2019). Tretman ozonom pokazao se učinkovitim u smanjenju količine aflatoksina na sjemenkama kikirikija (Proctor et al., 2004), a smanjenje aflatoksina na lješnjacima postignuto je i gama-zračenjem (Sen et al., 2019). Na temelju navedenoga vidljivo je da je prisutan brz razvoj novih tehnologija kojima bi se tehnološki i ekonomski prihvatljivima fizikalnim ili fizikalno-kemijskim metodama mogla učinkovito smanjiti ili ukloniti pojava aflatoksina. Takve tehnologije zasigurno će polako ulaziti u praksu te predstavljati velik korak u rješavanju problematike mikotoksina u hrani.

ZAKLJUČAK

S obzirom da se lijeska u Republici Hrvatskoj sve više kultivira, a u svijetu se sve više pridaje pažnje kakvoći i zdravstvenoj ispravnosti plodova lupinastih voćnih vrsta, proizvođači su primorani ovladati tehnologijama koji se odnose na berbu i postupke nakon berbe. U cijelom tom procesu pravodobna berba, pravilno sušenje, zadovoljavajući uvjeti tijekom skladištenja te postupci povezani s sprječavanjem kontaminacije mikotoksinima su nužni kako bi se postigla (zadržala) zadovoljavajuća kakvoća lješnjaka. U posljednje vrijeme došlo je do razvoja novih metoda kojima se poboljšava mogućnost očuvanja kakvoće lješnjaka, kao korištenje modificirane atmosfere ili primjena novih tehnologija u uklanjanju mikotoksina, što će značajno doprinijeti osiguranju kvalitete lješnjaka, uz preduvjet njihove isplativosti.

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