



Food contamination during food process



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ABSTRACT

Food contamination can come from different situations. A wide overview is presented in this paper, where the different steps applied to food, from the reception of raw materials to the final food intake by consumers, are shown.

Among the sources involved in the food contamination processes the following ones can be highlighted: a) External raw food contamination due to environmental contamination; b) Transport of raw materials to the factory where they will be processed; c) Food conditioning, which involves the storage of raw materials, preheating, disinfection, cleaning and sterilization steps; d) Heating steps either by boiling, cooking, baking, frying or combining with other ingredients at high temperature in an oven or in a reactor; e) Food packaging; f) Transport of packaged food and g) Storage and distribution of packaged food. The problems related to each step as well as the resulting contaminants for the food are shown and discussed.

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1. Introduction

It has been demonstrated that food contamination, either from microbiological or chemical origin, is the highest concern for consumers. For this reason, there is a continuous research to deep into the contamination sources and the way to prevent them. A great deal of effort has been devoted to developing analytical strategies to be able to detect and identify these contaminants, since they are commonly at trace amounts. Sample treatment devices, such as microextraction techniques able to remove the matrix interferences and to concentrate the analytes from the sample, have been developed and proposed as powerful tools for food analysis. But the task of identifying the contaminants, either those coming from the food production, the food processing or the packaging is still a challenge. Different analytical tools have been developed to facilitate the task, but none of them provide a unique solution. When the likely contaminants are known, target analysis is more feasible, even though the low concentration of target compounds requires the use of sample treatment techniques as well as sophisticated analytical instruments for the task. However, untarget analysis in which the contaminants are unknown is a very difficult task, where the screening procedures play an essential role. In this

frame the application of sample treatment techniques together with the high resolution mass spectrometry provide the powerful tools required for identifying the unknowns. Thus, the information about the likely contaminants coming from each step of the food processing is essential.

The food processing steps are shown in Fig. 1. In the following paragraphs the description of the main contaminants in each step, how to control them and how to prevent or diminish them from the food are discussed. This information is essential to identify the origin of the contaminants in the final food.

2. Food processing steps

2.1. External raw food contamination

Some chemicals may be already present in **raw food** at the beginning of food processing due to environmental contamination. Industrial growth, advances in the use of agrochemicals, or the urban activities can contribute to the presence of food contaminants. An important focus of food contaminants is the use of fertilizers and pesticides, since they can cause health problems if they are consumed by humans. Some studies detected pesticide residues in fruits and vegetables (Kobayashi, Otsuka, & Tamura, 2011) and also some derivatives with also adverse effects, such as metabolites from organochlorine pesticides have been found in fatty food (Chung & Chen, 2011). The use of fertilizers and pesticides is also

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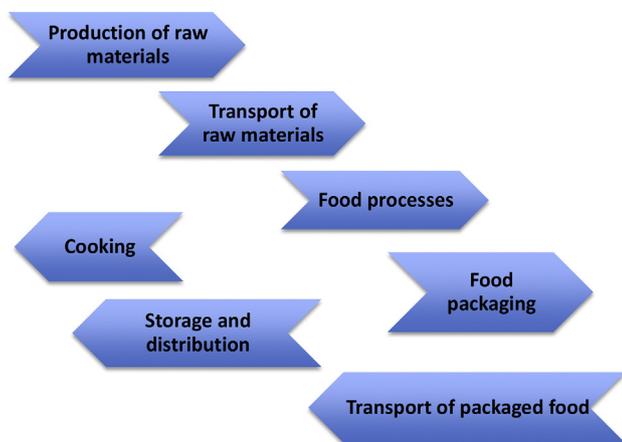


Fig. 1. The food processing steps.

supposed to be the main responsible for the release of toxic heavy metals. Heavy metals such as cadmium, lead, mercury, and arsenic, recognized as toxic (ATSRD, 2011), can be present in air, soil, and water (Zukowska & Biziuk, 2008) and therefore they can be transferred to foodstuff. The analysis of heavy metals has been performed in several foodstuffs such as honey, spinach, potatoes, fish and tea. The major techniques employed for heavy metal analysis are flame atomic absorption spectrometry (FAAS), graphite furnace atomic absorption spectrometry (GFAAS), cold vapor atomic absorption spectrometry (CVAAS), inductively coupled plasma atomic emission spectrometry (ICP-AES), and inductively coupled plasma mass spectrometry (ICP-MS) (Zukowska & Biziuk, 2008).

Another widely studied residues are antibiotic residues. They are used in animal farming, but without an appropriate quality control they can also be present as residues in food products. These residues can be harmful to humans if taken in large amounts. Several methods have been developed for determining antibiotic residues in foodstuff such as meat, eggs (Donkor, Newman, & Tay, 2011) or milk, such as using the microbial inhibition plate test described by Koenen-Dierick et al. (1995) (Koenen-Dierick et al., 1995) or by liquid chromatography methods (Freitas, Paim, & Silva, 2014).

2.2. Contamination during food transport

Food contamination can also take place during **transportation**. It can be caused by from vehicle exhausts of petrol and diesel or because a cross contamination in the vehicle used for food transportation. This cross-contamination can create a serious risk for food safety. In 1999, a major illness in the European Economic Community was attributed to fungicide-contaminated pallets used for transportation and storage of food packaging materials. Long distance transport ship has been also several times affected by cross contamination from chemicals used for disinfection or from other sources (Nerín, Canellas, Romero, & Rodríguez, 2007). The main problem is that usually the high barrier materials used for wrapping and protecting the food during long term transportation, for example by ship, are not always tested for the barrier properties against organic compounds, as only permanent gases such as O₂, CO₂ and water vapor permeation are commonly checked. These barrier properties cannot be extended to any organic compound. The study carried out by Nerín et al. (2007) is a good example of the contamination of food by permeation of naphthalene,

methylbromide, toluene, ethylbenzene, and ortho- and para-xylenes through a theoretical high barrier material.

2.3. Contamination caused by cleaning processes

Cleaning and disinfecting during food processing eliminate the presence of possible microorganisms and therefore, they are crucial to reduce food contamination. Chemicals used as cleaners or disinfectants must be appropriate for food contact surfaces and need to be accepted by the legislation. Products such as glass cleaners or some metal cleaners can't be used because they might leave unsafe residues. The addition of sanitizers in quantities far above permitted levels could leave some residual concentration on treated materials or food even in minimum processed fruits and vegetables, and therefore, to quantify the residual chemicals present in the food is important in order to certify that they have been completely removed.

Some common surfactants are quaternary ammonium compounds such as dodecyl-trimethyl-ammoniumchloride and nonionic surfactants such as stearyl alcohol ethoxylate. Factors affecting its elimination from different materials surfaces, such as rinsing time or water temperature, were studied by Helmschrott et al. (Helmschrott & Wildbrett, 1985). These compounds are commonly analyzed by liquid chromatography–mass spectrometry (Vidal, Vega, Lopez, & Frenich, 2004) (Li & Brownawell, 2009).

Problems related to residues coming from cleaning agents and disinfectants used in surfaces of food handling equipment and its transference to food that has been in contact with such surfaces have been discussed by several authors (Naegeli & Kuepper, 2006). The development of safe, efficient and environmentally compatible detergent formulas is an important issue for the food industry. The use of food grade and edible surfactants allowed by FDA (US Food and Drug Administration) is an interesting option. Other alternative is the use of ozone, due to its strong oxidant properties. It has been studied in order to ensure adequate levels of quality and safety. More recently, a mixture of inorganic peroxides has been also proposed for this task. However, the additional risk involved in this step is the degradation of some compounds by fast oxidation and the emerging neofomed compounds resulting from the interaction of the food components with the disinfection reagents. Emerging technologies such as electrical pulses, high pressures or beta and gamma irradiation on food, open a new area. In these technologies, the transformation of nutrients and food components and the neofomed compounds should be investigated in depth.

2.4. Contamination due to heating steps

Heating treatment is by far the most widely method for food process in the industry or at home, as around 80–90% of the consumed food is processed in one or another way. The use of high cooking temperatures in combination with external factors, can lead to the formation of toxic compounds, which can have a deleterious effect on the food quality and safety. Certain toxic compounds (e.g., acrylamide, nitrosamines chloropropanols, furanes or PAHs) can be formed in foods during their processing, such as during heating, baking, roasting, grilling, canning, hydrolysis or fermentation. Frying is by far the cooking process that can act as a generator of a wide variety of toxic compounds into the food.

Frying is a dehydration process in which oil acts as the medium for heat transfer. Oxidation processes in frying oil are inhibited by the food, especially by proteins, starch or phenolic compounds. Mutagenic polycyclic aromatic heterocycles (i.e., heterocyclic aromatic amines (HAA) and polycyclic aromatic hydrocarbons (PAH)) are produced during the interaction of frying fat and protein.

Oxidation products are bound to proteins and other components of the substrate. Flavor substances are produced by reactions of oxidized frying oil with proteins and other sulfur and nitrogen substances in the food. Various compounds are released from the food into frying oil, enhancing discoloration or off-flavors. Pigments present in frying oil may also be adsorbed on the surface of fried food.

One emerging class of heat induced contaminants, formed when salted food is in contact with oil at high temperature, is the chlorophenol fatty acid esters, such as 3-monochloro-1,2-propanediol (3-MCPD) and the related substances. Vegetable oils and edible fats, especially those submitted to deodorization processes at high temperature, form these compounds. 3-MCPD can reach levels up to 14.7 mg/kg. The values found are much higher than the TDI. Infant formula can also contain this compound. A risk assessment study for human exposure to this kind of contaminants should be investigated, due to their intrinsic toxicity and the levels found in the food. A recent report from EFSA [13] says that the mean exposure to 3 MCPD was $<1 \mu\text{g}/\text{kg}$ b.w. per day in most population groups (age groups across surveys; $N = 60$ out of 64). In four population groups mean dietary exposure was between 1 and $1.5 \mu\text{g}/\text{kg}$ b.w. per day. The P95 of exposure was below $2 \mu\text{g}/\text{kg}$ b.w. per day in 56 population groups and between 2 and $3 \mu\text{g}/\text{kg}$ b.w. per day in the remaining eight population groups. 'Margarine and similar products' was the main contributor to the exposure in 45 population groups (70%) and 'Vegetable fats and oils (excluding walnut oil)' in 18 population groups (28%). Other relevant contributors were 'Bread and rolls' (contribution to the total exposure in the range 6–26%), 'Fine bakery wares' (4–29%) and 'Preserved meat (smoked)' (3–18%).

3-MCPD can have other origins, it can be formed during the acid hydrolysis of wheat, soybean and other vegetable protein products (Johansson & Jägerstad, 1993) and it can also migrate from epichlorohydrin resins used for humidity protection in paper and cellulose materials often employed for sausages casings. Most of the analytical methods reported (>95%) for this compound use gas chromatography coupled to mass spectrometry (GC–MS) and a small proportion (5%) used high performance liquid chromatography (HPLC). Recent reports from EFSA (EFSA, 2011), recommended to further develop and establish standard analytical methods for analyzing 3-MCPD, in order to reduce the uncertainty in occurrence and exposure estimates.

Acrylamide and its precursors are also important contaminants coming from heating processes. Acrylamide is a rather reactive substance that is supposed to be genotoxic and carcinogenic because of animal tests. Acrylamide is predominantly formed in starchy and carbohydrate-rich foods (i.e., French fries) during food processing at high temperature ($>120^\circ\text{C}$). These contaminants are stripped out of the crust by water escaping from the food as steam, limited by the porosity of the crust or by the capillary structure of the matrix. The acrylamide formation depends on many conditions, the most important one is the heat transfer, which is a function of temperature and heat conductivity of the heating medium (air, fat and water), heating time, water activity and pH and concentration of amino and carbonyl reactant. Transfer of fat to and from the substrate into the frying fat depends on the fat content of food as well as on the frying conditions. Polar compounds (i.e., pigments) pass to the frying oil. Precursors of these contaminants can occur naturally in the food matrix, such as in the case of acrylamide, being formed during the Maillard reaction between the amino acid asparagine and a reducing sugar (especially in potato- and cereal-based, heat-treated products). However, acrylamide is also a monomer, with specific migration limit (SML) in the food contact plastics legislation. Surprisingly, the concentration of acrylamide in foods derived from heated cereals derivatives is much higher than

the SML established. A lot of effort has been made to reduce the acrylamide in these foodstuffs after finding out that the food processes were the main origin of this compound in many foodstuffs. A reduction in the processing temperature diminishes the concentration of acrylamide. Not only frying but heating in the oven, with and without air, also enhance the acrylamide formation.

The majority of analytical methods for acrylamide adopts a similar approach: a solid-phase extraction, and determination using either gas chromatography coupled to mass spectroscopy (GC/MS) after bromination, or direct measurement with liquid chromatography coupled to mass spectroscopy (LC/MS). The available methods generally show good agreement and are likely to be accurate with similar LOD/LOQ.

Certain processing contaminants, such as nitrosamines, can be formed by interaction of natural food components with food additives during heating. Nitrosodimethylamine has been detected in certain foods as a result of the direct-fire drying or roasting processes. In this case, nitrogen oxides in the drying air react with the amines in the food while heating. Nitrosodimethylamine is the most common volatile nitrosamine in food. Nitrosopyrrolidine also occurs but in a lesser extent. Cured meats can contain nitrosamines because meat contains amines and sodium nitrite, a source of nitrosating agents, which is often added to cured meats as a preservative. Bacon almost always contains detectable levels of nitrosamines, mainly nitrosopyrrolidine and, to a lesser extent, dimethylnitrosamine. Nitrosamine formation during vapor or boiling cookings (which implies lower temperatures, 100°C) are lower than the amount formed during frying, roasting or grill cooking. They can be measured by different methodologies, colorimetric and spectroscopic methods following gas or liquid chromatography or as a total N-nitroso group, by measurement of chemically released nitric oxide. Gas chromatography (GC) coupled to the specific thermal energy analyzer detector (TEA) is the most suitable, sensitive and widely used analytical method to detect volatile nitrosamines (Byun et al., 2004). The complex matrix of food samples and the low concentrations expected of the studied analytes make it necessary to include isolation and preconcentration steps in the analytical procedure.

Other processing contaminants formed during heating include polycyclic aromatic hydrocarbons (PAHs), present in grilled and smoked products, ethyl carbamate and other products or furan derivatives present in a variety of heat-treated foods, especially coffee and canned/jarred food. Furan contributes to the off flavor of the food and can be formed from a variety of precursors, like ascorbic acid, carbohydrates degradation, amino acids degradation as well as oxidation of fatty acids (Johansson & Jägerstad, 1993).

The production of mutagens is much lower in absence of fat. Model mixtures containing Maillard precursors such as glycine, glucose and creatinine were heated in contact with iron salts and fats. As result, substituted imidazoquinoxalines were identified among the mutagenic products (Freedman, 1999). The reaction was enhanced by oxidized fats and iron salts, and it was not inhibited by tocopherol. Some mutagenic activity of frying fats is also due to nitrogen-free lipid-hydroperoxide decomposition products and it is independent from the fried substrate. They are due only to oxidation products of oxidized and polymerized triacylglycerols or free fatty acids.

Microwave heating is becoming an increasingly used process for heating foodstuffs in home and in some industrial sectors. A broad spectrum of foods have been developed and modified over the last 10 years for the microwave market. A common characteristic of the microwaving cooking is that the food is cooked in the packaging material (wrapping film, container) in the microwave oven (Nerín, Fernandez, Domeno, Salafranca, 2003). Such microwavable packaging materials include plastics, paperboard and

composites, which during microwave cooking many of their components (i.e., plasticizers, antioxidants, monomers, stabilizers, etc) can migrate from the package into the food. This results in a decrease of food quality and food safety (Ehlert, Beumer, & Groot, 2008). During microwave heating high temperatures are often reached in short times. Microwaves can also increase the diffusion rates, cause degradation of migrants or polymer, or cause hot spots, which would increase the migration to higher levels than those expected from the bulk heating temperature (Nerin, Acosta, & Rubio, 2002). The extent of migration depends on heating time, microwave power setting, the nature of the food and the initial concentration of the migrant in the film.

2.5. Food packaging

Nowadays, most of food is sold inside a package. **Food packaging** provides many advantages such as physical protection, barrier protection and it also allows a better food preservation that will increase the shelf life of the product. During food packaging manufacture, different additives (such as antioxidants, stabilizers, slipping agents or plasticizers among others) are commonly added to the polymers in order to improve material properties. The direct or indirect contact between the food and the packaging material can end up the transference of these substances from the packaging to food, in a phenomenon called migration (Catala & Gavara, 2002). Migrants can pose a health risk for consumers if they have a toxic effect. To protect the consumers, there is a strict legislation in FDA, Europe, Mercosur, Australia and Euroasia as well as in many countries to avoid the contamination from the materials and articles to the food in contact with them. This applies to any article, either at consumer or at industrial level. In Europe, food packaging materials must comply with the framework Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food (European-Commission, 2004) and with Regulation (EC) No 2023/2006 on good manufacturing practice (European-Commission, 2006). In addition, depending on the packaging material used, they must also comply with more specific regulations. For example, migration from plastic food contact materials must fulfill the Regulation EU/10/2011 from the European Commission (European-Commission, 2011). Any compound with a molecular mass lower than 1000 amu can migrate and cross the polymeric or paper layers, arrive at the food and be dissolved in it. Migrant nature will depend on the material packaging composition and the migration process also depends on both the characteristics of food and the exposure conditions. When metallic cans are used for food packaging, corrosion phenomena in the metallic surface of the can could produce a migration of metallic ions to food, such as iron or tin (Buculei, Gutt, Sonia, Adriana, & Constantinescu, 2012). For this reason, the internal side of metallic cans are commonly coated with varnishes such as epoxy resins to protect them from corrosion. Minor by-products from the manufacture of epoxy resins, such as bisphenol A, bisphenol A diglycidyl ether (BADGE) or cyclo-di-BADGE among others can migrate to food (Cabado et al., 2008). These compounds have been described as endocrine disruptors.

Another common material used in marmalades, jams, vegetables, beans or sauces packaging is glass. In this case, migration comes from the metallic lids used for closing the glass jars. These lids usually have a PVC gasket in order to assure a good seal. Epoxidized soybean oil (ESBO) is one of the additives used as plasticizer in PVC and its migration to food has been reported by several authors (Pedersen et al., 2008).

Paper and board are commonly used for packaging dry food, such as flour or sugar, or products such as rice, cereals or frozen food. Migration from paperboard additives or from printing inks to foodstuff can take place. It has to be highlighted that paper is the

most recycled packaging material and the use of recycled materials can produce food contamination of substances such as mineral oils or plasticizers coming either from printing inks or adhesives (Nerin, Contin, & Asensio, 2007).

Typical polymers used in food packaging materials are polyethylene (PE), high density polyethylene (HDPE), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polystyrene (PS) and polycarbonate (PC). The type of material used depends on the final application. They can also be combined in multilayer materials in order to improve the final packaging properties. In these polymers, many substances may be added in order to improve the polymer characteristics, such as UV filters, antioxidants, plasticizers or colorants. All these additives will be potential migrants (Nerin, Fernandez, Domeno, & Salafranca, 2003; Paseiro-Cerrato et al., 2010). Multilayer materials can include different polymers, and also adhesive layers, printing inks or varnishes. Migration can take place from all the components even if they are not in direct contact with food, because of diffusion and partition processes of migrants. Several authors have studied migration from different kinds of adhesives used in food packaging such as acrylic, hot-melt, rubber or polyurethane adhesives (Aznar et al., 2011). Migration from inks has been also widely studied, specially migration of photoinitiators such as benzophenone (BP) or 2-isopropylthioxanthone (ITX) coming from UV curable inks (Sanchez-Silva et al., 2009). More recently migration from components coming from printing inks as a result of set-off transference has been reported (Margarita Aznar, Domeno, Nerin, & Bosetti, 2015). Plastic recycled materials have also special relevance, as they could contain chemical compounds coming from the previously packaged food, substances resulting from the misuse of the packaging by the consumer or intrinsic contaminants from the recycling process (chemical additives) (Bayer, 2002). For this reason a strict evaluation previous to the authorization for using recycled plastics for food contact is taking place by EFSA in Europe.

In addition to the substances intentionally added to food packaging materials, non intentionally added substance (NIAS) can also migrate to food and can have also adverse effects (Nerin, Alfaro, Aznar, & Domeno, 2013). There is a wide variety of possible sources of NIAS. They can come from degradation processes of the polymer itself due to high temperatures or high irradiation energies that take place during polymer manufacturing (Dabrowska, Borcz, & Nawrocki, 2003), and also from degradation processes of polymer additives (Aliin & Hakkarainen, 2011; Burman & Albertsson, 2005). Another source of NIAS are neoformed compounds. They can be formed by the reaction of substances present in the polymer (Felix, Isella, Bosetti, & Nerin, 2012) or by the reaction of the substances with foodstuffs. For example, when packaging materials manufactured with polyurethane adhesives are in contact with aqueous foodstuffs, primary aromatic amines (suspected to have carcinogenic effects) can be formed and migrate to food (Aznar, Canellas, & Nerin, 2009). Finally, NIAS can also come from impurities present in the raw materials (Aznar, Gómez-Estaca, Vélez, Devesa, & Nerin, 2013). Due to the high number of NIAS that can migrate to food, and the effect that they can have in food and in the consumers, NIAS identification is very critical. It is a difficult task, since in most of the cases the concentration of NIAS is very low and, in addition, the chemical nature of the compounds can be very different and is always unknown. Since NIAS can have different chemical structures and they are usually at very low concentration levels their detection and identification is a very complex task. For volatile NIAS the most useful technique is GC–MS analysis. The existence of wide mass spectral libraries such as Wiley or NIST makes possible the identification of most of the volatile NIAS detected. Some preconcentration steps such as solid phase micro-extraction (SPME) can also be used in order to increase the

sensitivity of the method. The identification of non volatile NIAS is much more complex due to the absence of mass spectra library. In this case, a liquid chromatography coupled to a high resolution mass spectrometry instrument such as a quadrupole-time-of-flight (Q-TOF) or an ion trap-TOF (IT-TOF) is required. These instruments will allow the user to obtain the accurate mass of the compounds detected (Nerin et al., 2013) and with this information, together with software tools and chemical database, the search and identification of the chemical compound is possible.

2.6. Contamination during food storage

Food storage conditions are key parameters in food quality and safety. Proper storage extends the shelf life of food, which depends on the food type, packaging and storage conditions, particularly temperature and humidity. During storage conditions (e.g., high temperature and humidity), packaging material properties can be affected. Migration and sorption of external/internal substances phenomena (which at the end can be released again from the packaging to the food) can occur anytime. Organoleptic changes should not occur during food storage (European-Commission, 2011) and therefore packaging materials used for long term storage should exhibit very good barrier properties. These barrier properties not only affect the permanent gases such as O₂, CO₂ or even water vapor, but also aromas and volatile organic compounds, as was above mentioned. These physico-chemical processes heavily depend on temperature and in a lesser extent on humidity, which controls the diffusion of these contaminants into the foodstuff. To minimize these unwanted phenomena, humidity in the storage environment should be low. Moisture can lead to the breakdown of some packaging materials (e.g., paper degradation and metal rusting). The optimal range of temperature is the cool to moderate range, between 4 and 21 °C. Direct sunlight can speed deterioration both on the food and on the packaging. Adsorption of unwanted off-odors is also a common phenomena in food storage. High fatty foods are prone to odor contamination. In addition, food contamination depends on the food type under consideration. Dry food and canned foods have a long shelf-life, but color, flavor, and nutritive value deteriorate over time. Freezer storage and refrigerator is necessary for meat, fish, eggs, dairy products, etc. Under these conditions food contamination by chemical or physical interactions is minimized, as at low temperature the kinetics of processes is slow and the reaction constants are also lower.

When using flexible plastic materials it is also important to evaluate its permeability, since depending on the barrier properties the transference of compounds through the packaging material will be different as was demonstrated by Nerin et al. (Nerin et al., 2007).

3. Concluding remarks

This work shows the main points where food contamination can take place during food process. This study is very relevant for preventing food contamination and therefore, for avoiding possible toxic effects affecting the consumer health. Some contaminants can already be present in raw materials, but others can be incorporated during transportation or food processing due to several factors such as cleansing processes of working surfaces or food heating processes. Food packaging can also be a contamination source, due to migration phenomena of packaging to food. These facts highlight the importance of performing chemical analysis during food processing that assures food safety for consumers.

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