Quality Management in Spice Paprika Production: From Cultivation to End Product

Szandra Klátyik, Helga Molnár, Miklós Pék,
Ildikó Bata-Vidács, Nóra Adányi and András Székács

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Abstract

There is ample historical and scientifically proven information regarding the health benefits of spice paprika, including favourable physiological effects, anti-oxidant and anti-inflammatory properties. Nonetheless, even though it is consumed in small portions, spice paprika has occasionally been reported for chemical/microbiological contamination, as well as fraud or food adulteration. Quality management can guarantee effective reduction of such contamination cases. Different production stages within cultivation and production are subject to different contamination types. Cultivation is a common source of pesticide residues, and unfavourable harvest conditions may give rise to mycotoxins by pathogenic fungi. Storage and post-ripening prior to processing is attributed with microbial contamination and possible increase in mycotoxin content may significantly affect quality features. Technology steps, for example, washing, separation, drying may worsen microbial contamination or quality, but normally do not lead to increase in mycotoxins; nonetheless, decontamination technology is a prerequisite for microbial safety of the product. Upon effective decontamination, finishing steps in the processing technology, for example, grinding, packaging and end product handling do not affect the microbial status, but other, occasionally deliberate contamination due to mixing and adulteration may occur at this stage.

Keywords: *Capsicum*, agro-environmental and food safety, contaminants, technology, critical control points

1. Introduction

Spice paprika, including bell pepper and chilli, is the second largest spice commodity worldwide (after black pepper) both in terms of its production volume and trade value [1]: the overall paprika/chilli production of the EU ranged between 48.8 and 108.0 thousand metric tons per year between 2002 and 2011, while 77.8–116.7 thousand metric tons per year was imported from non-EU countries during the same period. Spice paprika is a market leading commodity in certain countries such as Hungary. The latter is regarded as a spice paprika leader and the second largest per capita consumer in Europe, beside Spain [2].

Due to its agricultural origin, spice paprika is often naturally contaminated with various pathogenic or non-pathogenic bacteria (due to either poor growth, harvest/process sanitation or improper conditions during storage). Owing to its cultivation technologies and its volume in spice consumption, environmental and food safety of spice paprika cultivation and production expressed concern and can be assured by proper quality management along the entire technology chain from field to packaged end product. It is important to note, that deliberate contamination (e.g., food adulteration, intended malignant acts or even sabotage) may also cause safety risks.

1.1. Spice paprika as a *Hungaricum*

Spice paprika is a condiment that consists of dried and ground paprika or chilli, a family of the species *Capsicum annuum*, that originate in Central Mexico. The name "paprika" is Hungarian and stems from the Greek "peperi" and in the Latin "piper", both referring to pepper. The paprika varieties used to make spice paprika made their way to Hungary after Christopher Columbus brought them to Europe. From Spain, paprika cultivation spread to the South of France and to England. The industrialised production of the spice paprika started towards the end of the seventeenth century and grew to become highly developed by the mid-eighteenth century. It was during this period, when cultivation of the peppers in the Murcia region began. Paprika from Murcia would take on its own distinct character. In the years since the eighteenth century, the La Vera and Murcia regions have become the leading producers of Spanish paprika. The latter also arrived to Hungary as early as the sixteenth century. However, it remains unclear which route was opted. One hypothesis is that it was imported from Iberia as a substitute to spice pepper, when the Eastern trade paths were closed to the country being under Ottoman rule. Another theory is that it reached the country by the Southern Slavonic-Turkish mediation from the Balkan. Hungarians used paprika also as a medicine to prevent cholera and to treat typhus. Paprika varieties were afterwards cultivated there, and the climate of the regions of Kalocsa and Szeged proved ideal for growing. Central European paprika had a typically hot taste until the 1920s, when a Szeged breeder found a variety that produced a sweet tasting fruit, and then grafted it onto other plants. Both "hot" and "sweet" varieties of spice paprika have been cultivated in the Kalocsa and Szeged regions ever since, with practically closely similar cultivation and processing technologies, and similarly strict food safety requirements.

1.2. Food safety aspects

The EU food safety regulations, established in the time period 2002–2004, whilst being updated several times since, are based on strict and harmonised food safety standards. The EU agency responsible to ensure food safety is the European Food Safety Authority (EFSA) established by Regulation 178/2002. Subsequent regulations cover the entire food chain from farm to fork, and enhance both prevention and follow-up. They include Regulations [European Commission (EC)] No 852/2004 and (EC) No 853/2004 (control food hygiene), and official controls to ensure compliance with feed and food, as well as animal health and welfare laws as outlined by Regulation (EC) 882/2004.

Effective enforcement of the legal regulations concerning food safety within the EU is assured, among others, by the Rapid Alert System for Food and Feed (RASFF) established in 1979. This is a public, reactive, hazard-based reporting system at EU community level, allowing rapid information exchange among EU member states on hazards related to distributed consumer products, including not only food contamination, but also food fraud [3]. Acting in concert with governmental or EU-specific level regulations and RASFF, expert advisory systems operating on market-based mechanisms and supported by the governments in member states also serve food product quality assurance in the overall food chain from crop cultivation, feed and food raw material production, to processing, storage, transport and trade.

Spices and herbs, in spite of their consumption in small quantities, are of special concern for environmental and food safety due to their use in dried form for seasoning, their long production and trade chains, and possibilities of their deliberate contamination. Spice paprika has been worldwide reported for chemical and microbiological contamination, as well as for fraud or food adulteration [4]. Different production stages within cultivation and production are subject to different contamination types. Cultivation is a common source of pesticide residues, and unfavourable harvest conditions may give rise to mycotoxins by pathogenic fungi. Spice paprika, as other spices, often becomes naturally contaminated with various bacteria (e.g., *Salmonella* spp., *Bacillus cereus*, *Escherichia coli* [5]) generating microbial hazard [6]. Storage and post-ripening prior to processing is attributed with microbial contamination and possible increases in mycotoxin content, and may significantly affect quality features. Technology steps (e.g., washing, separation and drying) may worsen microbial contamination or quality features, but normally do not lead to rises in mycotoxin levels. Nonetheless, decontamination technologies are a prerequisite for microbial safety. Upon effective decontamination, finishing steps in the processing technology (e.g., grinding, packaging and end product handling) do not affect the microbial status, but other, occasionally deliberate contamination due to mixing and food adulteration may occur at this stage. The implementation of proper quality control measures at each of the above steps, in conjunction with effective interaction between producers' quality management practices and government activities are regarded as key factors in the provision of environmental and food safety of spice paprika production.

1.3. Aims and objectives

To illustrate the need and the difficulties in provision of environmental and food safety of spice paprika production, quality assurance measures established along technologies are surveyed with main critical control points (CCPs) identified [7]. Thus, points of vulnerability and each step in the technology chain (cultivation and plant protection, storage and post-ripening, grinding, slicing and mixing and decontamination) are surveyed. If concerted performance of internal (manufacturer) and external (state) quality control measures act in synergy then these may guarantee good production practice and support product quality in spice paprika cultivation and processing.

2. Points of vulnerability

The leading risk factors and contamination cases, notified in the RASFF in the last 10 years (2007–2016), draw attention to the most important points of vulnerability in the supply chain and/or product flow, where entering contamination (hazard), according to the risk assessment concept, may cause medium or high risk and thus, requires the development of preventive and/or elimination processes. It is worth noting at this point that during the 10-year period mentioned above, 373 notifications in total were issued. These included the trade of spice paprika and chilli products, either between EU countries or between an EU country and a "third country" (exporting into the EU).

Aforementioned notifications regarding spice paprika and chilli showed an almost steady distribution within those years, with an average of 37 notifications per annum in total, with the highest number of incidence occurrence in 2010 (70) and the lowest in 2014 (17). The priority list of the reasons of the notifications for spice paprika and chilli according to RASFF indicate the most important points of vulnerability during the entire production line, and draw attention to the accentuated necessity of quality control and management. Mycotoxins are the main risk sources (78%), but in some cases illegal dyes or other foreign compounds were detected (11%), and in further notifications pesticide residues (7%) and microbial infections (3%) were also reported (**Figure 1**).

As seen, the most important hazard of spice paprika and chilli products is mycotoxin contamination, where 225 and 62 events have been reported for aflatoxin and ochratoxin presence, respectively. Considering the number of incidents in temporal distribution, the highest number of aflatoxin contamination was reported in 2010 (52) and 2016 (37), while the lowest in 2009 (9) and 2014 (11). As for territorial distribution, the majority of cases occurred in products that originated from India (45%). Another 13 countries contributed more than 1% (more than 4 cases of incidents in the period studied) to the priority list. Another 28 EU and non-EU countries are responsible for the further 48 mycotoxin contamination events.

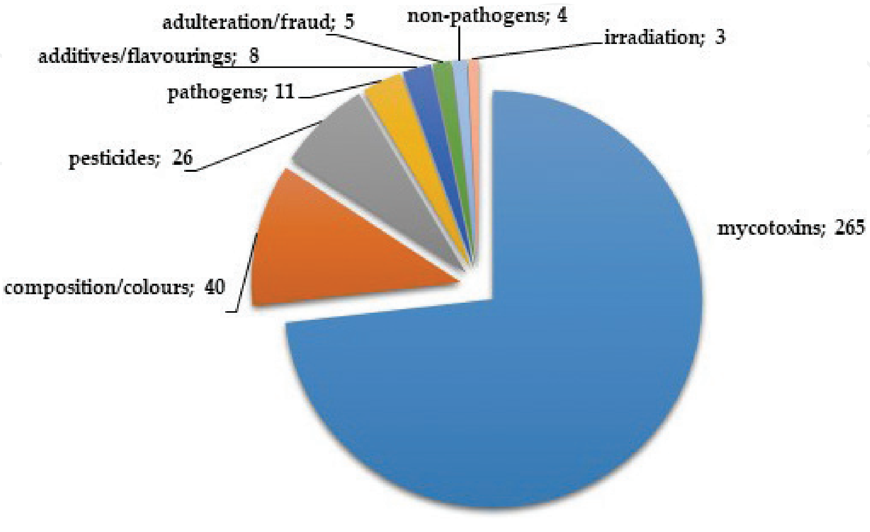

Figure 1. The number of notifications in RASSF between 2007 and 2016 regarding contamination of spice paprika.

To minimise the effects influencing quality, producers are obliged to operate quality management/assurance and food safety systems, for example, Hazard Analysis and Critical Control Points (HACCP), the documentation of which containing all steps of the technology, critical points, where human health risk could occur, self-control points, as well as solutions for possible problems. The authority is entitled to inspect and survey the documentation of self-control. For the latter to occur, own quality management systems are required to operate. These are similar among EU member states, yet may utilise different strategies in their approach. The implied reporting mechanisms (including data record systems) pertaining to biological and chemical contaminants are regulated by law.

In the analysis of the production line of spice paprika or chilli products, typical contaminants and technological errors have to be considered, and accordingly, the optimal positions of the CCPs in the production line have to be identified. A model was implemented for a HACCP system for prevention and control of mycotoxins during the production of dried chilli [8], in which the most important critical control points (e.g., drying and sorting) were identified. Good Agricultural Practice, Good Manufacturing Practice, Good Safety Practice and HACCP were shown to be necessary for processing plants in order to assure proper quality management.

3. Quality aspects of cultivation technologies, cultivated paprika varieties

For the grower side, there are several aspects that need to be taken into consideration. To control the quality of Hungarian ground spice paprika, the Government founded the Chemical Test and Spice Paprika Research Experimental Stations in Kalocsa (1917) and in Szeged (1921). The official selection of the commonly cultivated varieties began almost 80 years ago with the primal milestone: a non-pungent spice paprika cultivar was selected from the landrace populations by Ferenc Horváth. From the 1960s onwards, the selection and breeding continued in Kalocsa and Szeged at the reformed Research Stations, which were—and still are—supported by the Hungarian State.

Due to factors relating to the Hungarian soil and climate, the growers use only interior bred *Capsicum annuum* (L.) var. *'Longum'* cultivars for spice paprika production. The breeding objectives are specified by the growers and the processing industry, according to the requirements of the consumers. Nowadays, a wide assortment of spice paprika varieties is available including the traditional varieties for the extensive growing technology and new hybrids for the most up-to-date paprika production under plastic tunnel.

The successful open field spice paprika production is based on the selection of the growing area considering the soil type and the crucial facts of the microclimate. The sandy loam soil around Szeged region is applicable for direct sowing, as well as for transplanting spice paprika seedlings. Around the Kalocsa region, the soil contains more clay, which—depending on the humidity of the surface—could cause crust and therefore some difficulties at the germination stage. In order to prevent this from happening, the vegetation period is been extended by a few weeks, giving the chance to growers to grow transplants under plastic tunnels.

Based on performed research, it is worth mentioning at this point that in any given 10-year period, 2 or 3 years may limit the vegetation period by the probable latest frost at the end of April and the unpredictable chill point between the end of September and the first week of October. For the most profitable crop production, the growers prefer early (semi-determinate) and mid-early (indeterminate) cultivars for optimal yield (12–15 t/ha) at the harvest. Traditional open field direct sowing and transplanting cultivation technologies apply open pollinated semi-determinate (e.g., Kaldóm) or indeterminate sweet (e.g., Szegedi-80) and hot (e.g., Szegedi-178) varieties.

Considering the disadvantageous impacts of the climate change in the Carpathian Basin and the increasing demand for both quantity and quality of the crop, the cultivation technology requires continuous development and breeding high genetic potential, virus-resistant varieties or hybrids. Applying the black plastic covered ridge cultivation with drip irrigation and soluble fertilisers, the open pollinated indeterminate (e.g., Kárminvörös) and hybrid (e.g., Jubileum F1, Szikra F1) varieties could reach 20–25 t/ha yield with high quality. It is worth noting at this point though, that this intensive technology bears a number of risk factors such as extreme weather conditions and the insect (e.g., Aphids) transmission of viruses (e.g., CMV, Potato Y). Both open field production has the risk of yield loss caused by the bacterial leaf spot (*Xanthomonas campestris* pv. *vesicatoria*), which could be simply solved with the plantation of bacteria resistant sweet (e.g., Kaldóm) or hot (e.g., Kalóz) varieties.

Professional spice paprika production under non-heated plastic tunnel utilises the latest development of intensive growing technology with sweet (e.g., Bolero F1) and hot (e.g., Jubileum F1, Szikra F1) hybrids. The vegetation period is elongated from the middle of April to the end of November. The harvest period begins from the middle of July and ripened fruits could be harvested until the first serious frost. In case of continuous selective harvest, the average yield is up to 40 t/ha, approaching the genetic potential of the hybrid varieties. The fresh picked raw spice paprika material contains 150–180 American Spice Trade Association (ASTA) colour content with 16–18% dry matter content.

4. Pest control (biological, integrated)

In plant protection techniques, various agrochemicals, including numerous pesticide active ingredients and preparations have been registered for treatments in spice paprika cultivation. The choice of protection method is highly technology-dependent.

4.1. Intensive cultivation

Numerous pesticide active ingredients have been authorised on spice paprika over the decades, having been banned or withdrawn ever since. Currently, 51 active ingredients are authorised for paprika cultivation. RASFF notifications were issued in relation to the residues of 30 active ingredients, the vast majority (23) were insecticides, and the others were fungicides (5) and soil disinfectants (2) [8–10].

The effects of intensive cultivation conditions on the pesticide residue levels and the composition of bioactive substances were assessed [11]. In a cultivation modelling experiment, paprika plants were treated at three dosage levels of three recommended insecticides (pirimicarb, chlorpyrifos and cypermethrin) and a fungicide (penconazole). A small parcel experiment of intensively cultivated paprika was carried out, where the plants were treated 1–3 times with pesticide premixes at different dosages (three levels).The harvested and processed paprika was sampled and analysed for pesticide residues content and bioactive component amount. Residue levels of chlorpyrifos (0–1.747 μg/g dried paprika) detected in the differently treated paprika fruits negatively correlated the levels of capsanthin monoesters and β-carotene, as R^2 was obtained 0.65 and 0.74, respectively. The content of carotenoids and tocopherols compared to the negative control samples decreased by 3.3–6.2 and 10.6–21.5%, respectively.

4.2. Co-formulants and adjuvants used in pesticide formulations

Research conducted by the authors indicates that not only the pesticide active ingredients are subject to environmental concerns, but also the various additives used in their formulation to improve their physicochemical characteristics (stability, penetration and absorption). A recent outstanding example is the formulant polyethoxylated tallowamine used for the formulation of the herbicide active ingredient glyphosate, that has been found 2–3 orders of magnitude more toxic on given biochemical processes (e.g., cytotoxicity) or to non-target organisms [12, 13], and has recently been banned from the use in glyphosate-based herbicide preparations. Research carried out by the authors shows that glyphosate, as a total herbicide, is not used on paprika, except for pre-sowing or pre-emergence treatments. For neo-nicotinoid insecticides registered for use on paprika cultivation, however, it has been shown that the formulating agent modifies the toxicity of the formulated pesticide, many of them used in spice paprika, as compared to the corresponding active ingredients (glyphosate, isoproturon, fluroxypyr, pirimicarb, imidacloprid, acetamiprid, tebuconazole, epoxiconazole and prochloraz) [14], (clothianidin) [15]. As a result, authorisation of the formulating surfactants is expected to stricten [16].

4.3. Integrated pest management

The profitable open field spice paprika growing technology is associated with plant protection by Integrated Pest Management (IPM), based on pest population dynamics forecast and the use of preventive and alternative solutions to decrease the environmental impact with chemical treatments. Among preventive solutions, plant rotation is essential, and the best fore crops for spice paprika are cereals. Avoiding the accumulation of pests (e.g., nematodes) and diseases (e.g., viruses, bacteria and fungi) after cultivation of paprika (or other *Solanacea* species) for 3 or 4 years, other crop cultivation is recommended. Utilisation of original, sealed and pelleted seed prevents the propagation of tobamo (TMV, PMMV) viruses both in direct sowing and transplanting technology. To avoid possible transmission of TMV by direct contact (e.g., planting), resistant hybrids are recommended by the breeders and seed trade companies. Plant nurseries are usually maintained in greenhouses or plastic tunnels, and it is crucial to keep them, free from any pests (e.g., aphids, thrips and nematodes).

Aphids (e.g., *Myzus persicae*) are non-persistent vectors of the cucumber mosaic virus (CMV). Paprika infected by CMV produce at 20–30% lower yield. Preventing the infection of CMV by spraying mineral paraffin oil is recommended. It is the author's view that this may raise environmental concerns. In case of serious aphid invasion, reasonable utilisation of pyrethroid insecticide (e.g., deltamethrin) is allowed until the withdrawal period prior to harvest.

Thrips (e.g., Western flower thrips—*Frankliniella occidentalis*) cause their major damage by the nymph laying eggs in the plant tissue or the bud. The plant, the flowers and the small fruits are subsequently injured by feeding. Thrips are the major vectors of a serious plant disease, tomato spotted wilt virus (TSWV). The damage by thrips and TSWV in nurseries and under plastic tunnels threatens the economy of the entire production. Even though survival of the thrips is highly temperature-dependent, protection against them is difficult due to their special, hidden life-cycle. Indication of the presence of thrips in the plantation is simple with blue sticky traps, but efficient application of biological plant protection methods, for example, the thrips' natural predators, like *Orius genus* and *Amblyseius cucumeris* requires special climatic conditions. Should other control techniques fail, a reasonable utilisation of certain mild insecticides (e.g., abamectin) is allowed within IPM.

To avoid problems with nematodes (e.g., *Meloidogyne incognita*), plant nursery must always use nematode-free medium and plant trays for sowing. Utilisation of fresh medium also benefits to avoid the plant pathogenic fungi *Rhizoctonia solani*.

Preventing the damages of broad mite (*Polyphagotarsonemus latus*) in cultivation, plant nurseries must be treated with ventilated sulphur powder or spraying with an acaricide. After planting, at the end of May and the first decade of June, larvae of the turnip moth (*Agrotic segetum*) harm by cutting the seedlings. The hatch of the larvae is predictable with sex pheromone traps, and as such, a well-timed parathyroid treatment may optimise protection against young larvae. The cotton bollworm moth (*Helicoverpa armigera*) is the most harmful pest of spice paprika in open field plantation before harvest. The larvae feed on leaves, flowers and fruits, and finally hide into the fruit, consuming most of the seeds and leaving excrements. The damaged fruits are not only worthless, but potential sources of contamination. The swarming period of the imagoes is July to September. Protection is also based on light and sex pheromone traps, but the number of the possible treatments is limited by the harvest schedule.

According to the food market demands, the importance of biologically protected, high quality and healthy spice paprika is increasing, as in 10 years (2004–2014) the cultivation area increased from about 30 to 50 ha in Hungary. The up-to-date non-heated plastic tunnel is the optimal solution for intensive spice paprika growing with biological protection. Due to the control of the climate conditions via insect-proof ventilation and shading, plant protection can be solved with preventive insect traps, predators or parasitoids. The main pests in growing equipment are virus vector thrips and aphids. To keep aphids and cotton bollworm out, a simple solution is the utilisation of vector nets, and the use of protective clothing for the workers. If the moth imagoes are already in the equipment, a mix of *Trichogramma* species (*T. pintoi*, *T. evanescens*) appears to be efficient. The glasshouse whitefly (*Trialeurodes vaporariorum*) is current in greenhouses and plastic tunnels, and causes crop damage through both direct feeding and propagation of viruses. As a side effect of feeding, honeydew is excreted and in turn, a sooty mould covers the leaves and the fruits.

Yellow sticky traps are suitable to indicate and to thicken the whitefly population in the growing equipment. Biological protection is applicable with the parasitoid wasp *Encarsia formosa* is supported with climate control. Powdery mildew (*Leveillula taurica*) fungi may cause heavy yield losses in growing equipment. To prevent the disease, climate control is crucial. Protecting the crop by spraying with sulphur and potassium bicarbonate is acceptable for biologically grown paprika.

5. Effect of storage and post-ripening on product quality

As mentioned before, the freshly picked raw spice paprika contains 16–18% dry matter. High quality ground paprika as raw material needs at least 4 weeks of after-ripening to decrease the rate of water content and increase the rate of dry matter and stable carotenoids. From the middle of July to mid-September, solar energy can be used for pre-drying in a hygienic equipment, like grids under a shaded and ventilated plastic tunnel.

6. Technology steps

Preparing the dried material for grinding, additional (max. 50°C) drying is needed until the dry matter content decrease to 6–8% or less. After gentle grinding, the final result is high quality paprika with excellent ASTA colour content, outstanding aroma compounds and bioactive components. There are three CCPs in the production line of spice paprika one occurs at the drying step, the second at the microbial decontamination stage and the third applies at mixing, if imported half-products are being used.

The first of these CCPs, the drying step requires the highest foresight, because improper drying impairs the sensory and compositional properties of the product. Its temperature conditions have an apparent optimum: extensively high temperatures should not be applied to avoid formation of unpleasant aroma, pigment and flavour compounds, while drying at low temperature can lead to poor grinding characteristics.

Quality control laboratories at the processing plants carry-out the basic measurements (e.g., moisture, ash, sand, pigment content, microbiological status and colour determination by the protocol of the American Spice Trade Association (ASTA) at each marked points). To summarise the effects of processing, different steps were in-depth investigated regarding microbial contamination and concentration changes of the bioactive compounds.

During slicing, the microbial contamination of paprika increases, as the microbes present inside the berries emerge to the surface (**Figure 2A**). Drying greatly reduces microbial contamination, as most of the vegetative cells are killed. The numbers of mesophilic aerobic total bacteria and coliform counts dropped by 2–3 orders of magnitude, while *Escherichia coli*, *Enterobacteriaceae* and yeasts have almost entirely disappeared (**Figure 2B**).

Comparison of the dried half-product before and after grinding indicated complete eradication of coliforms, *Escherichia coli* and *Enterobacteriaceae*, while the mesophilic aerobic bacterial count

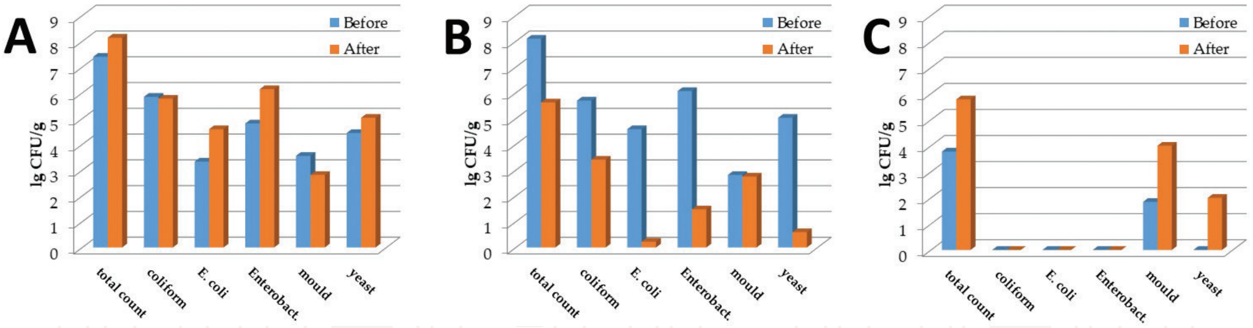

Figure 2. The effect of technology steps on the microbial status of the paprika half-product. **A**: slicing, **B**: drying, **C**: grinding.

and mould contamination increased by two orders of magnitude. This is due to the fact that the microbial load of paprika berries is not homogenous; a few heavily spoiled ones mixed with the healthy berries can contaminate the entire product (**Figure 2C**). The chemical composition, however, did not appear to undergo any significant change.

7. Effects of the decontamination steps on the quality of spice paprika

Another CCP in the technology chain is at the microbial decontamination. To enhance food safety of spice paprika, a decontamination step needs to be carried out to secure the microbial purity of the product and to avoid contamination of food seasoned with it [17]. Various methods are in use and are incorporated into the processing technology (generally after the grinding step) or available for decontamination [18]. Their efficiency in reducing the microbial load in dried spices has been evaluated in literature [19]. Nonetheless, even though red sweet paprika is appreciated being an excellent source of essential nutrients and bioactive compounds, these assessments generally do not evaluate the effects the decontamination step may exert on the composition of the bioactive, aroma and colour components.

7.1. Irradiation treatment

Microbial decontamination is most often carried out by steam treatment or by irradiation by ionising radiation (e.g., gamma irradiation—the maximum allowed average radiation dose being 10 kGy) [20]. In spite of the high efficacy of microbial decontamination by irradiation, and even though legal regulations allow (and even advise) this technology in the EU for decontamination of dried herbs and spices, producers tend to choose steam treatment due to consumer aversion from the food radiation technology [21]. Consumer acceptance of irradiation remains poor despite numerous efforts of food industry experts and the EU legislation to dispel misconceptions regarding the use of isotope techniques and ionising radiation [22]. It has to be also mentioned, that sensory and anti-oxidative properties of the finished product may be slightly affected by the technology used [23]. Irradiation (at 1, 5 and 10 kGy doses) was proven highly effective in the treatment of ground dry spice paprika: the aerobic mesophilic total count (log) decreased from 6.84 to 5.08, 4.71 and 2.91 log cfu/g, respectively, while the mould count (log) from 3.78 to 3.54, 3.18 and 2.30, respectively. The numbers of coliforms (log) 3.71 and *Enterobacteriaceae* (log) 3.28 decreased under the detection limit after the treatments, even at the lowest dose, 1 kGy. Interestingly by irradiation, the dominant microflora of *Bacilli* (*B. methylotrophicus*, *B. pumilus*) gradually disappeared and species less sensitive to irradiation (*Methylobacterium* spp., *Micrococcus* spp. and *Microbacterium* spp.) came into consideration, meanwhile more bacteria of possible human relevance (*Staphylococcus* spp., *Corynebacterium hansenii*) were also isolated. While the microbial status improved by irradiation, the concentration of the bioactive components, such as carotenoids, tocopherols, vitamin C and the ASTA value decreased ($p < 0.05$).

Studies [24] conducted on different decontamination methods by comparing the effects on the microbial status and chemical composition, especially the bioactive compounds, colour and volatile components concluded that earlier methods, for example, irradiation and steaming effectively lowered the microbial decontamination rate, while only slightly affected the bioactive component content, however, decreased the levels of volatile aroma compounds. In contrast, alternative methods, for example, enhanced microwave treatment and radio-frequency heat treatment were less effective in the reduction of the microbial counts, and harmed the colour of the samples, but the bioactive chemical compositional parameters were not affected significantly. Even though the levels of carotenoids, tocopherols, vitamin C or other bioactive compounds and the ASTA values decreased, changing the composition rates of the volatile aroma substances, irradiation was considered to be of outstanding efficacy [25–26].

A technology-dependent issue is, whether irradiation is carried out in bulk or in sealed packages of the finished product. Bioactive compounds are anticipated to decompose less in the latter case, although radiolysis products, involatile or volatile, may diffuse into the product from the packaging material [27]. Reduced amounts of carotenoids were reported at high irradiation dosages and long storage (e.g., 11.1 and 42.1% decrease in capsanthin levels upon irradiation at 10 kGy and a subsequent 10-month storage period, respectively) [28]. Approximately 40% reduction in anti-oxidant activity was seen upon a 20-week storage period, compared to 13% decrease in the control non-irradiated ground black pepper [29].

7.2. Steam treatment

Steaming is a decontamination technique of spices of proven and high utility. Due to steam treatment (saturated dry steam, 10^8–125°C for 20–120 s) the mesophilic aerobic total bacterial count from 1.8×10^5 cfu/g to 6.0×10^2 cfu/g and moulds from 1.3×10^2 cfu/g to under the detection limit were reduced, while yeasts, coliforms, *E. coli* and *Enterobacteriaceae* could not be detected. According to the molecular identification, the dominant bacteria were spore forming rods, family *Bacillaceae,* namely *B. methylotrophicus, B. pumilus, B. vallismortis* and *B. sonorensis* before, while *B. methylotrophicus, B. pumilus* and *B. amyloliquefaciens* after treatment. The concentration of the main bioactive compounds, as capsanthin esters, total carotenoids, tocopherols, vitamin C and the ASTA value did not change significantly, however, the total tocopherol content decreased by 6%. The area percentage (%) of the volatile aroma compounds (e.g., acetic acid and pentanal) decreased, while in some cases (e.g., geranyl acetone, β-ionone and dihydroactinidiolide) a slight increase was detected.

Steam treatment was shown to cause a reduction of volatile oil content along with discoloration [30], and although high-temperature steaming is effective against contaminating microorganisms, it can decrease the volatile oil content, cause colour degradation and may increase the moisture content of dried paprika product, which then reduces shelf-life [31]. Furthermore, steaming is not suitable for spore inactivation. These results confirm that steaming provides a good possibility to reduce the microbial load, without drastically changing the content of bioactive compounds.

7.3. Microwave and enhanced microwave heating

Even though well-described and evaluated industrial decontamination processes are available, alternative methods are also being developed and investigated for efficacy and effects. Microwave heating is advocated for effective reduction of the level of mesophilic bacteria. The method (98°C for 20 min) was indicated to reduce the total number of mesophilic bacteria $6.3*10^4$-fold [32]. Microwave heating (30 s in dry and wet treatment) was found to allow the highest reduction of the bacterial level in chilli among different spices studied [33]. It is worth noting at this point that the method (100 s at various temperatures) did not result in a relevant reduction of the total counts of mesophilic aerobic bacteria even at 95°C, but affected the colour of the treated paprika lot unfavourably, giving it a darker, brownish character.

To avoid the detrimental effect of the treatment method on the colour of spice paprika, a modified microwave treatment (including re-wetting of the sample, intensive mixing during the entire treatment and post-drying to the initial moisture level) was also evaluated by the authors. Mesophilic aerobic total bacterial counts were not significantly affected by the enhanced microwave treatment, however, mould populations and coliforms were reduced, if samples were kept at the given temperatures for at least 10 min. Significant changes were detected in carotenoids, and total tocopherol content decreased by 6.2% only at higher initial moisture content (30% and higher, 10 min, 95°C). Thus, enhanced microwave treatment allows a reduction of microbial contamination (principally for moulds and coliforms) without a decrease in the levels of bioactive compounds. The temperature did not significantly affect chemical composition, but had a significant effect on sample colour.

Nonetheless, in spite the corrected moisture content, all samples became browner and darker after the treatment, and as colour changes did not correlate with the observed levels in carotenoids and the ASTA value, it has been concluded that colour changes due to the treatment are likely to be related to plant carbohydrates and proteins.

7.4. Other treatments

Oregano essential oil was attempted as a natural anti-microbial agent to reduce microbial count in paprika [34]. Although it was not found to be of adequate activity by itself to allow sufficient inactivation of microbial spores in paprika, when used in combination with high-pressure carbon dioxide, microbial inactivation largely increased (by 99.5%).

In a number of food products, high hydrostatic pressures increase shelf-life and maintain nutritional and organoleptic properties better, the effect of high hydrostatic pressures and pasteurisation (in a water bath at 70°C for 10 min) was examined on the levels of given bioactive components and on the texture of spice paprika [35]. Pasteurisation treatment at high hydrostatic pressure (500 MPa) had less influence on the bioactive component content and on the texture, than at low pressure.

Chemical treatment with ethylene oxide is also a worldwide available decontamination technology, but the potential use is limited by its toxicity. Due to its carcinogenic potential to humans, the use of ethylene oxide is forbidden to be used in food processing in the EU [36].

8. The effect of the geographical origin

As mentioned above, the last one among the three CCPs within the spice paprika processing technology is at the mixing step, where the imported half-products get into the manufacturing process. Determination of the origin or ensuring the authenticity of red paprika products is of high importance from both food safety and commercial aspects. To assess the composition of bioactive ingredients in spice paprika and to support the safety of the spice product chains, a wide range of compositional examinations were performed on spice paprika samples of several geographical origins.

A method of combining strontium isotope ratios with a multi-element pattern by means of inductively coupled plasma mass spectrometry (ICP-MS) was used to create a unique fingerprint of authentic Szegedi Fűszerpaprika and to categorise authentic and purchased paprika from different known, declared and unknown geographical origins, using principal component and canonical discriminant analysis [37]. Changes in element and strontium isotopic composition ($^{87}Sr/^{86}Sr$ ratio) were examined throughout the production process. As such, the geographical origin of the spice paprika can be determined even after processing. Strontium isotope ratios are combined with multi-element pattern analysis in the “fingerprint” method, using ICP-MS, and another proper indicator of cultivation types (agrochemicals) and geographical origin (e.g., a distinction between Asia and Europe) is the δ15N value. A clear distinction between Japanese and foreign paprika products was achieved on the basis of their Cu and Rb content by ICP-MS [38]. Similarly, sweet, hot and hot/sweet paprika samples from Spain were assessed by their micro-elemental composition by ICP-MS followed by chemometric class-modelling techniques on variables selected by stepwise linear discriminant analysis [39, 40].

Origin-protected Spanish spice paprika samples (Murcia and Extremadura) were analysed by colour characteristics to differentiate between geographical origins [41]. Co-ordinates in the CIELAB colour space and ASTA scale were measured from acetone extracts of paprika samples in UV-Vis spectral range. For origin discrimination multi-layer perceptrons, artificial neural networks models presented the best results for all types of paprika. According to another strategy [42], the entire absorbance range from 380 to 780 nm was used, and data was combined and reduced by means of principal component analysis. The anti-oxidant activity and the composition of polyphenolics and carbohydrates of spice paprika (Lakošnička and Lemeška) were investigated to attempt to verify the regional and botanical origin of Serbian autochthonous clones of red spice paprika using multi-variate statistical methods [43]. In addition, distinction was achieved to be made between Dutch bell peppers and those from other countries, using analytical strategies based on bulk δ18O elemental analysis of source and paprika fruit water, and on compound-specific, n-alkane, δ2H gas chromatography coupled to isotope ratio mass spectrometry analysis [44].

Gas chromatography-olfactometry was also applied for the evaluation and identification of the odour-active compounds combined with the flavour dilution (FD) factors [45]. For the control of aflatoxin B1 and total aflatoxins in spice paprika powder, NIRS technique as an alternative method was applied using the Modified Partial Least Squares (MPLS) algorithm as a regression method [46]. Moreover, the contamination of mycotoxins (e.g., fumonisin B1, ochratoxin A and sterigmatocystin) and pesticide residues (e.g. metalaxyl fungicide) in spices were investigated by ultra-high performance liquid chromatography (UHPLC) coupled to a high resolution Orbitrap mass spectrometry (Orbitrap-HRMS) [47].

To identify major differences in characteristics and chemical component composition of spice paprika by their origin, a set of samples (53 pieces) was investigated [48]. Samples from Spain and Peru showed outstandingly high total carotenoids content (in average 3709 and 3810 μg/g, respectively), and the ratio of capsanthin diesters to free capsanthins was found to be a good indicator of origin, supposedly due to differing climate conditions in the two countries. The calculated capsanthin diesters/free capsanthins ratio was found to be in average 4.0, 5.3, 8.1, 8.2, 17.1 and 22.0 in samples from Serbia, Hungary, Spain, Bulgaria, China and Peru, respectively. According to the results of NIR evaluation of spice paprika samples, there occurred some clustering among the samples according the country of origin.

The geographical origin of spice paprika has also been successfully attempted to be characterised by their dominant microflora [49]. Although no substantial differences were found among the microbial loads of spice paprika samples from different countries (Brazil, Bulgaria, China, Hungary, India, Kenya, Peru, Serbia, Spain, Thailand and unknown origin) on the EU market, bacterial species in the dominant microflora, characteristic to climate, were identified. The presence of *B. mycoides* and *B. licheniformis* were found to be characteristic to Central Europe, *B. mojavensis* to Spain, *B. safensis* to tropical monsoon climate, *B. amyloliquefaciens* subsp. *plantarum* and *B. amyloliquefaciens* subsp. *amyloliquefaciens* to tropical climate, and no common species was identified for China.

9. Internal and external quality control measures

In addition to obligatory quality control and assurance measures by the producers and systematic analysis for compliance with food safety requirements at EU community level by RASFF, national authorities in EU member states also perform external control analyses to assure food safety (EC Regulation No 882/2004). At present, there are no microbiological criteria for dried spices in the European Community legislation, although, the Codex Code of Hygienic Practice specifies that dried spices should be free of pathogenic microorganisms at levels that may represent a health hazard. The European Spice Association (ESA) and the European Commission (EC) Recommendation 2004/24/EC specify that *Salmonella* spp. should be absent in 25 g of spice, *E. coli* must be under 10^2 cfu/g, and other bacteria requirements should be agreed between the buyer and the seller [50].

10. Conclusion

Proper quality control measures at each of the above steps along with effective interaction between producers' quality management practices and government activities are key factors in the provision of environmental and food safety of spice paprika production. To illustrate this, quality assurance measures established along spice paprika production technologies are surveyed with main CCPs identified. Concerted performance of internal (manufacturer) and external (state) quality control measures act in synergy to guarantee good production practice and to support product quality in spice paprika cultivation and processing.

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Author details

Szandra Klátyik[1], Helga Molnár[2], Miklós Pék[3], Ildikó Bata-Vidács[1], Nóra Adányi[2] and András Székács[1]*

*Address all correspondence to: a.szekacs@cfri.hu

1 Agro-Environmental Research Institute, National Agricultural Research and Innovation Centre, Budapest, Hungary

2 Food Science Research Institute, National Agricultural Research and Innovation Centre, Budapest, Hungary

3 Vegetable Crop Research Department, National Agricultural Research and Innovation Centre, Kalocsa, Hungary

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