Report of the Scientific Committee of the Spanish Agency for Consumers Affairs, Food Safety and Nutrition (AECOSAN) on safety criteria that limit exposure to acrylamide produced by frying potatoes

Section of Food Safety and Nutrition

Montaña Cámara Hurtado, María Pilar Conchello Moreno, Álvaro Daschner, Ramón Estruch Riba, Rosa María Giner Pons, María Elena González Fandos, Susana Guix Arnau, Ángeles Jos Gallego, Jordi Mañes Vinuesa, Olga Martín Belloso, María Aránzazu Martínez Caballero, José Alfredo Martínez Hernández, Alfredo Palop Gómez, David Rodríguez Lázaro, Gaspar Ros Berruezo, Carmen Rubio Armendáriz, María José Ruiz Leal, Pau Talens Oliag, Jesús Ángel Santos Buelga, Josep Antoni Tur Marí

Technical Secretary

Vicente Calderón Pascual

Reference number: AECOSAN-2017-007

Report approved by the Section of Food Safety and Nutrition of the Scientific Committee in its plenary session on 20 September 2017

Working group

Montaña Cámara Hurtado (Coordinator)
Pilar Conchello Moreno
María Elena González Fandos
Jordi Mañes Vinuesa
David Rodríguez Lázaro
Gaspar Ros Berruezo
Pau Talens Oliag

Abstract

Acrylamide is an organic compound with a low molecular weight, highly soluble in water, which is formed on cooking certain starchy foods, with a low humidity, at temperatures above 120 ºC and low moisture as deep-frying or roasting); this is mainly due to the Maillard reaction, which occurs between certain amino acids, including free asparagine, and reducing sugars (glucose, fructose and others), turning color to browns and also affects its taste.

Acrylamide is classified by the International Agency for Research on Cancer (IARC) as a probable human carcinogen (Group 2A), as acrylamide is biotransformed into the metabolite, glycidamide, with genotoxic activity with a special affinity for the nervous system.

To date, results from studies on humans have been inconclusive as regards its toxicity. Given that any level of exposure to a genotoxic substance might damage DNA and lead to the appearance of cancer, the European Food Safety Authority (EFSA) is not able to establish a tolerable daily intake (TDI) for acrylamide in food. Instead, the EFSA have estimated the dose range within which acrylamide is most likely to cause a small but measurable incidence of tumours (known as the neoplastic effect) or other potential adverse effects (neurological, pre- and postnatal development and male reproduction). The lower limit of this range (Benchmark Dose Lower Confidence Limit, $BMDL_{10}$) has been established by the EFSA at a $BMDL_{10}$ of 0.17 mg/kg body weight/day. For other effects, the most relevant neurological changes observed were those with a $BMDL_{10}$ of 0.43 mg/kg body weight/day.

Although the epidemiological associations have not demonstrated acrylamide to be a human carcinogen, the margins of exposure indicate a concern for neoplastic effects based on animal evidence.

Translated from the original published in the journal: Revista del Comité Científico de la AECOSAN, 26, pp: 29-55

Fried potatoes are one of the foods that most contribute to exposure to acrylamide in the general population.

The Scientific Committee of the Spanish Agency for Consumer Affairs, Food Safety and Nutrition (AECOSAN) has assessed the characteristics of potatoes as regards the dry matter in the raw material, the presence of reducing sugars and the colour index after frying, which affect the exposure to acrylamide generated as a result of the frying process. In addition, it considers the possible measures to be taken to prevent and reduce the formation of acrylamide in fried potatoes in a domestic environment, including storage temperature or washing potatoes before frying them.

Regarding the characteristics of potatoes affecting the exposure to acrylamide generated as a result of frying, the Scientific Committee concludes that:

Given that the water content of a fresh potato ranges between 75-80 %, the content of dry matter in the raw material should not be higher than 25 %.

Although the content of reducing sugars may vary considerably over time depending on storage conditions, potato varieties with a low content of reducing sugars, no more than 0.3 %, should be selected.

Potatoes intended for frying must be stored at temperatures of around 8 ºC.

Large tubers, measuring over 50 mm, should be selected for frying.

As regards the recommendations for minimising the production of acrylamide when cooking potatoes at home, the Scientific Committee concludes that:

When purchasing potatoes, only select potatoes at optimum ripeness level, without green parts or sprouts.

When storing potatoes at home, do not store potatoes at temperatures below 8 ºC (do not keep potatoes in the fridge) and avoid prolonged storage.

Before frying: cut the potato in thicker chunks or strips rather than thin slices; wash the potatoes after slicing under plenty of tap water and then dry thoroughly with kitchen paper. When cooking: boil potatoes or cook them in the microwave rather than frying. Avoid frying temperatures over 175 ºC at all times. Observe the colour that appears on the surface of the product. Potatoes must be fried until they are a golden yellow colour rather than golden brown and darker coloured potatoes should be thrown away.

Key words

Potato, acrylamide, exposure, frying.

1. Introduction

Acrylamide is an organic compound with a low molecular weight, highly soluble in water, which is formed on cooking certain starchy foods, with a low humidity, at temperatures above 120 ºC and low moisture as deep-frying or roasting); this is mainly due to the Maillard reaction, which occurs between certain amino acids, including free asparagine, and reducing sugars (glucose, fructose and others), which browns food, and also affects its taste (EFSA, 2015).

The Maillard reaction is a non-enzymatic browning reaction which includes a series of complex chemical reactions through which, given certain conditions, the reducing sugars react with a free amino group, coming from an amino acid or a protein and produce a series of brown pigments and modifications on smell and taste. These may be desirable in the case of fried foods, but they also lead to the formation of undesirable compounds including acrylamide. The formation of acrylamide therefore depends on the presence of precursors (mainly free sugars and the asparagine amino acid) in addition to the variables of time, temperature and moisture. Production increases with the exposure time of the food to elevated temperatures (>120 ºC) as well as low moisture levels.

The main food groups which significantly contribute to human exposure to acrylamide are fried potato products, bread, biscuits and coffee. In addition, acrylamide has been used industrially (registry No CAS 79-0601) since the 50s in the production of polyacrylamides which act as flocculants to clarify drinking water among other industrial applications.

1.1 Problems derived from intake-Risk assessment

Acrylamide was evaluated in 1994 by the International Agency for Research on Cancer (IARC), and due to the animal testing results, it was classified as a probable human carcinogen (Group 2A), as acrylamide is biotransformed into the metabolite glycidamide with genotoxic activity (IARC, 1994) an a special affinity for the nervous system. Acrylamide and glycidamide were clasified by the US Environmental Protection Agency (EPA) in the category B2, both substances defined as a "probable human carcinogen". In addition, the American Conference of Governmental Industrial Hygienists (ACGIH) classifies acrylamide in category A3, as "an animal carcinogen, unknown in humans". To date, results from studies on humans have been inconclusive as regards its toxicity (Fuhr et al., 2006) (EFSA, 2015).

Given that any level of exposure to a genotoxic substance might damage DNA and lead to the appearance of cancer, the European Food Safety Authority (EFSA) scientists are not able to establish a tolerable daily intake (TDI) for acrylamide in food. Instead, the EFSA experts estimate the dose range within which acrylamide is most likely to cause a small but measurable incidence of tumours (known as the neoplastic effect) or other potential adverse effects (neurological, pre- and postnatal development and male reproduction). The lower limit of this range is known as the Benchmark dose lower confidence limit ($BMDL_{10}$).

- For tumours, experts selected a $BMDL_{10}$ of 0.17 mg/kg b.w./day.
- For other effects, the most relevant neurological changes observed were those with a $BMDL_{10}$ of 0.43 mg/kg b.w./day.

Comparing the $BMDL_{10}$ with the dietary exposure of humans to acrylamide, scientists are able to indicate a "level of health concern" known as the margin of exposure (MOE). For the neoplastic effects of acrylamide, the values of the MOE for the general population were 425 (lower-bound) to 89 (upper-bound) and for high-level consumers they were 283 (lower-bound) and 50 (upper-bound). These MOE values are far lower than the value of 10 000, which is the minimum value considered by the EFSA as safe for substances which are genotoxic and carcinogenic.

On an international level, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) assessed acrylamide in 2005 and in 2010 and were not able to establish a toxicological reference value, at the expense of obtaining more results of carcinogenesis and neurotoxicity in the long-term from the studies underway, and therefore they used the same approach as the EFSA, the margin of exposure (MOE). The MOE calculated by the JECFA for the carcinogenic effects was 300 for the general population and 75 for high-level consumers, both very low margins, and consequently the risk cannot be dismissed. In this respect, the JEFCA recommends the reduction of levels of acrylamide in foods and the collection of data on acrylamide concentrations in ready to eat foods. The only legislated value for acrylamide in food is the maximum limit established for bottled drinking water which is 0.1 µg/l of water, in accordance with Royal Decree 1799/2010 (BOE, 2010), equal to the legal value for water intended for human consumption in Royal Decree 140/2003 (BOE, 2003).

Continuing with the above studies, the EFSA assessed the risk for public health linked to the presence of acrylamide in food. In the exposure assessment, they considered more than 40 000 test results for different foods provided by Member States. Based on the results obtained, EFSA concluded that although the epidemiological associations have not demonstrated acrylamide to be a human carcinogen, the margin of exposure indicates a concern for neoplastic effects based on animal evidence (EFSA, 2015).

The most important dietary sources of acrylamide are home-cooked fried potato products, industrial chips and coffee. The most important exposure for infants, babies and young children are cereal-based and other infant food whereas for children over the age of one year and adolescents, the most important source of exposure to acrylamide comes from potato crisps.

One of the main conclusions reached by the EFSA in their scientific opinion of 2015 is that home-cooking habits influence exposure to acrylamide. Specifically, the potato frying conditions at home may imply an increase of up to 80 % in the total dietary exposure to acrylamide.

1.2 Measures established to reduce the presence of acrylamide in food

Given the EFSA's concern about current levels of exposure to acrylamide and in order to reduce the dietary exposure, the European Commission, as a risk management measure, has recently approved the establishment of certain Codes of practice aimed at industries and the catering sector. These Codes, mandatory for food businesses, are also linked to certain indicative levels of acrylamide (EU, 2013) which have to be checked to ensure that all the mitigation measures are being implemented effectively and in this way, prevent and reduce, wherever possible, the formation of the compound. The Codes of practice are applicable to food processing companies although foods presented to the end consumer as raw material, as is the case of potatoes, are not included.

The indicative levels, understood as the usual levels in these foods all over the European Union and which are not linked to health, applicable to potatoes are as follows:

- French fries ready-to-eat: including those made with fresh potatoes or potato dough.
  - Indicative value (μg/kg): 600 μg/kg.
  - Comments: product sold as ready-to-eat, as defined in part C.1 of the Annex of Recommendation 2010/307/EU (EU, 2010).
- Crisps: Including those made with fresh potatoes or potato dough.
  - Indicative value (μg/kg): 1 000 μg/kg.
  - Comments: product as sold, as defined in part C.2 and C.10 of the Annex of Recommendation 2010/307/EU (EU, 2010).

Since the unintentional formation of relatively high concentrations of acrylamide in the processing of potatoes and cereal-based products was demonstrated in 2002, work has been carried out at international level to establish management measures conducive to reducing the levels in processed foods. A chronological list is given below of the principal tools developed by health authorities or industrial organisations, directed at the prevention and/or reduction of acrylamide in food.

1.2.1 International Food Safety Authorities Network-Acrylamide information note (INFOSAN, 2005)

The WHO (World Health Organisation) and the FAO (Food and Agriculture Organisation of the United Nations), in 2005, jointly published an INFOSAN information note listing the principal conclusions of the risk assessment of acrylamide carried out by the JECFA (FAO/WHO, 2005). This includes guidelines for national authorities regarding the safety of the foods, especially in the communication area, based on the international exchange of information on the technologies and methods to reduce acrylamide in food. To this purpose, the FAO/WHO had previously created in 2002, the computer network *Acrylamide Infonet* which serves as a global inventory of ongoing research on acrylamide in food and includes information relating to research to reduce levels.

1.2.2 HEATOX Project-Guidelines to authorities and consumer organisations on home cooking and consumption (HEATOX, 2007)

The final report of the HEATOX Project (Heat-generated food toxicants: identification, characterisation and risk minimisation) funded by the European Commission, publishes the conclusions obtained in 2003-2007 on the risks to health posed by acrylamide and other compounds formed by the heat treatment of food. The scientists taking part in the study concluded that although the acrylamide contribution from home-cooking is quite small, it can be reduced by applying known methods. One of the end products of this research project is a brochure which lists a series of recommendations to minimise the formation of acrylamide during the cooking of food.

1.2.3 *Codex Alimentarius* Commission (2009)-Code of practices for the reduction of acrylamide in food

The Code of Practice for the reduction of acrylamide in food (CAC/RCP 67-2009) adopted by the *Codex Alimentarius* Commission in 2009 includes recommended practices for industry and other involved parties for the preparation of potato products and cereal-based products throughout all the production phases. The guidelines include strategies for the raw materials, the addition of other ingredients, processing and the heat treatment of food.

1.2.4 Confederation of Food and Drink Industries of the EU-Acrylamide toolbox (CIAA, 2013)

This tool for the prevention and reduction of acrylamide in food intended for the industries concerned, was drawn up by Food and Drink Europe in collaboration with the European Commission and is regularly updated. The latest update in 2013 includes four different food categories: fried potatoes, bread (breakfast cereals, biscuits and bakery wares), coffee (roast and ground, soluble and coffee mixtures) and infant food (infant cereals and biscuits and infant food). The tool gives details of the methods existing to reduce acrylamide in food and to permit users to assess and select the reduction methods which must be used according to the manufacturing requirements. To make application easier, a number of different brochures have been developed (CIAA, 2013), one of which is directed at manufacturers of potato crisps, and includes directives to select the tools which best adapt to the product, method of preparation and product quality specifications.

1.2.5 European Food Safety Authority-Scientific Opinion of acrylamide in food (EFSA, 2015)

Following the scientific ruling on acrylamide in foods issued by the CONTAM panel in 2015, the EFSA published a fact sheet directed at consumers offering a simple explication of the risk to which the population might be exposed as a result of the intake of acrylamide, the food groups which most contribute to this intake and what the population can do to reduce this consumption.

1.2.6 Spanish Agency for Consumer Affairs, Food Safety and Nutrition-Recommendation on acrylamide in food (AECOSAN, 2015)

The AECOSAN has prepared recommendations at national level intended to reduce acrylamide levels in home-cooked food, including French fries.

1.2.7 Food and Drug Administration-Guidance for Industry Acrylamide in Foods (FDA, 2016)

Guide published by the Food and Drug Administration (FDA) in 2016 to help the food industry control the levels of acrylamide in foods. This guide provides information to help growers, manufacturers and food service operators to reduce acrylamide levels in certain foods (potato products, cereal-based products and others including coffee). It includes recommendations for the different stages of production, from the selection of the raw material, its storage, processing to marketing, but it does not establish maximum recommended values for acrylamide.

1.2.8 Food Standards Agency-Campaign to "Go for Gold" (FSA, 2017)

A campaign promoted by the Food Standards Agency (FSA) to make the population more aware and to minimise the daily consumption of acrylamide associated with the intake of potatoes and other starchy foods subjected to high temperatures. It explains four basic ways of reducing the presence of acrylamide, and other preventive measures adopted by the food industry.

1.2.9 European Potato Processors' Association-Golden Frying Recipe (EUPPA, 2007)

Although all the above tools are global, this is the only tool for a specific product. This tool is intended for professionals and consumers to reduce the content of acrylamide in fried potatoes. It was drafted by the European Potato Processors' Association (EUPPA, 2007) and includes recommendations and a video on how best to cook fried potatoes.

1.2.10 Direction génerale de la concurrence de la consommation et de la répression des fraudes (DG CCRF, 2017)

As in the previous case, these recommendations were established very recently in France to reduce the presence of acrylamide in home-cooked French fries, bakery ware and pastries.

1.2.11 European Commission, 2017

On 19 July 2017, the representatives of the Member States of the European Commission approved a Regulation on the mitigation measures and reference levels for acrylamide which includes certain binding Codes of Practice (CoP) directed at reducing the levels of acrylamide of the products offered to consumers directly for consumption, or even for consumers to cook at home. Once this measure comes into force, economic operators, both industries and the catering, hotel and mass catering sectors will be obliged to apply measures to mitigate the formation of acrylamide. The agreed text will be studied by the European parliament and the Council who will have 3 months to examine it before its final adoption by the Commission. It is expected to come into force in Spring 2018 and during this intermediate period the indicative levels from Recommendation 2013/647/EU will be in force.

The new reference levels (in accordance with Annex IV of the Regulation 2017) which will repeat the existing levels are as follows:

- French fries ready-to-eat: presence of acrylamide 500 µg/kg.
- Potato crisps: 750 µg/kg.

The Commission, as soon as this Regulation has been adopted, also intends to set up talks on additional measures, including the establishment of maximum levels of acrylamide in certain foods in the European Union.

1.3 Conditions for the sale of potatoes

In Spain, the conditions for the sale of potatoes are established in Royal Decree 31/2009, of 16 January, approving the commercial quality standard for ware potatoes in the national market

(BOE, 2009). This standard refers to the tubers of the commercial varieties (cultivars) of potato obtained from *Solanum tuberosum L* and from its hybrids, intended for delivery in their natural state to the consumer. Three commercial types of potato are established according to their condition:

- "De Primor" (early new) (potatoes which, in addition to being harvested before reaching full natural maturity, so that their epidermis or peel can be easily rubbed off, must be sold in the days immediately after their harvest).
- "New" (potatoes harvested when they have reached full natural maturity level and marketed in the weeks immediately after their harvest without further storage and/or conservation other than that necessary to ensure the normal development of the marketing process).
- "De Conservación" (Storage) (potatoes harvested in full maturity level, suitable for marketing after a period of storage and/or conservation more or less prolonged, without affecting their organoleptic properties).

This Royal Decree or regulation allows, optionally, the recommended culinary use to be indicated. In this respect, potatoes can be found on the market labelled as "specially for frying".

In some Member States of the European Union including France, the sector belonging to the National Inter-Professional Committee for the potato has agreed that, to permit the use of the label "specially for frying", the potatoes must first have meet certain requirements (CNIPT, 2016). This inter-professional agreement, applicable in said country until 2020, establishes certain acceptance criteria for, among others, the colour index after a frying test or the glucose rate in the juice obtained from the potato.

It should be noted that article 36 of Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on food information provided to the consumer establishes that all voluntary information provided must be based, where applicable, on scientific criteria (EU, 2011).

Consequently, the Section of Food Safety and Nutrition of the Scientific Committee of the Spanish Agency for Consumer Affairs, Food Safety and Nutrition (AECOSAN) were asked to assess the characteristics of potatoes with regard to the colour index after frying, the presence of reducing sugars and dry matter in the raw material, which have an influence on the exposure to acrylamide generated as a result of frying. This assessment might lead to the establishment, as a risk management measure, of the conditions in which the "specially for frying" label might be used correctly in the labelling of potatoes, in order to prevent higher exposure to the acrylamide generated as a consequence of this culinary practice. In addition, and with a view to preparing promotional material for the consumer on acrylamide, the Section of Food Safety and Nutrition of the Scientific Committee of the AECOSAN were asked to identify possible measures to be adopted to prevent and reduce the formation of acrylamide in home-cooked fried potatoes, such as the storage temperature or washing potatoes before frying.

2. Technical characteristics of the potatoes

2.1 The product: the potato

2.1.1 Variety of potato

Potatoes which have not undergone heat treatment do not contain acrylamide, however they contribute precursors to the Maillard reaction. It has been demonstrated that the final amount of acrylamide in this product is linked to the asparagine precursor, the principal free amino acid present in potatoes (*Solanum tuberosum*) and reducing sugars (Olsson et al., 2004) (Williams, 2005). Several studies have shown that the concentration of reducing sugars and asparagine varies with the variety of potato (Knutsen et al., 2009) (Marchettini et al., 2013). Nevertheless, De Wilde et al. (2006) in a study of 16 different varieties of potato, demonstrated that only the content of reducing sugars is correlated with the formation of acrylamide. Other authors confirm that the formation of acrylamide is associated more to the content of reducing sugars than to the asparagine content (Mestdagh et al., 2008a) (Medeiros et al., 2010) (Marchettini et al., 2013). In addition to the reducing sugars, Kalita et al. (2013) concluded that the differences existing in the content of polyphenols may also affect the content of acrylamide obtained from different varieties of potato. However, it is important to remember that the content of reducing sugars not only depends on the variety of potato but also on the growing conditions, weather factors and seasonal fluctuations as well as the post-harvest storage conditions (Low et al., 2006).

2.1.2 Tuber size

Torres y Parreño (2009) suggest that the size of the tuber also affects the quantity of reducing sugars such that smaller tubers tend to accumulate (proportionally) a higher content of reducing sugars.

2.1.3 Degree of maturity

Another factor to be considered in the selection of the raw product is the degree of maturity determined by the time of sowing and harvest and by the post-harvest treatment, as it has been shown that immature tubers have a higher content of reducing sugars (De Wilde et al., 2006). The potatoes should have the optimum degree of maturity and avoid immature tubers before cooking.

2.1.4 Irradiation of potatoes

Some researchers indicate that irradiation of potatoes with doses of 60 Gy followed by storage for 6 months at ambient temperatures of 4 and 14 ºC, lead to a 7-8 % reduction of acrylamide in chips (Mulla et al., 2011). It should be noted that this treatment method is not authorised in Spain.

2.1.5 Genetically modified potatoes

The repercussion of genetically modified potatoes on the formation of acrylamide have been studied, with the result that there is a significant decrease of 69 % in the acrylamide content for genetically modified potatoes stored at 5 ºC (Pinhero et al., 2012). The United States has approved the cultivation of a biotechnologically improved variety of potato ("Innate" potato) with a reduced content of asparagine in order to reduce the acrylamide content generated in the frying process by 70 %. As with the above case, this method of genetic improvement applied to potatoes is not authorised in Spain.

2.2 Storage conditions

2.2.1 Temperature

There is scientific evidence that if potatoes are stored at temperatures below 8 ºC before the heat treatment, the enzymatic activity on the starch increases, generating an increase in the amount of reducing sugars, which facilitates the subsequent formation of acrylamide during the cooking process, especially if the product is fried or roasted (Dunovská et al., 2004) (Knutsen et al., 2009) (Viklund et al., 2008, 2010). Some authors indicate that the effect on the content of reducing sugars produced by the cold temperatures is reversible by reconditioning the potato at 15 ºC for 3 weeks prior to processing (De Wilde et al., 2005). It has also been demonstrated that the storage of potatoes at ambient temperatures below 10 ºC does not affect the asparagine content (Olsson et al., 2004) (De Wilde et al., 2005). To establish directives on the storage of potatoes, it must also be remembered that storage at ambient temperature favours sprouting, and given the influence of this factor on the content of reducing sugars, temperatures of above 8 ºC are recommended.

2.2.2 Other conditions (ventilation and darkness)

Other factors must also be considered as well as temperature. These include ventilation and darkness to prevent sprouting.

3. Requirements for the use of the "specially for frying" label

In relation to the potatoes available in our markets, Mesías et al. (2017) have conducted a study on the formation of acrylamide under controlled conditions of handling and frying on different batches of stored potato, labelled as "specially for frying". Random samples were taken from February to April from six food retailers in order to assess how the characteristics of the fresh potatoes available to consumers in the retail market might affect the exposure of the end user to acrylamide. A significant correlation was observed between the sugars and the formation of acrylamide. Depending on the point of sale, acrylamide exposure ranged from 7.0 to 153 µg/person/day. Consequently, according to the authors, the commercial label "specially for frying" is not apt for offering guidance to consumers. Therefore, additional efforts are necessary in the food distribution chain to provide consumers with potato tubers with the necessary characteristics to help to mitigate the formation of acrylamide in the home environment.

In some countries, mandatory requirements have been established for the use of the "specially for frying" label in the sale of potatoes. Similarly, in the agreement of the *Comité National Interprofessionnel de la Pomme de Terre* of France (CNIPT, 2016), relating to the use in the labelling of the culinary statement "for frying", the technical characteristics required of the potatoes are specified, and include:

- the dry matter, which must be in the range between 18.5 and 23 % with a tolerance of ± 0.5 %.

- the glucose rate in the juice, using a commercial method, the acceptance criteria is a result less than or equal to 0.40 % of glucose in the juice.
- the colour index after frying, establishing as an obligatory method for assessing this, the protocol "Test Frites" Arvalis/CNIPT (SPE003) and as the criteria of acceptance, a colour index less than or equal to 3.2.

3.1 Dry matter

The potato has a high water content (75-80 %) when it is fresh. Considering the dry matter, 75 % of the potato is made up of starch, a complex carbohydrate. The concentration of soluble starches is low (0.1-0.7 %) where the most important are glucose, fructose and sucrose. For industrial use, the higher the dry matter content, the higher the yield. From the point of view of the formation of acrylamide, this is increased when the content of dry matter is increased.

3.2 Content in reducing sugars (glucose rate)

In potatoes, the Maillard reaction takes place between reducing sugars (glucose and fructose) and asparagine. To control the Maillard reaction and, therefore, reduce the formation of acrylamide in fried potatoes, one alternative is to reduce its precursors in potatoes, specifically the content of reducing sugars (Amrein et al., 2003). Factors influencing the content of reducing sugars in potatoes include: the variety of potato, the weather conditions during cultivation, the degree of maturity, the size of the tuber, temperature and the duration of the storage (Hertog et al., 1997) (Tareke et al., 2002) (De Wilde et al., 2005, 2006) (Mojska et al., 2007) (Mestdagh et al., 2008a).

3.2.1 Variety of potato

Varieties with a lower content of reducing sugars are associated with a lower production of acrylamide during frying, therefore if the potato is intended for frying (both at industrial level and domestic level), varieties of potato with a low content of reducing sugars should be selected (Palermo et al., 2016), specifically a sugar content of less than 0.3 % of fresh weight (Pedreschi, 2007). Some authors recommend a content of reducing sugars of less than 0.2 % of the sugars in the fresh potato (Pedreschi, 2007) (Torres y Parreño, 2009) recommend using varieties of potato with different characteristics for frying French fries or chips.

3.2.2 Degree of maturity

Potatoes intended for frying must not be harvested until they are fully mature, so that the dry matter increases and the content of reducing sugars decreases. Small potatoes should not be harvested as these are associated with a higher content of reducing sugars and therefore an increase in the formation of acrylamide during frying (De Wilde et al., 2006) (Medeiros et al., 2012). De Wilde et al. (2006) indicated that the concentration of reducing sugars is higher in small tubers less than 50 mm in size than those which are larger than 50 mm. These authors observed concentrations of reducing sugars of 1.62 % in dry matter in tubers of less than 50 mm, whereas in the larger tubers (over 50 mm), the concentration of reducing sugars was 0.19 % in dry matter.

They also observed that the percentage of dry matter was higher in large tubers (20.20 %) in comparison to small tubers (17.64 %). Therefore, the size of the potatoes intended for frying must be larger. Small tubers should be removed.

3.2.3 Temperature and storage time

The temperature and storage time of the potatoes affects the content of reducing sugars. The accumulation of sugars is favoured by low temperatures and the ageing of the product. Potatoes have an equilibrium between the content of starch and the content of reducing sugars. Storage at temperatures below 10 ºC moves the equilibrium towards the release of reducing sugars which intervene in the Maillard reaction. As the content of reducing sugars in the frying process is increased, a higher quantity of acrylamide is formed. The glucose content is four times higher and the fructose content is five times higher in potatoes stored at 3 ºC than in potatoes stored at 10 ºC (Olsson et al., 2004, 2005). Other authors have also indicated a high content of reduced sugars in potatoes stored at 4 ºC in comparison to those stored at 8 ºC (Amrein et al., 2003) (De Wilde et al., 2005). Therefore, potatoes intended for frying should be stored at temperatures above 8 ºC (Palermo et al., 2016). This will minimise the effect of sweetening due to low temperature. At lower temperatures, reducing sugars are accumulated, especially when the storage is for prolonged periods (Sowokinos, 2001) (Mestdagh et al., 2008). Storage at temperatures of more than 10 ºC moves the equilibrium towards the synthesis of starch at the expense of the reducing sugars. Therefore, potatoes which have been refrigerated must be reconditioned at higher temperatures for 3 weeks at 15 ºC (De Wilde et al., 2005). On the other hand, storage at higher temperatures may cause problems, as the higher the storage temperature, the early the sprouting. Sprouting should be avoided as this causes changes to the tubers, and is also associated with an increase in the reducing sugars.

At an industrial level, in the United States, the FDA (2016) recommends manufacturers consult the local agrarian extension services to identify varieties of potato with a low content of reducing sugars available in the region and at different times of the year, or to ask suppliers who offer varieties with a low content of reducing sugars where possible. In view of this problem in the United States, new varieties of potato are being developed with a lower content of reducing sugars and a higher resistance to cold-induced sweetening. Similarly, cultivars are being developed (both using conventional genetic improvement and genetic engineering) with lower levels of asparagine, the precursor to acrylamide.

3.3 Colour index

When frying the potatoes, the required sensory properties are developed, especially the colour and the aroma as a consequence of the Maillard reaction. Nevertheless, if the reaction is excessive, bitter flavours and dark colours are produced making fried potatoes unattractive to the consumer. This is why the colour of fried potatoes is a most important attribute of quality, as it determines acceptability by the consumer. In addition, a number of studies have demonstrated the importance of colour as an indicator of the content of acrylamide (Pedreschi et al., 2005, 2006,

2007) (Gökmen and Senyuva, 2006) (Viklund et al., 2007) (Mestdagh et al., 2008a) (Gökmen and Mogol, 2010) (Mesías y Morales, 2015). The colour of fried potatoes mainly depends on the content of reducing sugars in the potatoes used. A content that is too high appears as an undesirable dark brown colour. The acrylamide content and the colour of fried potatoes have been found to be a function of the glucose/fructose ratio in the potatoes. A higher fructose content in relation to the glucose content stimulates the formation of acrylamide more than the colour developed by the Maillard reaction. The opposite effect has been observed if the glucose content is higher than the fructose content (Mestdagh et al., 2008a). The glucose/fructose ratio depends on the enzymatic activity in the potato during cultivation and post-harvest and on the variety of potato (Hertog et al., 1997).

The colour of the potatoes also depends on the storage temperature given that, as mentioned above, it affects the sugar content. Therefore, if potatoes stored at 3 ºC are used, the colour of the fried potatoes is darker than if potatoes stored at 10 ºC are used (Olsson et al., 2004).

4. Recommended measures for home-cooking

Some authors indicate that reducing the cooking time, blanching the potatoes before frying them (that is, immersing them in boiling water first) and then drying them (dry in convection or hot air oven after frying) reduces the acrylamide content in certain foods (Kita et al., 2004) (Skog et al., 2008).

4.1 Pre-treatment before cooking

The sugar levels can also be reduced by dipping the potatoes in warm or hot water or leaving them to soak at room temperature before frying or roasting them.

4.1.1 Washing/soaking in water

A number of publications scientifically agree that soaking the potatoes in warm water before cooking reduces the formation of acrylamide during the frying process by between 20 and 30 % (Mestdagh et al., 2008b) (Pedreschi et al., 2009) (Medeiros et al., 2010) (Viklund et al., 2010). This effect is explained by the extraction of reducing sugars and amino acids from the surface of the potato. This is positive from the point of view of the acrylamide reduction but may have a negative effect from the organoleptic point of view, as it affects the components that determine the sensory quality of the potatoes (Masson et al., 2006).

The influence of the water temperature and immersion time have also been studied, concluding that both the elimination of amino acids and of reducing sugars increases as the temperature of the water and the pre-treatment time in water increase. Haase et al. (2003) indicate that the reduction of the sugar content using blanching may reduce the acrylamide concentration by up to 60 % in chips. Mestdagh et al. (2008b) found a reduction of acrylamide of 65 and 96 % in French fries (strips) or chips, respectively, after blanching at 70 ºC for 10-15 minutes, and indicated that the water temperature has a greater effect on the efficiency of the sugar extraction than the blanching time. To the contrary, Pedreschi et al. (2004) obtained a greater reduction in the acrylamide content, more than 90 %, after blanching at 50 ºC/70 minutes and at 70 ºC/40 minutes, concluding that the blanching time is a critical factor.

4.1.2 Pre-treatment in a solution of organic acids

The pH affects the reaction speed between the sugars and the amino acids, and is ideal at a low acidic pH. Jung et al. (2003) demonstrated that the acidification of the washing water with citric acid prior to frying reduces the formation of acrylamide by 73 % in frying potatoes after frying for 6 minutes at 190 ºC at atmospheric pressure. Pedreschi et al. (2004) obtained similar results for potatoes fried at 150 ºC with a pre-wash in a citric acid solution of 10 and 20 g/l.

Other authors (Kita et al., 2004) have confirmed that the acid type affects the efficiency of the extraction of sugars and asparagine depending on the blanching water temperature, at 20 ºC, citric acid is more efficient while at 70 ºC acetic acid has more effect. Nevertheless, it should be remembered that the limiting factor of this control strategy is the concentration of acid which is compatible with the organoleptic characteristics of the product, and the maximum limit has been established at a concentration of 1 % citric acid (Jung et al., 2003).

4.1.3 Pre-treatment with antioxidants

The effect of antioxidant compounds on the formation of acrylamide in potatoes has been assessed with different results (Kotsiou et al., 2010). Experimentally, it has been found that the application of extracts of antioxidant compounds (green tea, cinnamon, oregano) during the soaking of the potatoes before frying may be a strategy for use in the home to reduce the acrylamide content without affecting the organoleptic characteristics of the fried potatoes (Morales et al., 2014).

4.1.4 Drying

Some authors (Gökmen et al., 2006) have observed a reduction in the formation of acrylamide in potatoes which are dried prior to frying, linked to a shortening in the frying time necessary to obtain the typical characteristics of French fries.

4.1.5 Surface/volume ratio

The formation of acrylamide is considered a surface phenomenon as it mainly appears on the surface of the food, where the temperatures above which acrylamide is formed are reached most quickly. The distribution of the temperature from the exterior to the interior of the potato is influenced by the surface/volume ratio. The higher this ratio, the greater the loss in moisture of the product and the higher the temperature reached in the centre, two factors linked to a higher risk of synthesis of acrylamide (Gökmen and Palazoğlu, 2009). This is the reason why the surface area of the potato should be reduced by cutting them into thicker slices before frying or roasting and not using the finer slices (fine slices of potato) after frying or roasting (*Codex Alimentarius* Commission, 2009).

4.1.6 Defrosting the potato in strips

Tuta et al. (2010) demonstrated experimentally that the final content of acrylamide in the frozen potato for frying is significantly reduced, up to 89 % for frying at 180 ºC, if the product is first defrosted in the microwave. This reduction is related to the reduced frying time required to obtain the organoleptic characteristics similar to the non-frozen product.

4.2 Processing conditions

4.2.1 Culinary processing time and temperature

The effect of the culinary processing temperature on the amount of acrylamide formed has been widely investigated. Results show that temperature has a direct and significant effect on the quantity of acrylamide and that the levels of acrylamide in the culinary preparation of potatoes can be reduced by controlling the application of heat, especially during frying.

The majority of studies indicate that the formation of acrylamide is generated above temperatures of 120 ºC (Mottram et al., 2002) (Stadler et al., 2002) (Becalski et al., 2003) (Gökmen et al., 2006); some authors indicate that it increases significantly at temperatures above 150 ºC; others establish the critical temperature at around 175 ºC (Gertz and Klostermann, 2002) (Yasuhara et al., 2003), and at higher temperatures (180-200 ºC), the drastic increase in acrylamide levels is followed by a rapid decrease due to the acrylamide degradation reactions (Sanny et al., 2010). The latest studies show that the effect of the frying temperature between 150 and 190 ºC on the formation of acrylamide, varies depending on the variety of potato according to the sugar and moisture content. They conclude that in addition to the reducing sugars and asparagine there are other factors dependent on the variety of potato. This includes the sucrose content which may be linked to the formation of acrylamide during frying (Yang et al., 2016). All the studies agree on the existence of a lineal increase between the concentration of acrylamide and the heating time.

In any case, the effects of temperature and time on the acrylamide content are associated with a loss in moisture and an increase in the speed of the Maillard reaction (Dunovská et al., 2004). Consequently, recommendations for the cooking of potatoes refer to the control of the temperature and time, to prevent critical temperature and moisture values from being reached in the product during the heating process. The majority of the studies have focussed on the frying process which is analysed below.

4.2.2 Type of cooking

The way in which foods are cooked may have a substantial impact on the level of acrylamide in food. The differences observed in the content of this compound are attributed to the influence of the cooking method on the moisture and internal temperature reached by the product.

In the frying process temperatures of over 120 ºC and a moisture level of below 2.5 % may be reached. As a result, fried potatoes have higher levels of acrylamide than boiled or roast potatoes. Nevertheless, Palazoğlu et al. (2010) showed that at temperatures of 170 ºC roast potatoes had a higher content of acrylamide than fried potatoes, whereas at temperatures of 180 and 190 ºC the opposite occurs.

As with frying, in the roasting process, 99 % of the acrylamide is formed on the crust, as the interior does not reach temperatures of more than 100 ºC (Sadd and Hamlet, 2005), and the levels increase with the time and temperature applied (Claus et al., 2008) (Keramat et al., 2011). In addition, it has been shown that in convection ovens, the air circulation leads to faster and more intense drying of the surface, significantly increasing the acrylamide content (Claus et al., 2008). In this type of cooking, a maximum temperature of 230 ºC should be applied and the relative humidity kept high throughout the roasting process (CIAA, 2013).

Microwave frying may be an alternative to traditional frying as this not only results in significant reductions in the frying temperature and time but also because of the protective effect of the flow of steam from the centre of the product which helps to remove both the acrylamide and its precursors (Barutcu et al., 2009). Other studies show that the effect of microwaving on the reduction of acrylamide is greater as the power applied increases. However, the main limitation in the frying process is the low levels of uniformity in the heating of the centre of the product, which is reflected in the heterogeneity of the sensory properties of the final product. Nevertheless, precooking the potatoes in the microwave may result in, according to some authors, a reduction of up to 60 % in the acrylamide content after frying the potato chips at 190 ºC (Belgin, 2007) (Tuta et al., 2010).

In general, potatoes should be boiled, microwaved or roasted instead of frying.

4.3 Frying conditions

4.3.1 Oil temperature and frying time

Several studies have demonstrated that minor fluctuations in the frying temperature may have major consequences for the final concentration of acrylamide in the fried potatoes, and that the majority of acrylamide is formed at the end of the frying process when the water content of the product reaches critical values. Haase et al. (2003) confirmed that by reducing the temperature from 185 to 165 ºC when frying potatoes, it is possible to halve the formation of acrylamide.

In addition, it has been confirmed that after frying at 150, 170 and 190 ºC for 9 minutes, the acrylamide content is significantly higher on the surface than in the inside of the potatoes. This is because the moisture content rapidly decreases on the surface due to the evaporation of water at high temperatures, while in the interior, temperatures of 103-104 ºC are not exceeded (Gökmen et al., 2006). In addition, it has been shown that the longer the frying time, the lower the moisture content and the greater the formation of acrylamide in the product. Gökmen and Palazoğlu (2009), among others, have confirmed that the acrylamide concentration in potatoes increases lineally during a frying time of 5 minutes and Romani et al. (2008) showed that the frying time for French fries at 180 ºC is a critical factor after 4 minutes. Nevertheless, in this type of cooking, the possibility of reducing the temperature and time of the process is conditioned by the acceptability of the product by the consumer. In this case, the compromise between reducing acrylamide levels during the frying process and maintaining the organoleptic properties of the product must be considered.

Below temperatures of 140 ºC, the frying time is extended. Given that the majority of acrylamide is formed at the end of the frying process, the general recommendation for preventing high levels of acrylamide is not to exceed temperatures of 170-175 ºC from the start of the process and to lower the temperature towards the end of the process.

Other factors which may affect the amount of acrylamide in the fried potatoes have also been studied. Gökmen and Palazoğlu (2009) found losses of acrylamide due to evaporation which increased from 0.7 to 1.8 % with an increase in frying temperature from 150 to 180 ºC and an increase in the surface/volume ratio of the product. In addition, using kinetic studies, Hui-Tsung et al. (2016) demonstrated that the acrylamide formed during the frying of potatoes is distributed into three stages: solid (fried potatoes), liquid (frying oil) and gaseous (water vapour) and that the acrylamide content gradually increases in the three stages until reaching a stable value. Although the quantity lost through evaporation is insignificant with respect to that remaining in the product, this fact may imply an additional risk of exposure to acrylamide due to its build-up in the kitchen atmosphere. Therefore, the kitchen should be well-ventilated after frying. Moreover, distribution of part of the acrylamide formed in the frying oil implies that reuse of the oil should be avoided.

4.3.2 Mass/oil ratio

In general, acrylamide levels decrease as the mass ratio between the food and the oil increases. This is due to the fall in temperature of the oil at the start of the process when the potatoes are placed in the oil, and the consequent increase in time required to return to the frying temperature. This mass/oil ratio must be adjusted so that the temperature does not fall below 140 ºC in order to obtain optimum product quality (texture and flavour) while reducing the acrylamide concentration. Romani et al. (2009) demonstrated that aside from the mass/oil ratio, the thermal capacity of the fryer is a determining factor in the recovery of the initial temperature, affecting the loss of moisture and the amount of acrylamide in the final product.

Depending on the heating power of the fryer, the amount of potatoes immersed in the oil should aim to provide an effective cooking temperature which starts at 140 ºC and ends at 160 ºC. Greater reductions in temperature after adding all the potatoes would increase the absorption of fat and a higher final temperature would increase the formation of acrylamide (*Codex Alimentarius* Commission, 2009).

4.3.3 Type and characteristics of frying oil

According to some authors, the type of oil, olive or sunflower oil, used in the frying process does not seem to be linked to the acrylamide content in the chips (Mesías y Morales, 2015). However, other authors have found a higher acrylamide content in potatoes fried in palm oil than in sunflower or rapeseed oil (Gertz and Klostermann, 2002) and also in olive oil with respect to corn oil (Becalski et al., 2003).

The differences observed between different types of oil may be linked to their content in polyunsaturated fatty acids, which would be involved in the formation of acrylamide by other paths alternative to the Maillard reaction (Marchettini et al., 2013).

Napolitano et al. (2008) among other authors, have studied the effect of the phenolic composition of olive oil in the formation of acrylamide in fried potatoes, and Jin et al. (2013) after a complete review of the results published, concluded that the role of the antioxidant agents present in frying oil in the acrylamide formation process is complex and conclusive data is still not available.

In addition, some studies concluded that the degree of oxidisation of the oil, measured by the content of glycerol and of mono- and diacylglycerols, does not have a significant effect on the acrylamide content in fried potatoes (Mestdagh et al., 2007). However, Dunovská et al. (2004) obtained an increase of acrylamide to the order of ten times in chips, at 150 ºC in used oil in relation to the same product fried in new oil at the same temperature, and more recently Urbančič et al. (2014) demonstrated, at experimental level, that the level of acrylamide doubles in French fries when the oil has reached a critical degree of oxidation.

4.4 Recommendations from food safety agencies and other international bodies

Different food safety agencies and other international bodies have provided recommendations for the consumer in order to reduce exposure to acrylamide as a consequence of domestic culinary practices.

In France, the aforementioned agreement of the CNIPT indicates that storing potatoes at temperatures between 8 and 10 ºC for periods of over 6 months, helps to maintain the content of reducing sugars at levels similar to those observed at harvest time.

In Germany, the Federal Institute for Risk Assessment (BfR, 2011) recommends "baking golden brown instead of charring" to consumers and the catering sector as the level of acrylamide increases with the intensity of browning.

In the United Kingdom, in January 2017,the Food Standards Agency (FSA), based on the results of their study "Total diet study of inorganic contaminants, acrylamide & mycotoxins" launched a campaign to Go for Gold to help consumers to understand ways in which they might minimise exposure to acrylamide in home-cooking. This also recommends not storing raw potatoes in the fridge if they are to be roasted or fried. Storage should ideally be in a dark cool place at temperatures above 6 °C (FSA, 2017).

The *Codex Alimentarius* Commission (2009) recommends, to obtain significant reductions in the acrylamide content in fried potatoes, that the temperature of the oil when starting to fry should not exceed 170-175 ºC and the potatoes should be fried until they are golden yellow rather than golden brown.

Conclusions of the Scientific Committee

Characteristics of potatoes which influence the exposure to acrylamide generated as a result of frying

Given that the water content of a fresh potato ranges between 75-80 %, the content of dry matter in the raw material should not be higher than 25 %.

Varieties of potatoes with a low reducing sugar content should be selected.

Potatoes with more than 0.3 % of reducing sugars must not be used for frying as this is associated with a higher acrylamide formation. However, the content of reducing sugars may vary considerably with time depending on the storage conditions.

Potatoes intended for frying must be stored at temperatures of around 8 ºC.

Large tubers, measuring over 50 mm, should be selected for frying.

With respect to the test methods employed, in addition to the method used in France, the glucose rate in juice might be considered using the Fehling volumetric test for measuring the reducing sugars or the colorimetric method with o-toluidine. In Spain, the INIA (2017) recommends the use of the dinitrosalicylic colorimetric method.

Recommendations for minimising the production of acrylamide when cooking potatoes at home

- General recommendation:
  - Eat a varied and balanced diet.
- When buying potatoes:
  - Only use potatoes that are perfectly mature, without sprouts or green parts.
- When storing potatoes at home:
  - Do not store potatoes at temperatures of less than 8 ºC: Do not keep potatoes in the fridge.
  - Store potatoes in a dry dark place to prevent sprouting, as this causes changes to the tubers, and is also associated with an increase in the reducing sugars.
  - Avoid prolonged storage: purchase and consumer potatoes on a weekly basis.
- Before frying:
  - Dice potatoes or cut in strips (chips) rather than in fine slices.
  - Wash cut potatoes under plenty of running water.
  - Thoroughly dry potatoes with kitchen paper.
- When cooking:
  - Cook potatoes by boiling, in the oven or microwave rather than frying them.
  - For processed potatoes, observe manufacturers' instructions for cooking them correctly and ensure that they are neither overcooked nor cooked at very high temperatures.
  - Avoid frying temperatures of more than 175 ºC at all times.
  - Reduce frying times when cooking small quantities of potatoes.
  - Observe the colour that appears on the surface of the product. Potatoes must be fried until they are a golden yellow colour rather than golden brown.
  - Reject darker-coloured potatoes.
  - Limit the re-use of frying oil. It is better to use new oil for frying.
  - The kitchen should be well-ventilated after frying.

References

AECOSAN (2015). Agencia Española de Consumo, Seguridad Alimentaria y Nutrición. Informe de AECOSAN sobre la acrilamida en los alimentos. Disponible en: http://www.aecosan.msssi.gob.es/AECOSAN/web/seguridad_alimentaria/subdetalle/acrilamida.htm [acceso: 12-09-17].

Amrein, T.M., Bachmann, S., Noti, A., Biedermann, M., Ferraz, M., Biedermann, S., Grob, K., Keiser, A., Realini, P., Escher, F. and Amadoä, R. (2003). Potential of Acrylamide Formation, Sugars, and Free Asparagine in Potatoes: A Comparison of Cultivars and Farming Systems. *Journal of Agriculture and Food Chemistry*, 51, pp: 5556-5560.

Barutcu, I., Sahin, S. and Sumnu, G. (2009). Acrylamide formation in different batter formulations during microwave frying. *LWT-Food Science and Technology*, 42, pp: 17-22.

Becalski, A., Lau, B., Lewis, D. and Seaman, S. (2003). Acrylamide in foods: occurrence, sources and modelling. *Journal of Agriculture and Food Chemistry*, 51, pp: 802-808.

Belgin, E.S. (2007). Reduction of acrylamide formation in French fries by microwave pre-cooking of potato strips. *Journal of the Science of Food and Agriculture*, 87, pp: 133-137.

BfR (2011). Federal Institute for Risk Assessment. Acrylamid in Lebensmitteln-Opinion Nr. 043/2011. Available at: http://www.bfr.bund.de/de/a-z_index/acrylamid-4185.html [accessed: 12-09-17].

BOE (2003). Real Decreto 140/2003, de 7 de febrero, por el que se establecen los criterios sanitarios de la calidad del agua de consumo humano. BOE Nº 45 de 21 de febrero de 2003, pp: 7228-7245.

BOE (2009). Real Decreto 31/2009, de 16 de enero, por el que se aprueba la norma de calidad comercial para las patatas de consumo en el mercado nacional y se modifica el anexo I del Real Decreto 2192/1984, de 28 de noviembre, por el que se aprueba el Reglamento de aplicación de las normas de calidad para las frutas y hortalizas frescas comercializadas en el mercado interior. BOE Nº 21 de 24 de enero de 2009, pp: 8175-8182.

BOE (2010). Real Decreto 1799/2010, de 30 de diciembre, por el que se regula el proceso de elaboración y comercialización de aguas preparadas envasadas para el consumo humano. BOE Nº 17 de 20 de enero de 2011, pp: 6292-6304.

CIAA (2013). Confederation of Food and Drink Industries of the EU. Acrylamide 'Toolbox' Revision 13. Available at: http://www.fooddrinkeurope.eu/publications/category/toolkits/ [accessed: 12-09-17].

Claus, A., Mongili, M., Weisz, G., Schieber, A. and Carle, R. (2008). Impact of formulation and technological factors on the acrylamide content of wheat bread and bread rolls. *Journal of Cereal Science*, 47, pp: 546-554.

CNIPT (2016). Comité National Interprofessionnel de la Pomme de Terre. Accord Interprofessionel relatif à l'utilisation de l'allégation culinaire "frites" seule ou associée à dáutres allégations culinaires sur les lots de pommes de terre de conservation. Available at: http://www.cnipt.fr/accord-interprofessionnel-pour-les-pommes-de-terre-frire/ [accessed: 12-09-17].

Codex Alimentarius Commission (2009). Código de prácticas para reducir el contenido de acrilamida en los alimentos (CAC/RCP 67-2009), pp: 1-8.

De Wilde, T., De Meulenaer, B., Mestdagh, F., Govaert, Y., Vandeburie, S. and Ooghe, W. (2005). Influence of storage practices on acrylamide formation during potato frying. *Journal of Agricultural and Food Chemistry,* 53, pp: 6550-6557

De Wilde, T., De Meulenaer, B., Mestdagh, F., Govaert, Y., Ooghe, W. and Fraselle, S. (2006). Selection criteria for potato tubers to minimize acrylamide formation during frying. *Journal of Agricultural and Food Chemistry,* 54, pp: 2199-2205.

DG CCRF (2017). Direction génerale de la concurrence de la consommation et de la répression des fraudes. Available at: https://www.economie.gouv.fr/dgccrf/contamination-des-aliments-par-certains-composes-neoformes-2016 [accessed: 12-09-17].

Dunovská, L., Hajlová, J., Hájková, T., Holadová, K. and Hájková, K. (2004). Changes of acrylamide levels in food products during technological processing. *Czech Journal Food Scienc*e, 22 Special Issue, pp: 283-286.

EFSA (2015). European Food Safety Authority. Panel on Contaminants in the Food Chain (CONTAM). Scientific opinion on acrylamide in food. *EFSA Journal*, 13 (6): 4104.

EU (2010). Commission Recommendation of 2 June 2010 on the monitoring of acrylamide levels in food (2010/307/UE). OJ L 137 of 3 June 2011, pp: 4-10.

EU (2011). Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the provision of food information to consumers, amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004. OJ L 304 of 22 November 2011, pp: 1-72.

EU (2013). Commission Recommendation of 8 November 2013 on investigations into the levels of acrylamide in food (2013/647/UE). OJ L 301 of 12 November 2013, pp: 15-17.

EU (2017). Proyecto de Reglamento (UE) de la Comisión, por el que se establecen medidas de mitigación y niveles de referencia para reducir la presencia de acrilamida en los alimentos. SANTE/11059/2016 Rev.2.

EUPPA (2007). Asociación Europea de Transformadores de la Patata. Entrance control for raw material (potatoes) currently used in the french fries industry. Available at: www.euppa.eu [accessed: 12-09-17].

FAO/OMS (2005). Organización de las Naciones Unidas para la Alimentación y la Agricultura/Organización Mundial de la Salud. Joint FAO/WHO Expert Committee on Food Additives: Summary and Conclusions Report from Sixty-fourth Meeting, Rome, 8-17 February 2005. (Rep. No. JECFA/64/SC).

FDA (2016). Food and Drug Administration. Guidance for Industry Acrylamide in Foods. Available at:: https://www.fda.gov/downloads/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/ChemicalContaminantsMetalsNaturalToxinsPesticides/UCM374534.pdf [accessed: 12-09-17].

Fuhr, U., Boettcher, M., Kinzig-Schippers, M., Weyer, A., Jetter, A., Lazar, A., Taubert, D., Tomalik-Scharte, D., Pournara, P., Jakob, V., Harlfinger, S., Klaassen, T., Berkessel, A., Angerer, J., Sörgel, F. and Schömig, E. (2006). Toxicokinetics of acrylamide in humans after ingestion of a defined dose in a test meal to improve risk assessment for acrylamide carcinogenicity. *Cancer Epidemiology Biomarkers and Prevention*, 15 (2), pp: 266-271.

FSA (2017). Food Standards Agency. Campaña "Go for Gold". Available at: https://www.food.gov.uk/science/research/chemical-safety-research/env-cont/fs102081 [accessed: 12-09-17].

Gertz, C. and Klostermann, S. (2002). Analysis of acrilamide and mechanisms of its formation in deep-fried products. *European Journal of Lipid Science and Technology*, 104, pp: 762-771.

Gökmen, V. and Senyuva, H.Z. (2006). Study of colour and acrylamide formation in coffee, wheat our and potato chips during heating. *Food Chemistry*, 99, pp: 238-243.

Gökmen, V. y Palazoglu, T.K. (2009). Measurement of evaporated acrylamide during frying of potatoes: Effect of frying conditions and surface area-to-volume ratio. *Journal of Food Engineering*, 93, pp: 172-176.

Gökmen, V. and Mogol, B.A. (2010). Computer vision-based image analysis for rapid detection of acrylamide in heated foods. *Quality Assurance and Safety of Crops & Foods*, 2, pp: 203-207.

Haase, U.N., Matthaus, B. and Vosmann, K. (2003). Acrylamide formation in foodstuffs-Minimising strategies for potato crisps. *Deutsche Lebensmittel-Rundschau*, 99 (3), pp: 87-90.

HEATOX (2007). Heat-generated food toxicants: Identification, characterisation and risk minimisation. Lund, Sweden: Lund University. Available at: http://heatox.org/ [accessed: 12-09-17].

Hertog, M.L.A.T., Putz, B. and Tijskens, L.M.M. (1997). The effect of harvest time on the accumulation of reducing sugars during storage of potato (*Solanum tuberosum* L.) tubers: Experimental data described, using a physiological based, mathematical model. *Potato Reserach*, 40, pp: 69-78.

Hui-Tsung, H., Ming-Jen, C., Tzu-Ping, T., Li-Hsin, C., Li-Jen, H. and Tai-Sheng, Y. (2016). Kinetics for the distribution of acrylamide in French fries, fried oil and vapour during frying of potatoes. *Food Chemistry*, 211, pp: 669-678.

INIA (2017). Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria. Métodos de valoración para las patatas. Available at: http://wwwsp.inia.es/Investigacion/OtrasUni/DTEVPF/Unidades/CentrosEnsayo/EstacionEnsayos/Documents/M%C3%A9todospatata.pdf [accessed: 12-09-17].

INFOSAN (2005). International Food Safety Authorities Nota de información Acrilamida. Available at: http://www.acrylamide-food.org/ [accessed: 12-09-17].

Jin, C., Wu, X. and Zhang, Y. (2013). Relationship between antioxidants and acrylamide formation: a review. *Food Research International*, 51, pp: 611-620.

Jung, M.Y., Choi, D.S. and Ju, J.W. (2003). A novel technique for limitation of acrylamide formation in fried and baked corn chips and in french fries. *Journal of Food Science*, 68, pp: 1287-1290.

Kalita, D., Holm, D.G. and Jayanty, S. (2013). Role of polyphenols in acrylamide formation in the fried products of potato tubers with colored flesh. *Food Research International*, 54, pp: 753-759.

Keramat, J., LeBail, A., Prost, C. and Safari, M. (2011). Acrylamide in Baking Products: A Review Article. *Food and Bioprocess Technology*, 4, pp: 530-543.

Kita, A., Brathen, E., Knutsen, S.H. and Wicklund, T. (2004). Effective ways of decreasing acrylamide content in potato crisps during processing. *Journal of Agricultural and Food Chemistry*, 52 (23), pp: 7011-7016.

Knutsen, S.H., Dimitrijevic, S., Molteberg, E.L., Segtnan, V.H., Kaaber, L. and Wicklund, T. (2009). The influence of variety, agronomical factors and storage on the potential for acrylamide formation in potatoes grown in Norway. *LWT-Food Science and Technology*, 42, pp: 550-556.

Kotsiou, K., Tasioula-Margari, M., Kukurov, K. and Ciesarov, Z. (2010). Impact of oregano and virgin olive oil phenolic compounds on acrylamide content in a model system and fresh potatoes. *Food Chemistry*, 123, pp: 1149-1155.

Low, M.Y., Koutsidis, G., Parker, J.K., Elmore, J.S., Dodson, A.T. and Mottram, D.S. (2006). Effect of citric acid and glycine addition on acrylamide and flavor in a potato model system. *Journal of Agricultural and Food Chemistry*, 54, pp: 5976-5983.

Marchettini, N., Focardi, S., Guarnieri, M., Guerranti, C. and Perra, G. (2013). Determination of acrylamide in local and commercial cultivar of potatoes from biological farm. *Food Chemistry*, 136, pp: 1426-1428.

Masson, L., Romero, N., Castro, J., Camilo, C., Encina, C., Hernández, L., Muñoz, J., y Robert, P. (2006). Informe de avance Proyecto HEATOX 506820. Graz, Austria.

Medeiros, R., Mestdagh, F., De Muer, N., Van Peteghem, C. and De Meulenaer, B. (2010). Effective quality control of incoming potatoes as an acrylamide mitigation strategy for the french fries industry. *Food Additives and Contaminants Part A. Chemistry Analysis Control Exposure & Risk Assessment*, 27, pp: 417-425.

Medeiros, R., Mestdagh, F. and De Meulenaer, B. (2012). Acrylamide formation in fried potato products. Present and future, a critical review on mitigation strategies. *Food Chemistry*, 133, pp: 1138-1154.

Mesías, M. and Morales, F.J. (2015). Acrylamide in commercial potato crisps from Spanish market: Trends from 2004 to 2014 and assessment of the dietary exposure. *Food and Chemical Toxicology*, 81, pp: 104-110.

Mesías, M., Holgado, F., Márquez-Ruiz, G. and Morales, F.J. (2017). Impact of the characteristics of fresh potatoes available in-retail on exposure to acrylamide: Case study for French fries. *Food Control*, 73, Part B, pp: 1407-1414.

Mestdagh, F., De Meulenaer, B. and Van Peteghem, C. (2007). Influence of oil degradation on the amounts of acrylamide generated in a model system and in french fries. *Food Chemistry*, 100, pp: 1153-1159.

Mestdagh, E., Wilde T.D., Castelein, P., Nemeth, O., Van Peteghem, C. and Meulenaer, B. (2008a). Impact of the reducing sugars on the relationship between acrylamide and Maillard browning in French fries. *European Food Research and Technology*, 227, pp: 69-76.

Mestdagh, F., De Wilde, T., Fraselle, S., Govaert, Y., Ooghe, W., Degroodt, J.M., et al. (2008b). Optimization of the blanching process to reduce acrylamide in fried potatoes. *Lwt-Food Science and Technology*, 41, pp: 1648-1654.

Mojska, H., Gielecinska, I. and Szponar, L. (2007). Acrylamide content in heat-treated carbohydrate-rich foods in Poland. *Roczniki Panstwowego Zakladu Higieny*, 58 (1), pp: 345-349.

Morales, G., Jiménez, M., García, O., Mendoza, M.R. and Beristain, C.I. (2014). Effect of natural extracts on the formation of acrylamide in fried potatoes. *LWT-Food Science and Technology*, 58, pp: 587-593.

Mottram, D.S., Wedzicha, B.L. and Dodson, A.T. (2002). Acrylamide is formed in the Maillard reaction. *Nature*, 419 (6906), pp: 448-449.

Mulla, M.Z., Bharadwaj, V.R., Annapure, U.S. and Singhal, R.S. (2011). Effect of formulation and processing parameters on acrylamide formation: A case study on extrusion of blends of potato flour and semolina. *LWT-Food Science and Technology*, 44 (7), pp: 1643-1648.

Napolitano, A., Morales, F., Sacchi, R. and Fogliano, V. (2008). Relationship between virgin olive oil phenolic compounds and acrylamide formation in fried crisps. *Journal Agricultural and Food Chemistry*, 56, pp: 2034-2040.

Olsson, K., Svensson, R, and Roslund, C. (2004). Tuber components affecting acrylamide formation and colour in fried potato: variation by variety, year, storage temperature and storage time. *Journal of the Science of Food Agriculture*, 84, pp: 447-458.

Olsson, K., Svensson, R. and Roslund, C.A. (2005). Variation in tuber components affecting acrylamide formation and color in fried potato. *Acta Horticulturae*, 684, pp: 159-164.

Palazoğlu, T.K, Savran, D. and Gökmen, V.J. (2010). Effect of cooking method (baking compared with frying) on acrylamide level of potato chips. *Food Science*, 75 (1), pp: E25-E29.

Palermo, M., Gökmen, V., De Meulenaer, B., Ciesarová, Z., Zhang, Y., Pedreschi, F. and Fogliano, V. (2016). Acrylamide mitigation strategies: critical appraisal of the Food Drink Europe toolbox. *Food & Function*, 7, pp: 2516-2525.

Pedreschi, F., Kaackb, K. and Granbyc, K. (2004). Reduction of acrylamide formation in potato slices during frying. *LWT-Food Science and Technology*, 37 (6), pp: 679-685.

Pedreschi, F., Moyano, P., Kaack, K. and Granby, K. (2005). Color changes and acrylamide formation in fried potato slices. *Food Research International*, 38, pp: 1-9.

Pedreschi, F., Kaack, K. and Granby, K. (2006). Acrylamide content and color development in fried potato strips. *Food Research International*, 39, pp: 40-46.

Pedreschi, F. (2007). The canon potato science: 49. Acrylamide. *Potato Research*, 50, pp: 411-413.

Pedreschi, F., Leon, J., Mery, D., Moyano, P., Pedreschi, R. and Kaack, K. (2007). Color development and acrylamide content of pre-dried potato chips. *Journal of Food Engineering*, 79, pp: 786-793.

Pedreschi, F., Travisany, X., Reyes, C., Troncoso, E. and Pedreschi, R. (2009). Kinetics of extraction of reducing sugar during blanching of potato slices. *Journal of Food Engineering*, 91, pp: 443-447.

Pinhero, R., Pazhekattu, R., Kyly, W., Marangoni, A.G., Liu, Q. and Yada, R.Y. (2012). Effect of genetic modification and storage on the physico-chemical properties of potato dry matter and acrylamide content of potato chips. *Food Research International*, 49, pp: 7-14.

Romani, S., Bacchiocca, M., Rocculi, P. and Rosa, M.D. (2008). Effect of frying time on acrylamide content and quality aspects of French fries. *European Food Research and Technology*, 226 (3), pp: 555-560.

Romani, S., Bacchiocca, M., Rocculi, P. and Rosa, M.D. (2009). Influence of frying conditions on acrylamide content and other quality characteristics of French fries. *Journal of Food Composition and Analysis*, 22, pp: 582-588.

Sadd, P. and Hamlet, C. (2005). The formation of acrylamide in UK cereal products. *Advances in experimental medicine and biology*, 561, pp: 415-429.

Sanny, M., Luning, P.A., Marcelis, W.J., Jinap, S. and Van Boekel, M.A.J.S. (2010). Impact of control behaviour on unacceptable variation in acrylamide in French fries. *Trends in Food Science and Technology,* 21 (5), pp: 256-267.

Skog, K., Viklund, G., Olsson, K. and Sjoholm, I. (2008). Acrylamide in home-prepared roasted potatoes. *Molecular Nutrition and Food Research*, 52 (3), pp: 307-312.

Sowokinos, J.R. (2001). Biochemical and molecular control of cold-induced sweetening in potatoes. *American Journal of Potato Research*, 78, pp: 221-236.

Stadler, R.H., Blank, I., Varga, N., Robert, F., Hau, J. and Guy, P.A. (2002). Acrylamide from Maillard reaction products. *Nature*, 419, pp: 449-450.

Tareke, E., Rydberg, P., Karlsson, P., Eriksson, S. and Tornqvist, M. (2002). Analysis of acrylamide, a carcinogen formed in heated foodstuffs. *Journal of Agricultural and Food Chemistry*, 50 (17), pp: 4998-5006.

Torres, M.D.A. and Parreño, W.C. (2009). Thermal processing and quality optimization. En libro: *Advances in Potato Chemistry and Technology.* Singh, J. y Kaur, L. Elsevier Ed., pp: 163-219.

Tuta, S., Palazoğlu, T. and Gökmen, V. (2010). Effect of microwave pre-thawing of frozen potato strips on acrylamide level and quality of French fries. *Journal of Food Engineering*, 97, pp: 261-266.

Urbančič, S., Kolar, M.H., Dimitrijevic, D., Demsar, L. and Vidrih, R. (2014). Stabilisation of sun ower oil and reduction of acrylamide formation of potato with rosemary extract during deep-fat frying. *LWT-Food Science and Technology*, 57, pp: 671-678.

Viklund, G., Mendoza, F., Sjöholm, I. and Skog, K. (2007). An experimental set-up for studying acrylamide formation in potato crisps. *LWT-Food Science and Technology*, 40, pp: 1066-1071.

Viklund, G., Olsson, K., Sjoholm, I. and Skog, K. (2008). Variety and storage conditions affect the percursor content and amount of acrylamide in potato crisps. *Journal of the Science of Food and Agriculture*, 88, pp: 305-312.

Viklund, G.A.I., Olsson, K.M., Sjoholm, I.M. and Skog, K.I. (2010). Acrylamide in crisps: effect of blanching studied on long-term stored potato clones. *Journal of Food Composition and Analysis*, 23, pp: 194-198.

Williams, J. (2005). Influence of variety and processing conditions on acrylamide levels in fried potato crisps. *Food Chemistry*, 90, pp: 875-881.

Yang, Y., Achaerandio, I. and Pujolà, M. (2016). Influence of the frying process and potato cultivar on acrylamide formation in French fries. *Food Control*, 62, pp: 216-223.

Yasuhara, A., Tanaka, Y., Hengel, M, and Shibamoto, T. (2003). Gas chromatographic investigation of acrylamide formation in browning model systems. *Journal Agriculture Food Chemistry*, 51 (14), pp: 3999-4000.