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# Development of the Maillard reaction in foods cooked by different techniques. Intake of Maillard-derived compounds

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ABSTRACT

Specific and non-specific Maillard reaction (MR) indices such as CIELab colour, browning measurement, furosine, hydroxymethylfurfural (HMF) and furfural, as well as the nutrient content, were analysed for commonly consumed dishes, to test the effects of different culinary treatment on dishes composed of the same ingredients. In addition, the consumption of early MR products (MRP), Amadori compounds, HMF and furfural from a normal serving of these dishes was calculated. As expected, recipes including frying, apart from their particular composition, led to significantly higher values of furosine and HMF, ranging from 4.40 to 175 and from 0.30 to 22.7 mg/kg, respectively; consequently they provided the highest levels of Amadori compounds and HMF intake (0.42–26.8 and 0.02–2.38 mg/serving, respectively). Even so, MRP intake/serving was not very high in comparison with levels reported in the bibliography on some individual foods typically studied in terms of MR development, suggesting that the culinary treatments used do not make a great contribution to the daily MRP consumption.



## 1. Introduction

Most foods must be processed to some extent before they are consumed, in order to ensure their preservation, adequate microbiological security, enzymatic inactivation and the destruction of toxic substances, as well as to enhance the development of aromas, colours and flavours, and hence palatability (Friedman, 1996). Clearly, this processing may give rise to the appearance of new substances, whose nutritive consequences and biological effects must then be considered.

Some forms of food processing, together with the food composition, facilitate the development of the Maillard reaction (MR) and the formation of browning products, which are often responsible for improvements in food palatability (Ames, 1998). The formation of Maillard reaction products (MRP) depends directly on the processing temperature and time, and is greatly heightened by long exposure to high heat (Hardy, Parmentier, & Fanni, 1999). Therefore, MRP content in foods is not only related to their composition, but also to the method and conditions of the industrial or culinary preparation, as well as to possible reheating (Li, Risch, & Reineccius, 1994). Culinary treatments such as frying or baking have a greater impact on the formation of MRP than boiling (Chao, Hsu, & Yin, 2009) and different nutritional studies set up to analyse the basal excretion of MRP recommend avoiding the consumption of roasted foods, bakery products, beer, coffee, etc. (Foerster & Henle, 2003).

MRP are inherent in the Western diet (Delgado-Andrade, Seiquer, Navarro, & Morales, 2007; Förster, Kühne, & Henle, 2005), and are known to produce both benefits and possible risks. In this sense, the challenge is to strike the best balance between benefits and potential risks and then to establish guidelines for optimum treatment/food health. Health problems could arise if excessive amounts of processed foods are consumed – including overheated foods, which often feature in Western diets. Therefore, although consumption of MRP, is associated with some positive biological actions (Bedinghaus & Ockerman, 1995; Friedman, 1996; Somoza, 2005), their antinutritional properties and their implications in degenerative metabolic diseases, like diabetes, cardiovascular disease and osteoporosis (Förster et al., 2005; Yamagishi, Nakamura, & Inoue, 2005), must be considered.

Thus, it is important to characterise and quantify the presence of MRP in common dishes in order to identify their positive and negative effects. Data have been published concerning the presence of MRP in individual foods, such as milk (Morales, Romero, & Jiménez-Pérez, 1996), bread (Ramírez-Jiménez, García-Villanova, & Guerra-Hernández, 2000) or coffee (Del Castillo, Ames, & Gordon, 2002). However, there is not much information about the presence of MRP in whole dishes, and even less about the effect of different cooking procedures on dishes composed of the same ingredients.

The purpose of this study was to compare MR development in different dishes commonly consumed in the Western diet, analysing the effects of different forms of culinary treatment. In

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addition, we quantified the consumption of early MRP, the Amadori compounds (indirectly analysed as furosine), and some intermediate derivatives of the reaction, such as hydroxymethylfurfural (HMF) and furfural, contained in a standard serving of the complete dish.

## 2. Methods and materials

### 2.1. Chemicals

All chemicals used were of analytical grade and were obtained from Merck (Darmstadt, Germany), unless stated otherwise. Acetonitrile (HPLC grade) was obtained from Lab-Scan (Dublin, Ireland). Methanol, potassium ferrocyanide and zinc acetate were purchased from Panreac (Barcelona, Spain). Furosine was obtained from Neosystem Laboratories (Strasbourg, France).

### 2.2. Dishes

Five main foods were selected. Each one was prepared by applying two different recipes (with the same major ingredients) and cooking methods. The dishes were prepared at least in triplicate and on different days with different raw materials purchased in local markets. The following dishes were obtained: pork loin (roasted in salt *vs.* grilled); chicken (casserole *vs.* roasted); rice (stew *vs.* paella); potatoes (boiled *vs.* fried) and anchovies (in vinegar *vs.* fried). A detailed description of the ingredients and culinary techniques applied to each dish is given in Table 1. Once prepared, the edible portion of each serving was removed, weighed and homogenised with a hand blender (Taurus, Vital CM, Spain). The samples were then lyophilised and stored at −20 °C until analysis. Each parameter analysed was determined at least in duplicate.

### 2.3. Determination of chemical composition

The chemical composition of the dishes elaborated was determined in triplicate by official methods (AOAC, 1995). In particular, nitrogen was analysed in a LECO model FP-2000 (Leco Instruments, Madrid, Spain) protein/nitrogen analyser calibrated with EDTA (Dumas method). The nitrogen-to-protein conversion factor considered was 6.25. Results are expressed as grams of protein/100 g of edible portion. The quantity of fat was determined using traditional Soxhlet apparatus. The energy data were obtained from an adiabatic bomb calorimeter (Gallenkamp Autobomb CBA 305, Loughborough, UK). Moisture and ash content were determined by gravimetric methods.

### 2.4. Non-specific marker of Maillard reaction

#### 2.4.1. Measurement of colour

The colour of different samples was determined using a Chroma Meter CR-400 optical sensor (Konica Minolta Sensing, Inc., Osaka, Japan) according to the CIELab scale (CIE Colorimetric Committee, 1974; McLaren & Rigg, 1976). The system provides the values of three colour components; $L^*$ (black-white component, luminosity), and the chromaticity coordinates, $a^*$ (+red to −green component) and $b^*$ (+yellow to −blue component) (Hunter, 1942). The samples were placed in a 34-mm optical glass cell. The sample was illuminated with D65-artificial daylight (10° standard angle) in accordance with the manufacturer's instructions. Solid colours are categorised following Kelly and Judd (1976). Each colour value reported was the mean of two determinations at 22–24 °C.

#### 2.4.2. Absorbance measurement

In the first stage of the MR, reducing sugars react with amino acids, giving rise to non-colour compounds which do not absorb in the visible spectra (Renn & Sathe, 1997). For this reason, the formation of the early low molecular weight compounds was monitored at 280 nm, and a pool of more advanced ones at 360 nm. The progress of the reaction involves the production of high molecular weight compounds, termed melanoidins, with chromophore groups with a characteristic absorbance maximum at 420 nm (Morales & Jiménez-Pérez, 2004). Briefly, the measurement of absorbance at 280, 360 and 420 nm was performed as follows: 0.5 g of sample was suspended in 10 ml of deionised water. The tube was vortexed vigorously for 15 s and then sonicated in an ultrasonic disintegrator (Sonics and Material, Inc., Danbury, CT) for 10 min. The tube was then vortexed again for 5 s and centrifuged at 14,000*g* for 10 min at 4 °C. The supernatant obtained was suitably diluted and measured at 280, 360 and 420 nm in a UV/Vis spectrophotometer (UV-1700 Pharmaspec, Shimadzu Corporation, Kyoto, Japan). Analyses were performed in triplicate.

### 2.5. Specific markers of Maillard reaction

#### 2.5.1. HPLC determination of furosine

Furosine determination was performed following the methods described by Delgado, Corzo, Santa-María, Jimeno, and Olano

**Table 1**
Ingredients and culinary treatment of cooked dishes.

| Non-severe culinary treatment | | | Severe culinary treatment | | |
|---|---|---|---|---|---|
| Dishes | Ingredients | Preparation | Dishes | Ingredients | Preparation |
| Pork loin roasted in salt | Pork loin, salt | Oven: the whole piece, 20 min, 200 °C | Grilled pork loin | Pork loin, salt, olive oil | Pan: quick grilled steaks, 3 min each side, 230 °C |
| Chicken casserole | Chicken, olive oil, salt, garlic, mixture of spices, water | Rapid pressured pot: pressure-cooked, 11 min at 230 °C + 5 min at 50 °C | Roast chicken | Whole chicken, olive oil, salt, spices mixture | Roaster: 45 min, 200 °C |
| Rice stew | Fish and seafood, green pepper, tomatoes, artichoke, green beans, pork meat, rice, olive oil, pepper grains, salt, parsley, food colouring, water | Pot: boiled at 100 °C, 30 min | Paella | Fish and seafood, green pepper, tomatoes, artichoke, green beans, pork meat, rice, olive oil, pepper grains, salt, parsley, water | Paellera[a]: frying ingredients, except rice, lightly fried 15 min, 180 °C. Addition of rice and water and boiled at 100 °C, 20 min |
| Boiled potatoes | Potatoes, salt, water | Pot: 20 min, 100 °C | Fried potatoes | Potatoes, salt, olive oil | Fryer: deep-frying 8 min, 180 °C |
| Anchovies in vinegar | Anchovies, salt, vinegar, garlic, parsley, olive oil | Cleaned and salted anchovies cured in vinegar for 8 h. Removing the vinegar and addition of the remaining raw ingredients | Fried anchovies | Anchovies, salt, wheat flour, olive oil | Fryer: deep-frying of floured fish for 5 min, 180 °C |

[a] Typical Spanish pan for paella cooking.