Avrupa Bilim ve Teknoloji Dergisi
Sayı 14, S. 39-48, Aralık 2018

Derleme Makale

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
No. 14, pp. 39-48, December 2018

Review Article

Patulin Contamination in Fruit Juices and Its Control Measures

Ahmet Erdoğan[2], Dipak Ghimire[2], Mustafa Gürses[2], Bülent Çetin[2], Alper Baran[1*]

[1] Atatürk Üniversitesi, Erzurum Meslek Yüksekokulu, Gıda Kalite Kontrol ve Analizi Programı, Erzurum, Türkiye
[2] Atatürk Üniversitesi, Ziraat Fakültesi, Gıda Mühendisliği Bölümü, Erzurum, Türkiye

(First received 19 June 2018 and in final form 23 October 2018)

(DOI: 10.31590/ejosat.434750)

Abstract

Patulin is a mycotoxin produced by some Penicillium, Aspergillus, and Byssochlamys mold species. It has been found to impose many adverse health effects, and frequently detection in commercial fruit juices and apple products makes it a public health concern. The most important organism responsible for the patulin contamination in apple and derived products is Penicillium expansum (P. expansum). There are many studies on inhibition of P. expansum growth in apples/fruits and reduction of patulin contamination in fruit products, however, it remains as a major contamination problem in these products all around the world. The contamination of Patulin in apple and other fruit derived products could be prevented by using of various physical, chemical, and biological control methods. The preventive measures such as Good Pre-harvest and Post-harvest Practices in combination with processing hurdles could be the best solution to avoid the contamination. Researches and development to improve the current technologies, understanding and optimization the novel technologies also could serve the best solutions to eliminate the problem.

Keywords: Patulin, fruit juice, molds, Penicillium expansum.

1. Introduction

1.1. Patulin

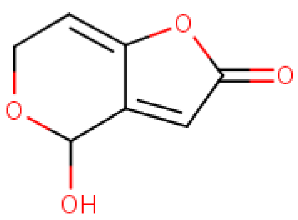

Figure 2. D structure of patulin

Patulin is a fungal secondary metabolite that produced by some Penicillium, Aspergillus and Byssochlamys mold species. It was originally isolated from Penicillium patulum (now Penicillium griseofulvum), later found to be produced by other fungi species too (Jha, 2016). This toxin had been originally discovered as a water-soluble broad spectrum lactone antibiotic in 1940 (Moake et al., 2005), but during the 1960s it was found to be toxic to biological systems comprising of bacteria, mammalian cell cultures, higher plants, and animals. The adverse effects of patulin in biological systems are genotoxicity, carcinogenicity, embryotoxicity, and teratogenicity, immunotoxicity, and genotoxicity (Hayes et al., 1979; C. S. Reddy et al., 1979; Selmanoğlu, 2006). Regarding the carcinogenicity of this toxin, the International Agency for Research on Cancer (IARC) has classified it in Group: 3, not classifiable as to its carcinogenicity to humans.'

The level of Patulin in food is regulated in many countries, including the European Union (EU) at the levels of 50 µg/kg in fruit juices and apples, 25 µg/kg in solid apple products and 10 µg/kg in apple-based products intended for infants (EU, 2003). Its provisional maximum tolerable daily intake (PMTDI) has been set to 0.4 µg/kg/day by Joint FAO/WHO Food Standard Program, CODEX Committee on Contaminants in Food (Alimentarius, 2017).

1.2. Patulin producers

Penicillium expansum is a common spoilage mold in apple and other fruits. But some other molds from the genus Aspergillus and Byssochlamys e.g., Byssochlamys nivea (Dombrink-Kurtzman et al., 2006; Roland et al., 1984), Aspergillus clavatus (Lovett et al., 1978) have been found to produce patulin in varieties of fruits, also. Penicillium expansum is capable of producing patulin in a variety of fruits including apple, apricot, kiwi, peaches, and plum (K. R. Reddy et al., 2010). Chunmei et al. (2013) reported that the Aspergillus and Penicillium molds (Aspergillus sydowii, A. oryzae, Penicillium expansum, P. purpurogenum, P. chrysogenum, P. purpurogenum, P. griseofulvum, P. roqueforti, P. miczynskii) in grapes can produce the patulin in Potato Dextrose Broth (PDB).

Fruits are liable to spoilage and patulin contamination by

[1] Corresponding Author: Atatürk Üniversitesi, Erzurum Meslek Yüksekokulu, Gıda Kalite Kontrol ve Analizi Programı, Erzurum, Türkiye, alper.baran@atauni.edu.tr

toxigenic fungi (Chunmei et al., 2013). The internal (seed cavity) and external parts (surface) of fruits are host for a variety of molds. In apple, P. expansum, A. flavus, A. Pullulans, Botrytis cinerea, Byssochlamys nivea, Cladosporidium spp., Mucor spp, Alternaria spp.,

Rhizopus spp. etc. are the most encountered mold species (Cunha et al., 2014; Tournas et al., 2009). Among the many pathogenic fungi which are commonly associated with spoilage of fruits and fruit products, Penicillium expansum is in the center of research interests because of its ubiquitous nature within agricultural environments. And also, it's well known that it can be contaminate the various food products. It is a causative agent for a devastating fruit disease 'blue mold spoilage' and it has a high capability to produce patulin in spoiled fruits (Wright, 2015). Fruit and fruit products including apples, apricots, grapes, pears, peaches, sour cherry, black currant, orange, pineapple, strawberry, cranberry, and passion fruit etc. are susceptible to possibly contamination from this microorganism (Moake et al., 2005). In some particular cases, spoiled apples have been found to contain an extremely high level of patulin; concentrations ranging from 800–12.500 ppb (K. R. Reddy et al., 2010), 0.002-113.343 ppm (Beretta et al., 2000), 1.01-120.40 ppm (Celli et al., 2009) in rotten tissues.

Over the years, many studies have been carried out to understand the microbial community, their ability to produce patulin in fruits and derived products using a variety of models; mostly on apple and in vitro models. The level of mold growth and subsequent production of patulin can vary depending on the types of the fruit, toxigenic properties of mold caused the contamination (Karina Juhnevica, 2011; Morales et al., 2008; Paster et al., 1995; K. R. Reddy et al., 2010; Salomao et al., 2009; Tournas et al., 2009) and environmental factors such as water activity, temperature nutrients, pH and acid contents, texture of the fruit, storage air composition etc. (McCallum et al., 2002; Salomao et al., 2009). However, as already discussed above, the type of invading fungi and level of patulin production in fruits are variable depending on environmental factors and physicochemical properties of the fruit (Cunha et al., 2014; S. Marín et al., 2006; Salomao et al., 2009; Sommer et al., 1974) and thus, the presence of patulin-producing fungi does not always ensure the presence of patulin in fruit and fruit products (Moss, 2008). Nevertheless, the interaction between the causative agents, the physicochemical properties of the host and external environment seems to play important role in patulin production by molds in the fruits/apple.

1.3. The occurrence of patulin in fruits and fruits derived products

The contamination of Patulin in fruit and fruit-derived products, especially in apple and derived products is very common worldwide. A list of Patulin level recorded in fruits and fruit products during 2000-2011 summarized by Sonia Marín et al. (2011). This list show that the few records from Turkey, Iran, and Italy, and one record from Spain. We've tried to give a summarized view on the status of Patulin contamination of fruit and derived products in the Table 1.

Table 1. *Some selected records of incidence of patulin in fruits and derived products*

Fruit Products	Country	Total positive samples	Range (ppb)^a	>50 ppb^b	Mean (ppb)^c	References
Apple juices Nectars, jams, Baby foods Concentrates- Apple Pear peach	Spain	7.1% 0 42.4% 50.0% 26.7%	6.0 - 74.4 126.9 21.3	0 0 5/34 5/10 0	ng ng ng ng ng	(Sonia Marín et al., 2011)
Apple juice; Organic conventional	Belgium	 12.3% 13.3%	 122.6 15.6	 2/65 0/65	 8.8±17.8 4.1±2.1	(K. Baert et al., 2006)
Apple, orange and grape juice	South Korea	87.5%	30.9	0/65	ng	(Cho et al., 2010)
Fruit juices	Serbia	51.40%	65.4	1/142	4.3 ± 8.6	(Torovic et al., 2018)
Apple juice	Japan	2.1%	15.0	0/140	8±3	(Watanabe et al., 2005)
Apple based drinks	Brazil	3%	7.0	0	ng	(Iha et al., 2008)
Apple Juice	Tunisia	64.28%	122.3	12/42	45.71±6	(Zouaoui et al., 2015)
Apple juice	Quatar	100%	82.2	25%	35.37±1.6	(Hammami et al., 2017)

Baby apple juice	Quatar	100%	61.3	50%	30.67± 6.7	(Hammami et al., 2017)
Apple Juice	Turkey	25%	281.4	18.75 %	ng	(Oskay, 2012)
Apple Juice	China	87.4%	94.7	16%	20.4	(Yuan Yuan et al., 2010)
Commercial apple products	India	18%	112.2	ng	ng	(G. S. Chandra et al., 2016)
Apple Juice	China	100%	78	4/198 7	ng	(Y. GuoZhou et al., 2013)
Mixed Juice	Tunisia	50%	55.7	2	28.5±3.9	(Zouaoui et al., 2015)
Apple based beverages (retail)	USA	23%	2700	11.3%	226.0±85.4	(Harris et al., 2009)
Apple cider (from cider mills)	USA	18.7%	473	2.2%	36.9±7.2	(Harris et al., 2009)
Pear Juice	Tunisia	47.6%	231	9/42	62.5±12.3	(Zouaoui et al., 2015)
Apple Juice	Iran	100%	173	3/8	71.87±25.26	(Azizi et al., 2013)
Apple leather	Iran	100%	2559	32/35	620	(Montaseri et al., 2014)
Apple and pear product	Tunisia	22.4%	889	48/24	89 ± 13.6[d]	(Zouaoui et al., 2015)
Apple juice Tomato Products	Portugal	44.4% 35.7%	45.77 47.72	0/9 0/35	ng	(Cunha et al., 2014)
Dried Fig	Turkey		151.6		ng	(Karaca et al., 2006)
Dried longans Dried figs	China China	90.4% 61.9%	194.3 278.9	11/21 12/21	68.4 87.6	(Ji et al., 2017)
Concentrated juice	Tunisia	80%	889	12/30	158.1±46.5	(Zouaoui et al., 2015)
Pear Jam	Tunisia	43.7%	554	4/16	123.7±4	(Zouaoui et al., 2015)
Apple Jam	Tunisia	33.3%	554	4/15	302±9.6	(Zouaoui et al., 2015)

([a]) maximum concentration reported.

([b]) number or percentage of samples containing more than 50 ppb patulin.

([c]) patulin mean concentration in the total analyzed samples.

([d]) mean patulin concentration of the positive samples only.

ng- not given

2. Control of Patulin Contamination in Fruit and Fruit Products

Surface and cores of fruits indigenously contain a diversity of microorganisms including the patulin producing species. However, the infection by these microorganisms and patulin production occur only after the available molds find a way through the protective layer of skin or seed cavity to the soft tissue. The major causes of this type of infection are insect infestation, diseases, and physical hazards. Therefore, the best way to avoid the patulin contamination in fruit products is to avoid the pest infestations and physical hazards when in the orchard, during harvesting, transportation, and storage.

The utmost important way to avoid contamination of patulin in fruit and fruit-derived products is Good Agricultural Practices (GAPs) and Good Manufacturing Practices (GMPs) during processing and production. In the context of reducing the hazardous level of microorganisms and their toxins, Food and Agriculture Organization of the United Nations (FAO) has recommended a set of good agricultural and manufacturing practices. The measures start from implementing good commercial practice and disease control measures in the orchard. Precautions during harvesting and transportations such as handling the fruits carefully to minimize the physical damage and contamination by soil, carefully selecting the fruits intended for immediate marketing, processing, and long-term storage, careful monitoring of storage conditions such as humidity, temperature, gas composition and rot damage during storage are important. In the processing of plant, GMP such as quality inspection of the fruits before processing, sorting to remove damaged fruits, pressure washing the fruits are some of the practices which help to minimize the contamination by the toxin (Alimentarius, 2003).

Storage parameters such as temperature, humidity, and air composition can affect the spoilage levels of stored fruit by P. expansum and subsequently the Patulin content of products as indicated in many studies. Controlled Atmospheric (CA) storage has been found to be effective in controlling the mold growth and patulin production; the low oxygen content (1.5-2.5%) and high carbon dioxide (up to 3%) has been seen to be a promising environment for long-term storage (Karina Juhnevica, 2011; Paster et al., 1995). Although CA storage gives the opportunity to store apples for long period, the risk of mold growth and patulin contamination also increases with increased storage time. CA stored apples have been found to increase patulin level in juice as compared to juice prepared from freshly harvested/picked apples and also, the increased deck storage time before processing causes a significant increase in patulin level in apple juice (Katleen Baert et al., 2012).

The major part of the patulin which is present in fruits is removed or degraded during processing (Bandoh et al., 2009; Gökmen et al., 2001; Moss et al., 2002; Sydenham et al., 1995). Processing steps such as sorting and grading, washing, depectinization, pasteurization, fermentation etc. can significantly remove the patulin from the juice. Acar reported that the patulin found in the fruit decreased by 54% using washing methods. Acar et al. (1998) reported that the level of patulin found in the fruits decreased by more than 54% using high-pressure water washing of the fruits, clarification, and filtration of the juice. It was demonstrated that removal of the decayed part and washing significantly reduces the patulin (Bandoh et al. (2009)). Also according to this study selecting spoiled fruits and removing spoiled parts could be a cumbersome work to perform in factory-scale processing. Alcoholic fermentation during cider processing has been shown to degrade the patulin completely. The efficiency of fermentation to remove patulin has been found to be affected by the yeast strain used and fermentation conditions (Moss et al., 2002; Stinson et al., 1978).

Apart from the above-mentioned methods which are the integral part of a fruit product production chain, there are many other methods which can control the growth of P. expansum, other toxigenic molds and subsequent patulin production as well as remove/degrade patulin which is already present in fruit juices. Some of the widely studied and promising methods are described below.

2.1. Biological Control measures

The biological control measures including both the prevention of growth and patulin production by fungi as well as removal of the patulin from products are using microorganisms and their enzymes. Several antagonist microorganisms and their extracts to inhibit mold growth and patulin production have been successfully tested in apples and laboratory culture media by many researchers. Successfully using of antagonist yeasts; Pichia caribbica (Cao et al., 2013), Torulaspora delbrueckii and Candida membranifaciens in combination with silicon (Ebrahimi et al., 2012), (Farahani et al., 2012), Cryptococcus albidus KKUY0017 and Wickerhamomyces anomalus KKUY0051 have been reported. Some Lactic Acid Bacteria (LAB) and their cell-free supernatants and peptides have also been found to inhibit P. expansum and other patulin producing molds (Gourama, 1997; Luz et al., 2017). Dip treatment of Pseudomonas fluorescens isolates cell suspension (1×108) on McIntosh and Spartan apples just before dip treatment with P. expansum spore suspension (1×104) have been shown to inhibit the mold growth on apples at commercial cold storage. The inhibition obtained by these P. fluorescens isolates (isolate 1-112, 4-6 on McIntosh and 2-28 on Spartan) have been reported to be comparable with the commercial fungicides (BioSave and Scholar) tested in that study during commercial cold storage at 10C. The proposed mechanisms of inhibition are the competition for the nutrients and space and production of metabolites which inhibit the spore germination and mycelial growth (Wallace et al., 2017). Similarly, Zhou et al. (2001) have successfully achieved the control of P. expansum and Botrytis cinerea using Pseudomonas syringae (P. syringae) isolates (MA-4, MB-4, MD-3b, and NSA-6) during 28 days of storage at 40C. They have also reported that the efficiency of P. syringae MA-4 applied by dip treatment on ‘Empire’ and ‘Delicious’ apples was more pronounced than BioSave™ (a commercially available biofungicide) of under controlled atmospheric conditions. The concentrations used for this experiments were 1×107 cfu/ml P. syringae and 1×103 spores/mL of the molds spores suspension (Zhou et al., 2001). The combination of antagonists with physical and chemical control agents has been found to be more efficient than if the only a single agent is used (Ebrahimi et al., 2012; Hossein Ahari Mostafavi et al., 2011).

Efficient removal of patulin from fruit juices using yeasts, bacteria and their extracts or supernatants and molds have also been reported by some researchers (Hatab et al., 2012). Hatab et al. (2012) have reported that patulin is removed by both live and dead cells of the LAB and the removal of the patulin was dependent on specific temperatures for specific strains. The lower level of patulin in the medium has been found to increase the efficiency of removal. Yuan et al. (2014) reported that the patulin from juice containing 100 ppb decreased by 88% with the using of 49 g/L of inactivated Alicyclobacillus spp, And also, X. Zhang et al. (2016)) reported that they have removed of patulin from media containing as much as 500 ppb patulin by using a non-patulin-producing strain of Byssochlamys nivea (FF1-2). In another study, caustic treatment of cider yeast biomass was also found to be effective in removing patulin from fruit juice. Immobilizing the biomass in Ca-Alginate was superior in removing patulin with optimal operating pH of 4.5 (Caixia GuoYue et al., 2013).

The mode of action for growth inhibition and patulin removal is not understood adequately, however, it has been given foresight by some researchers. Initially, the inhibition of patulin production might be due to competition for the space and nutrition available, production of biologically active compounds by antagonist rivals, direct predation of mold spores and hyphae by antagonists microorganism (Pimenta et al., 2008), induction of pathogenesis resistant protein accumulation in fruits (Quaglia et al., 2011) etc. Zheng et al. (2017) have reported that inhibition of toxin production by P. expansum co-inoculated with antagonist yeast is due to the the inhibition of mycellial growth of P. expansum by the antagonist. The primary mechanisms of biological removal of patulin proposed are; the biosorption of patulin by microbial cells (C. Guo et al., 2012; Caixia GuoYue et al., 2013; Wang et al., 2015), degradation of patulin by microbial enzymes (R. Zhu et al., 2015), patulin-glutathione adducts or reaction of patulin with thiol group present in protein extracts and therefore destroying its functional properties (Folger, 2014; Luz et al., 2017). The presence of patulin in growth media induces the synthesis of patulin degrading enzymes in patulin resistant/degrading yeasts (Zheng et al., 2016; R. Zhu et al., 2015).

As like the mechanism of inhibition or degradation, degradation products are also not well understood. However, some degradation products have been characterized so far. Patulin is degraded to E-ascladiol and Z-ascladiol by Saccharomyces cerevisiae (Y. Chen et al., 2017; Moss et al., 2002), to hydroascladiol by L. plantarum (Hawar et al., 2013; Zheng et al., 2016), desoxypatulinic acid by Rhodosporidium paludigenum which is significantly less toxic than the parent molecule (R. Zhu et al., 2015).

2.2. Chemical Control Measures

Many chemical substances have been successfully tested for their antifungal properties against P. expansum and other patulin producing molds. Application of phenolic compounds like quercetin, umbeliferone, and ferolic acid on Granny Smith and Golden delicious apples by dip and wound application (Sanzani et al., 2009). Isothiocyanates bioactive packaging in the concentrations of 50, 100 and 200 ppb (Saladino et al., 2016) have been found to be effective in controlling P. expansum on apples. Monoterpenoids and essential oils from plants extracts (Kadoglidou et al., 2011), garlic extract on PDA and garlic vapor exposure on apples have shown significant inhibition of P. expansum growth (Ikeura et al., 2011). Significant inhibition in the rate of spore germination of P. expansum inoculated in apples and pears by exogenous potassium phosphite have been reported by Lai et al., 2017. β-aminobutyric acid (C. Zhang et al., 2011), gamma-aminobutyric acid and beta-aminobutyric acid (Fu et al., 2017) have also been reported. Boric acid (Lai et al., 2016), potassium sorbate, and sodium propionate have also been successfully applied to control P. expansum growth and patulin production (Lennox et al., 1984). Sodium hypochlorite and hydrogen peroxide have been found to inhibit the P. expansum spore germination and mycelia growth (Cerioni et al., 2013; L. Chen et al., 2004). Similarly, acetic acid wash treatment (2-5%) have been found to be effective against P. expansum growth in apples (L. Chen et al., 2004). Acetic acid vapor treatment (6 microliters/L) for 24 hours has also been effective against Penicillium sp. and Botrytis cinerea (Fotouh, 2009) in apples.

Ozone treatment of apple juice has also been found effective in removing patulin. Hakan Karaca (2009) have demonstrated that ozone treatment at the residual concentration of 0.19 mg/L is enough to remove more than 98% of patulin from media containing 250 ppb patulin. The effect of different metal ions on the efficiency of ozone to degrade patulin has also been reported in the same study. Manganese had been found to have inhibitory effect and aluminium, copper, zinc, and calcium, a promotive effect on the degradation of patulin. This indicates that the various metal ions juice samples could affect the efficiency of the degradation process (Hakan Karaca, 2009). Similarly, degradation of patulin by ozone treatment has been demonstrated in other studies, too (Cataldo, 2008; Julius, 2010). Ascorbic acid and ascorbate which are naturally present in apple have been found to reduce the patulin in the apple juice but the reduction has low without added ascorbic acid (Drusch et al., 2007; Fremy et al., 1995; Yun et al., 2008). However, the ascorbic acid in the presence of light and oxygen has been reported to cause rapid degradation of patulin. Free radicals produced by metal oxidation of ascorbic acid and free metal ascorbate complex has been attributed to the degradation of patulin (Drusch et al., 2007). Sulfur dioxide was also used in some studies and some contradictory results were reported. Burroughs (1977) reported that SO_2 at level of <200 ppm, which is the maximum permitted limit in use in food applications were not effective in degrading patulin. The researcher reported that 2000 ppm of SO_2 treatment for 2 days was able to degrade 90% of 15ppm patulin (Burroughs, 1977). However, Ough et al. (1980) have reported that adding 100 ppm of patulin in grape juice containing 25 ppm has caused 54% reduction in patulin after only 15 minutes concentrations (Burroughs, 1977; Ough et al., 1980). Since the concentration of patulin used in these studies is so high which are unlikely to present in fruit juices in the market, the lower concentration of SO_2 might also be useful for patulin reduction in fruit juices.

2.3. Physical Control measures

Irradiation has widely been studied for its ability removal of patulin from in fruit juices. Gamma rays and UV-lights have been found to be effective as demonstrated in many studies (Assatarakul et al., 2012; S. Chandra et al.; Żegota et al., 1988; Y. Zhu et al., 2014). The efficiency of UV-radiation was negatively affected by suspended particles, tannic acids in juices and ciders and increased by fructose (Tikekar et al., 2014). Malic acid, lactic acid, and ascorbic acid, which are the organic acids predominantly present in apple, have been shown to inhibit the radio degradation of patulin in an aqueous medium. No information of degradation products could be found. Although, the degradation product is not well understood, G. S. Chandra et al. (2016) have reported that the UV-C irradiated apple juice which contained 200 ppb patulin had significantly lower toxic effect (cell viability 81.64%) on human peripheral blood cells as compared to the UV-C untreated juice (cell viability 43.6%) which indicates that the degradation products is less toxic than patulin.

Adsorption removal of patulin from apple juice has also been widely studied and shown a great potential for use in industrial scale. Adsorbent materials prepared from chitosan e.g., using magnetic chitosan (chitosan mixed with Fe_3O_4), adsorption of up to 19 mg patulin per gram of the adsorbent with recovery of adsorbent more than 99.5% have been reported by Luo et al. (2016). In an another study, inactivated Candida utilis CICC1769 strain immobilized in chitosan nanoparticles was able to remove 91.5% of patulin from juice containing 500 ppb at 200C during 15 hours of treatment and the amount of the adsorbent used was just 0.5g/L (Ge et al., 2017). In all the above-mentioned studies, no significant changes in quality parameters of juice have been observed.

Similarly, several reports are available on the use of activated carbon to remove patulin from apple juice. Some researchers have reported that the using of activated carbon has negative effects on quality of juice (Bahram Fathi-Achachlouei, 2007; C. Kadakal et al., 2002), but this is not always the case. The method of carbon activation has been found to significantly affect the quality of juice treated with activated carbon; the steam activation has been found to remove patulin more efficiently and without significant effect on quality parameters of juice with compared to acid wash activated carbon (Leggott et al., 2001). Another simple solution might the entrapping activated carbon in calcium-alginate beads. This method has been found to be efficient in removing patulin from apple juice and without significant effects on quality parameters (Yue et al., 2013). The mechanism of removal patulin was adsorption of patulin in micropores formed during the activation process and different activation process result in different pore sizes and their distribution in the material (Leggott et al., 2001).

High Hydrostatic Pressure, which is a non-thermal food processing method, has also been found to be effective in removing patulin from apple juice (Avsaroglu et al., 2015; Luo et al., 2016). But the knowledge of the degradation product is lacking.

3. Conclusions

Patulin contamination in fruit juices is a serious quality and consumer safety problem. Many plants, animal, and microbial study have concluded its adverse health effects and thus the suitable and adequate measures to control its presence in fruits' products are necessary.

To avoid the patulin contamination in fruit products, control measures should be implemented throughout the entire product chain, i.e. from the orchards itself to the processing and distribution. The physical damages caused by insect infestation and poor handling while in orchard, harvesting, transportation, storage etc. could allow the pathogenic molds to infect the fruit and start spoilage. Application of Good Pre-harvest and Post-harvest Practices could limit the physical damages and insect infestation, and subsequently infections by toxigenic fungi and patulin production. Good Commercial Practices (GCPs), Good Agricultural Practices (GAPs) in orchards, and Good Manufacturing Practices (GMP) during juice manufacturing are the most prominent solutions as suggested by FAO (Alimentarius, 2003) and is clearly evident in many studies. Carefully designing the storehouse parameters (temperature, humidity, CO2 and O2 level) could reduce the incidence and extent of molds in stored apples (Karina Juhnevica, 2011; Morales et al., 2008; Paster et al., 1995; K. R. Reddy et al., 2010). Use of fungicides is also a good preventive measure but there are issues with chemical fungicides such as a residue and their toxicity, resistance development by the fungal strains, and impact on environment etc. However, this could be solved by the rotational use of fungicides or combination with another suitable fungicide or antagonist organisms (Errampalli et al., 2004; Zhou et al., 2002).

Different processing steps of apple juice production could significantly remove contaminants from fruit and the final product. Pressure washing, sorting, removing spoiled parts are the important steps of processing which could remove patulin from the spoiled fruits (Bandoh et al., 2009; Gokmen et al., 1998; Sydenham et al., 1995). However, some operations like sorting out the spoiled fruits and removing spoiled parts from the bulk might be labor intensive and might not be economically or technically feasible for all processors and may increase waste material. Clarification, centrifugation, and pasteurization also contribute significantly to the removal of patulin (Acar et al., 1998). But if the extent of spoilage and patulin content is high in raw materials, these processing steps might not be enough and further degradation and removal are required. However, whatever be the secondary measures to alleviate the problem, the primary step is to prevent the problem to occur in the first place i.e. the fruits to be used for juice and other product manufacturing should be free of spoilage.

Biological agents like live and dead microbial cells, enzyme, proteins and culture extracts of yeasts and LAB have been also shown to be a promising.

Enzymatic degradation, fermentation and adsorption by yeast, LAB and other microorganisms are the mechanisms involved in degradation or removal of patulin from fruit juices by biological agents (Hatab et al., 2012; Hawar et al., 2013; Moss et al., 2002; Y. Yuan et al., 2014; Zhou et al., 2001). The use of biological agents does not impart significant changes in quality too. However, the mechanisms of patulin removal have been illucidated to some extent, a thorough knowledge of the process is lacking. Further, an ideal condition for the efficient use of biological agents is difficult to obtain because the factors like pH of the medium, temperature, incubation time, microbial strain and concentration (Hatab et al., 2012), pre culture conditions (R. Zhu et al., 2015) affect the efficiency of removal or degradation. Also, the breakdown products and their toxicity are poorly known although some progress has been made in recent years in understanding the process. So, further work is required to fully understand the mechanisms and safety of these methods as well as to develop an optimal set of parameters to use in fruit juice industry.

Use of adsorbents like activated carbon and chitosan resins are other promising solutions. Adsorbent materials like activated carbons (C. Kadakal et al., 2002) and modified chitosan resins have been found efficient in removing patulin from fruit juices in laboratory conditions. The use of modified chitosan resins like thiouria modified chitosan resin, magnetic chitosan have shown good efficiency of patulin removal and these adsorbents seem to have no significant effects on juice quality too (Anene et al., 2016; Ge et al., 2017; Leggott et al., 2001; Liu et al., 2015; Luo et al., 2016). The mechanism of removal is also quite clearer compared to other methods and there is no risks of degradation products' toxicity if the adsorbent is selected carefully and sufficiently recovered from the juice (Luo et al., 2017).

Thermal pasteurization, which is a processing step of apple juice production could reduce patulin from fruit juices to some extent. But, given the stable nature of the patulin at lower pH, thermal pasteurization alone could not be considered effective in removing patulin from fruit juices (Acar et al., 1998; Ç. Kadakal et al., 2003). However, non-thermal processing such as Irradiation (UV, Pulsed light, and gamma irradiation) and high hydrostatic pressure could be effective in removing patulin from apple juices (Assatarakul et al., 2012; Avsaroglu et al., 2015; G. S. Chandra et al., 2016; S. Chandra et al.; Funes et al., 2013; Y. Zhu et al., 2014). In fact, UV-pasteurization is already in use for apple cider pasteurization. It has been have reported that UV pasteurized cider had lower patulin content compared to conventional heat pasteurized ciders (Harris et al., 2009). The feasibility of the application, importantly the cost factor; as these methods require highly specialized equipment, may be the limiting factor for small-scale juice processors and again, the breakdown products and their toxicity are poorly known.

Use of chemical substances to control the patulin in fruit products has also been studied widely. Using of fungicides is already a commonly used method to prevent fungal growth and subsequent patulin production on fruit commodities. Substances like plant extracts and volatiles, phenolic compounds like isothiocyanates that are natural components of plants and apples are itself are also effective in controlling the growth of toxigenic molds in fruits and their uses are safe. Many of the chemicals which are allowed in food processing like ascorbic acid, SO2, hydrogen peroxide and others like ammonia and potassium permanganate also degrade the patulin (Drusch et al., 2007; Fremy et al., 1995; Hakan Karaca, 2009). But there is an inherent problem with chemical substances; there use in food processing is vigorously controlled and attracts too much attention. Also, the use of the chemicals only for reducing mycotoxin in juices might not be allowed in food laws. In addition, the degradation products and their toxicity are poorly understood. So, further studies are required to understand the mechanism and degradation products, optimal conditions and feasibility of application in industrial scale.

In conclusion, there are numerous substances and methods which can inhibit the growth of patulin producing fungi in fruits and remove patulin from fruit juices. Some of them have potential for wide application too, however, they could not be applied in all scale and types of processing as an ideal solution because the factors such as, variations in the microbial strains, physicochemical properties of the fruits and juice matrices, concentration of patulin in juice, environmental conditions etc. affect the efficiency of any method to inhibit the mold growth or remove patulin from juices. This is rather a multifaced problem and should be addressed by all the stakeholders of the apple juice production chain; from the apple farmers, transporters and storehouses to the processors, juice distributors, and quality control and health agencies too. Hurdle approach, GAPs, GMPs, regular monitoring, continuous research, and development to improve and understand the existing and emerging technologies could serve this purpose the best.

References

Acar, J., Gökmen, V., Taydas, E. E. 1998. The effects of processing technology on the patulin content of juice during commercial apple juice concentrate production. Zeitschrift für Lebensmitteluntersuchung und -Forschung A 207(4), 328-331.

Anene, A., Hosni, K., Chevalier, Y., Kalfat, R.Hbaieb, S. 2016. Molecularly imprinted polymer for extraction of patulin in apple juice samples. Food Control 70(Supplement C), 90-95.

Assatarakul, K., Churey, J. J., Manns, D. C., Worobo, R. W. 2012. Patulin reduction in apple juice from concentrate by UV radiation and comparison of kinetic degradation models between apple juice and apple cider. Journal of Food Protection 75(4), 717-724.

Avsaroglu, M. D., Bozoglu, F., Alpas, H., Largeteau, A., Demazeau, G. 2015. Use of pulsed-high hydrostatic pressure treatment to decrease patulin in apple juice. High Pressure Research 35(2), 214-222.

Azizi, I. G., Rouhi, S. 2013. Determination of patulin in fruit juices and compote of apple and pear. Toxin Reviews 32(3), 39-42.

Baert, K., De Meulenaer, B., Kamala, A., Kasase, C., Devlieghere, F. 2006. Occurrence of patulin in organic, conventional, and handcrafted apple juices marketed in Belgium. Journal of Food Protection 69(6), 1371-1378.

Baert, K., Devlieghere, F., Amiri, A., De Meulenaer, B. 2012. Evaluation of strategies for reducing patulin contamination of apple juice using a farm to fork risk assessment model. International Journal of Food Microbiology 154(3), 119-129.

Bahram Fathi-Achachlouei, A. A.Z., Y. Assadi, Hesari J. 2007. Reduction of patulin content in apple juice concentrate using activated carbon and its effects on several chemical constituents. Journal of Food, Agriculture & Environment 5(1), 12-18.

Bandoh, S., Takeuchi, M., Ohsawa, K., Higashihara, K., Kawamoto, Y., Goto, T. 2009. Patulin distribution in decayed apple and its reduction. International Biodeterioration & Biodegradation 63(4), 379-382.

Beretta, B., Gaiaschi, A., Galli, C. L., Restani, P. 2000. Patulin in apple-based foods: occurrence and safety evaluation. Food Additives and Contaminants 17(5), 399-406.

Burroughs, L. F. 1977. Stability of patulin to sulfur dioxide and to yeast fermentation. Journal - Association of Official Analytical Chemists 60(1), 100-103.

Cao, J., Zhang, H., Yang, Q., Ren, R. 2013. Efficacy of Pichia caribbica in controlling blue mold rot and patulin degradation in apples. International Journal of Food Microbiology 162(2), 167-173.

Cataldo, F. 2008. Ozone Decomposition of Patulin—A Micotoxin and Food Contaminant. Ozone: Science & Engineering 30(3), 197-201.

Celli, M., Coelho, A., Wosiacki, G., Boscolo, M., Cruz, C. G. 2009. Patulin determination in apples with rotten areas. World Mycotoxin Journal 2(3), 279-283.

Cerioni, L., Lazarte, M. d. l. Á., Villegas, J. M., Rodríguez-Montelongo, L., Volentini, S. I. 2013. Inhibition of Penicillium expansum by an oxidative treatment. Food Microbiology 33(2), 298-301.

Chandra, G. S., Baskaran, P. B. 2016. Patulin prevalence and detoxification profile in apple juices marketed in Chennai, India. Toxicology Letters 258(Supplement), 173.

Chandra, S., Patras, A., Pokharel, B., Bansode, R. R., Begum, A., Sasges, M. 2017. Patulin degradation and cytotoxicity evaluation of UV irradiated apple juice using human peripheral blood mononuclear cells. Journal of Food Process Engineering 40 (6), 1-9.

Chen, L., Ingham, B. H., Ingham, S. C. 2004. Survival of Penicillium expansum and Patulin Production on Stored Apples after Wash Treatments. Journal of Food Science 69(8), C669-C675.

Chen, Y., Peng, H.-M., Wang, X., Li, B.-Q., Long, M.-Y., Tian, S.-P. 2017. Biodegradation Mechanisms of Patulin in Candida guilliermondii: An iTRAQ-Based Proteomic Analysis. Toxins 9(2), 48.

Cho, M. S., Kim, K., Seo, E., Kassim, N., Mtenga, A. B., Shim, W.-B., Lee, S.H., Chung, D.H. 2010. Occurrence of patulin in various fruit juices from South Korea: An exposure assessment. Food Science and Biotechnology 19(1), 1-5.

Chunmei, J., Junling, S., Qi'an, H., Yanlin, L. 2013. Occurrence of toxin-producing fungi in intact and rotten table and wine grapes and related influencing factors. Food Control 31(1), 5-13.

Codex Alimentarius, 2003. Code of Practice for the Prevention and Reduction of Patulin Contamination in Apple Juice and Apple Juice Ingredients in Other Beverages.

Codex Alimentarius, 2017. General Standard For Contaminants and Toxins in Food and Feed (Vol. CXS 193-1995).

Cunha, S. C., Faria, M. A., Pereira, V. L., Oliveira, T. M., Lima, A. C., Pinto, E. 2014. Patulin assessment and fungi identification in organic and conventional fruits and derived products. Food Control 44(Supplement C), 185-190.

Dombrink-Kurtzman, M. A., Engberg, A. E. 2006. Byssochlamys nivea with patulin-producing capability has an isoepoxydon dehydrogenase gene (idh) with sequence homology to Penicillium expansum and P. griseofulvum. Mycological Research 110(9), 1111-1118.

Drusch, S., Kopka, S., Kaeding, J. 2007. Stability of patulin in a juice-like aqueous model system in the presence of ascorbic acid. Food Chemistry 100(1), 192-197.

Ebrahimi, L., Aminian, H., Etebarian, H. R., Sahebani, N. 2012. Control of apple blue mould disease with Torulaspora delbrueckii in combination with Silicon. Archives of Phytopathology and Plant Protection 45(17), 2057-2065.

Errampalli, D., Crnko, N. 2004. Control of blue mold caused by Penicillium expansum on apples 'Empire' with fludioxonil and cyprodinil. Canadian Journal of Plant Pathology 26(1), 70-75.

European Union Commission Regulation. 2003. (EC) No 1425/2003 of 11 August 2003 amending Regulation (EC) No 466/2001 as regards patulin (Text with EEA relevance). In E. Union (Ed.), (Vol. (EC) No 466/2001, pp. 1-3): Official Journal of European Union.

Farahani, L., Etebarian, H. R., Sahebani, N., Aminian, H. 2012. Biocontrol of blue mold of apple by Candida membranifaciens in combination with silicon. Archives of Phytopathology and Plant Protection 45(3), 310-317.

Folger, B. C. 2014. Patulin degradation by yeast protein extract. University of Minosita, Master of Science Dissertation, pp. 83, Minosita.

Fotouh, Y. O. 2009. Controlling grey and blue mould diseases of apple fruits using acetic acid vapours. Archives of Phytopathology and Plant Protection 42(8), 777-782.

Fremy, J. M., Castegnaro, M. J., Gleizes, E., De Meo, M., Laget, M. 1995. Procedures for destruction of patulin in laboratory wastes. Food Addit Contam 12(3), 331-336.

Fu, D., Sun, Y., Yu, C., Zheng, X., Yu, T., Lu, H. 2017. Comparison of the effects of three types of aminobutyric acids on the control of Penicillium expansum infection in pear fruit. Journal of the Science of Food and Agriculture 97(5), 1497-1501.

Funes, G. J., Gómez, P. L., Resnik, S. L., Alzamora, S. M. 2013. Application of pulsed light to patulin reduction in McIlvaine buffer and apple products. Food Control 30(2), 405-410.

Ge, N., Xu, J., Li, F., Peng, B., Pan, S. 2017. Immobilization of inactivated microbial cells on magnetic Fe3O4@CTS nanoparticles for constructing a new biosorbent for removal of patulin in fruit juice. Food Control 82(Supplement C), 83-90.

Gokmen, V., Acar, J. 1998. Incidence of patulin in apple juice concentrates produced in Turkey. Journal of Chromatography A 815(1), 99-102.

Gourama, H. 1997. Inhibition of Growth and Mycotoxin Production of Penicillium by Lactobacillus Species. Lebensmittel-Wissenschaft + Technologie 30(3), 279-283.

Gökmen, V., Artık, N., Acar, J., Kahraman, N., Poyrazoğlu, E. 2001. Effects of various clarification treatments on patulin, phenolic compound and organic acid compositions of apple juice. European Food Research and Technology 213(3), 194-199.

Guo, C., Yuan, Y., Yue, T., Hatab, S., Wang, Z. 2012. Binding mechanism of patulin to heat-treated yeast cell. Letters in Applied Microbiology 55(6), 453-459.

Guo, C., Yue, T., Yuan, Y., Wang, Z., Guo, Y., Wang, L., Li, Z. 2013. Biosorption of patulin from apple juice by caustic treated waste cider yeast biomass. Food Control 32(1), 99-104.

Guo, Y., Zhou, Z., Yuan, Y., Yue, T. 2013. Survey of patulin in apple juice concentrates in Shaanxi (China) and its dietary intake. Food Control 34(2), 570-573.

Karaca, H., Velioğlu, Y. S. 2009. Effects of Some Metals and Chelating Agents on Patulin Degradation by Ozone. Ozone: Science & Engineering 31(3), 224-231.

Hammami, W., Al-Thani, R., Fiori, S., Al-Meer, S., Atia, F. A., Rabah, D., Migheli, Q., Jaoua, S. 2017. Patulin and patulin producing Penicillium spp. occurrence in apples and apple-based products including baby food. Journal of Infection in Developing Countries 11(4), 343-349.

Harris, K. L., Bobe, G., Bourquin, L. D. 2009. Patulin surveillance in apple cider and juice marketed in Michigan. Journal of Food Protection 72(6), 1255-1261.

Hatab, S., Yue, T., Mohamad, O. 2012. Reduction of patulin in aqueous solution by lactic acid bacteria. Journal of Food Science 77(4), M238-241.

Hawar, S., Vevers, W., Karieb, S., Ali, B. K., Billington, R., Beal, J. 2013. Biotransformation of patulin to hydroascladiol by Lactobacillus plantarum. Food Control 34(2), 502-508.

Hayes, A. W., Phillips, T. D., Williams, W. L., Ciegler, A. 1979. Acute toxicity of patulin in mice and rats. Toxicology 13(Supplement C), 91-100.

Mostafavi, H. A., Mirmajlessi, S. M., Fathollahi, H., Minassyan, V., Mirjalili, S. M. 2011. Evaluation of gamma irradiation effect and Pseudomonas flourescens against Penicillium expansum. African Journal of Biotechnology 10(54), 11290-11293.

Iha, M. H., Sabino, M. 2008. Incidence of patulin in Brazilian apple-based drinks. Food Control 19(4), 417-422.

Ikeura, H., Somsak, N., Kobayashi, F., Kanlayanarat, S., Hayata, Y. 2011. Application of selected plant extracts to inhibit growth of Penicillium expansum on apple fruits. Plant Pathology Journal 10(2), 79-84.

Jha, S. N. 2016. Rapid Detection of Food Adulterants and Contaminants. Academic Press, pp. 266, San Diego.

Ji, X., Li, R., Yang, H., Qi, P., Xiao, Y., Qian, M. 2017. Occurrence of patulin in various fruit products and dietary exposure assessment for consumers in China. Food Control 78(Supplement C), 100-107.

Julius, A. G. 2010. Kinetics and Predictive Modeling of Patulin Degradation by Ozone in Apple Juice and Apple Cider. Pennsylvania State University, Master Dissertation, pp. 175, Pennsylvania.

Kadakal, C., Nas, S. 2002. Effect of activated charcoal on patulin, fumaric acid and some other properties of apple juice. Nahrung 46(1), 31-33.

Kadakal, Ç., Nas, S. 2003. Effect of heat treatment and evaporation on patulin and some other properties of apple juice. Journal of the Science of Food and Agriculture 83(9), 987-990.

Kadoglidou, K., Lagopodi, A., Karamanoli, K., Vokou, D., Bardas, G. A., Menexes, G., Constantinidou, H.I. A. 2011. Inhibitory and stimulatory effects of essential oils and individual monoterpenoids on growth and sporulation of four soil-borne fungal isolates of Aspergillus terreus, Fusarium oxysporum, Penicillium expansum, and Verticillium dahliae. European Journal of Plant Pathology 130(3), 297-309.

Karaca, H., Nas, S. 2006. Aflatoxins, patulin and ergosterol contents of dried figs in Turkey. Food Additives & Contaminants 23(5), 502-508.

Karina Juhnevica, G. S., Skudra, L. 2011. Evaluation of microbiological contamination of apple fruit stored in a modified atmospher. Environmetal and Experimental Biology 9, 53-59.

Lai, T., Wang, Y., Bai, X., Qi, Q., Xu, M., Zhou, T. 2016. Dissecting inhibitory effect of boric acid on virulence and patulin production of Penicillium expansum. Postharvest Biology and Technology 117(Supplement C), 187-196.

Lai, T., Wang, Y., Fan, Y., Zhou, Y., Bao, Y., Zhou, T. 2017. The response of growth and patulin production of postharvest pathogen Penicillium expansum to exogenous potassium phosphite treatment. International Journal of Food Microbiology 244(Supplement C), 1-10.

Leggott, N. L., Shephard, G. S., StockenstrÖm, S., Staal, E., Van Schalkwyk, D. J. 2001. The reduction of patulin in apple juice by three different types of activated carbon. Food Additives & Contaminants 18(9), 825-829.

Lennox, J. E., McElroy, L. J. 1984. Inhibition of growth and patulin synthesis in Penicillium expansum by potassium sorbate and sodium propionate in culture. Applied and Environmental Microbiology 48(5), 1031-1033.

Liu, B., Peng, X., Chen, W., Li, Y., Meng, X., Wang, D., Yu, G. 2015. Adsorptive removal of patulin from aqueous solution using thiourea modified chitosan resin. International Journal of Biological Macromolecules 80(Supplement C), 520-528.

Lovett, J., Thompson, R. G. 1978. Patulin Production by Species of Aspergillus and Penicillium at 1.7, 7.2, and 12.8 C. Journal of Food Protection 41(3), 195-197.

Luo, Y., Li, Z., Yuan, Y., Yue, T. 2016. Bioadsorption of patulin from kiwi fruit juice onto a superior magnetic chitosan. Journal of Alloys and Compounds 667(Supplement C), 101-108.

Luo, Y., Zhou, Z., Yue, T. 2017. Synthesis and characterization of nontoxic chitosan-coated Fe3O4 particles for patulin adsorption in a juice-pH simulation aqueous. Food Chemistry 221(Supplement C), 317-323.

Luz, C., Saladino, F., Luciano, F. B., Mañes, J., Meca, G. 2017. In vitro antifungal activity of bioactive peptides produced by Lactobacillus plantarum against Aspergillus parasiticus and Penicillium expansum. LWT - Food Science and Technology 81(Supplement C), 128-135.

Marín, S., Mateo, E. M., Sanchis, V., Valle-Algarra, F. M., Ramos, A. J., Jiménez, M. 2011. Patulin contamination in fruit derivatives, including baby food, from the Spanish market. Food Chemistry 124(2), 563-568.

Marín, S., Morales, H., Hasan, H. A. H., Ramos, A. J., Sanchis, V. 2006. Patulin distribution in Fuji and Golden apples contaminated with Penicillium expansum. Food Additives & Contaminants 23(12), 1316-1322.

McCallum, J. L., Tsao, R., Zhou, T. 2002. Factors affecting patulin production by Penicillium expansum. Journal of Food Protection 65(12), 1937-1942.

Moake, M. M., Padilla-Zakour, O. I., Worobo, R. W. 2005. Comprehensive Review of Patulin Control Methods in Foods. Comprehensive Reviews in Food Science and Food Safety 4(1), 8-21.

Montaseri, H., Eskandari, M. H., Yeganeh, A. T., Karami, S., Javidnia, K., Dehghanzadeh, G. R., Mesbahi, G. R., Niakousari, M. 2014. Patulin in apple leather in Iran. Food Additives & Contaminants Part B-Surveillance 7(2), 106-109.

Morales, H., Barros, G., Marín, S., Chulze, S., Ramos, A. J., Sanchis, V. 2008. Effects of apple and pear varieties and pH on patulin accumulation by Penicillium expansum. Journal of the Science of Food and Agriculture 88(15), 2738-2743.

Moss, M. O. 2008. Fungi, quality and safety issues in fresh fruits and vegetables. Journal of Applied Microbiology 104(5), 1239-1243.

Moss, M. O., Long, M. T. 2002. Fate of patulin in the presence of the yeast Saccharomyces cerevisiae. Food Additives & Contaminants 19(4), 387-399.

Oskay, N. 2012. Survey of Patulin Occurrence in Fruit Juices and Detoxification of Patulin by Lactic Acid Bacteria Anadolu University, Master of Science, pp. 107, Eskişehir.

Ough, C. S., Corison, C. A. 1980. Measurement of patulin in grapes and wines. Journal of Food Science 45(3), 476-478.

Paster, N., Huppert, D., Barkai-Golan, R. 1995. Production of patulin by different strains of Penicillium expansum in pear and apple cultivars stored at different temperatures and modified atmospheres. Food Additives & Contaminants 12(1), 51-58.

Pimenta, R. S., Silva, F. L., Silva, J. F. M., Morais, P. B., Braga, D. T., Rosa, C. A., Corrêa Jr, A. 2008. Biological control of Penicillium italicum, P. digitatum and P. expansum by the predacious yeast Saccharomycopsis schoenii on oranges. Brazilian Journal of Microbiology 39(1), 85-90.

Quaglia, M., Ederli, L., Pasqualini, S., Zazzerini, A. 2011. Biological control agents and chemical inducers of resistance for postharvest control of Penicillium expansum Link. on apple fruit. Postharvest Biology and Technology 59(3), 307-315.

Reddy, C. S., Chan, P. K., Hayes, A. W., Williams, W. L., Ciegler, A. 1979. Acute toxicity of patulin and its interaction with penicillic acid in dogs. Food and Cosmetics Toxicology 17(6), 605-609.

Reddy, K. R., Spadaro, D., Lore, A., Gullino, M. , L.Garibaldi, A. 2010. Potential of patulin production by Penicillium expansum strains on various fruits. Mycotoxin Research 26(4), 257-265.

Roland, J. O., Beuchat, L. R. 1984. Biomass and Patulin Production by Byssochlamys nivea in Apple Juice as Affected by Sorbate, Benzoate, SO2 and Temperature. Journal of Food Science 49(2), 402-406.

Saladino, F., Manyes, L., Luciano, F. B., Mañes, J., Fernandez-Franzon, M., Meca, G. 2016. Bioactive compounds from mustard flours for the control of patulin production in wheat tortillas. LWT - Food Science and Technology 66(Supplement C), 101-107.

Salomao, B. C., Aragao, G. M., Churey, J. J., Padilla-Zakour, O. I., Worobo, R. W. 2009. Influence of storage temperature and apple variety on patulin production by Penicillium expansum. Journal of Food Protection 72(5), 1030-1036.

Sanzani, S. M., De Girolamo, A., Schena, L., Solfrizzo, M., Ippolito, A., Visconti, A. 2009. Control of Penicillium expansum and patulin accumulation on apples by quercetin and umbelliferone. European Food Research and Technology 228(3), 381-389.

Selmanoğlu, G. 2006. Evaluation of the reproductive toxicity of patulin in growing male rats. Food and Chemical Toxicology 44(12), 2019-2024.

Sommer, N. F., Buchanan, J. R., Fortlage, R. J. 1974. Production of Patulin by Penicillium expansum. Applied Microbiology 28(4), 589-593.

Stinson, E. E., Osman, S. F., Huhtanen, C. N., Bills, D. D. 1978. Disappearance of Patulin During Alcoholic Fermentation of Apple Juice. Applied and Environmental Microbiology 36(4), 620-622.

Sydenham, E. W., Vismer, H. F., Marasas, W. F. O., Brown, N., Schlechter, M., van der Westhuizen, L., Rheeder, J. P. 1995. Reduction of patulin in apple juice samples — influence of initial processing. Food Control 6(4), 195-200.

Tikekar, R. V., Anantheswaran, R. C., LaBorde, L. F. 2014. Patulin Degradation in a Model Apple Juice System and in Apple Juice during Ultraviolet Processing. Journal of Food Processing and Preservation 38(3), 924-934.

Torovic, L., Dimitrov, N., Lopes, A., Martins, C., Alvito, P., Assuncao, R. 2018. Patulin in fruit juices: occurrence, bioaccessibility, and risk assessment for Serbian population. Food Addit Contam Part A Chem Anal Control Expo Risk Assess, 1-11.

Tournas, V. H., Uppal Memon, S. 2009. Internal contamination and spoilage of harvested apples by patulin-producing and other toxigenic fungi. International Journal of Food Microbiology 133(1), 206-209.

Wallace, R. L., Hirkala, D. L., Nelson, L. M. 2017. Postharvest biological control of blue mold of apple by Pseudomonas fluorescens during commercial storage and potential modes of action. Postharvest Biology and Technology 133(Supplement C), 1-11.

Wang, L., Wang, Z., Yuan, Y., Cai, R., Niu, C., Yue, T. 2015. Identification of Key Factors Involved in the Biosorption of Patulin by Inactivated Lactic Acid Bacteria (LAB) Cells. PLoS One 10(11), e0143431.

Watanabe, M., Shimizu, H. 2005. Detection of patulin in apple juices marketed in the Tohoku district, Japan. Journal of Food Protection 68(3), 610-612.

Wright, S. A. I. 2015. Patulin in food. Current Opinion in Food Science 5, 105-109.

Yuan, Y., Wang, X., Hatab, S., Wang, Z., Wang, Y., Luo, Y., Yue, T. 2014. Patulin reduction in apple juice by inactivated Alicyclobacillus spp. Letters in Applied Microbiology 59(6), 604-609.

Yuan, Y., Zhuang, H., Zhang, T., Liu, J. 2010. Patulin content in apple products marketed in Northeast China. Food Control 21(11), 1488-1491.

Yue, T., Guo, C., Yuan, Y., Wang, Z., Luo, Y., Wang, L. 2013. Adsorptive removal of patulin from apple juice using Ca-alginate-activated carbon beads. Journal of Food Science 78(10), T1629-1635.

Yun, H., Lim, S., Jo, C., Chung, J., Kim, S., Kwon, J.H., Kim, D. 2008. Effects of organic acids, amino acids and ethanol on the radio-degradation of patulin in an aqueous model system. Radiation Physics and Chemistry 77(6), 830-834.

Żegota, H., Żegota, A., Bachmann, S. 1988. Effect of irradiation and storage on patulin disappearance and some chemical constituents of apple juice concentrate. Zeitschrift für Lebensmittel-Untersuchung und Forschung 187(4), 321-324.

Zhang, C., Wang, J., Zhang, J., Hou, C., Wang, G. 2011. Effects of β-aminobutyric acid on control of postharvest blue mould of apple fruit and its possible mechanisms of action. Postharvest Biology and Technology 61(2), 145-151.

Zhang, X., Guo, Y., Ma, Y., Chai, Y., Li, Y. 2016. Biodegradation of patulin by a Byssochlamys nivea strain. Food Control 64(Supplement C), 142-150.

Zheng, X., Yang, Q., Zhang, H., Cao, J., Zhang, X., Apaliya, M. T. 2016. The Possible Mechanisms Involved in Degradation of Patulin by Pichia caribbica. Toxins 8(10), 289.

Zheng, X., Yang, Q., Zhang, X., Apaliya, M. T., Ianiri, G., Zhang, H., Castoria, R. 2017. Biocontrol Agents Increase the Specific Rate of Patulin Production by Penicillium expansum but Decrease the Disease and Total Patulin Contamination of Apples. Frontiers in Microbiology 8(1240).

Zhou, T., Chu, C.-L., Liu, W. T., Schaneider, K. E. 2001. Postharvest control of blue mold and gray mold on apples using isolates of Pseudomonas syringae. Canadian Journal of Plant Pathology 23(3), 246-252.

Zhou, T., Northover, J., Schneider, K. E., Lu, X. 2002. Interactions between Pseudomonas syringae MA-4 and cyprodinil in the control of blue mold and gray mold of apples. Canadian Journal of Plant Pathology 24(2), 154-161.

Zhu, R., Feussner, K., Wu, T., Yan, F., Karlovsky, P., Zheng, X. 2015. Detoxification of mycotoxin patulin by the yeast Rhodosporidium paludigenum. Food Chemistry 179(Supplement C), 1-5.

Zhu, Y., Koutchma, T., Warriner, K., Zhou, T. 2014. Reduction of patulin in apple juice products by UV light of different wavelengths in the UVC range. Journal of Food Protection 77(6), 963-971.

Zouaoui, N., Sbaii, N., Bacha, H., Abid-Essefi, S. 2015. Occurrence of patulin in various fruit juice marketed in Tunisia. Food Control 51(Supplement C), 356-360.