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# STEAM OVEN COOKING : EFFECT OF DIFFERENT RELATIVE HUMIDITIES ON PHYSICAL CHARACTERISTICS, WATER STATUS AND SENSORIAL QUALITY OF TURKEY MEAT.

Tutor
Prof. Davide Barbanti

Ph.D. coordinator
Prof. Germano Mucchetti

**Ph.D. Beatrice Mora**

*To my family*

*Genius is one percent inspiration*
*and ninety-nine percent perspiration*

*T.A. Edison (1847-1931)*

# Summary

Steam oven cooking of turkey meat is widely used in industrial processing, foodservice and domestic cooking. Steam cooking is achieved by steam injection in the oven chamber coupled with the air forced convection.

Despite the large application of steam in cooking, its effect on cooking yield, heating profiles, texture, colour and sensory properties of cooked meat has not yet been clearly explained. Published data about the use of steam-convection oven are still rather limited and contradictory, and mainly deal with steam cooking in the saturation condition compared to dry oven cooking. Only little information is available on the use of steam quantities lower than the saturation condition.

In this work the effect of different steam levels (air relative humidities) on turkey meat cooking with a systematic and multi-analytical approach was evaluated. The cooking trials were performed with an experimental steam cooking device expressly designed to modulate the air relative humidity. Quality evaluation of cooked turkey meat was carried out investigating physical characteristics (texture, colour, shrinkage), water status and sensorial properties. The description of the water status with different parameters such as moisture content, water holding capacity and $^{1}H$ NMR mobility resulted a very valuable tool for a better understanding of physical characteristics and sensorial properties of cooked meat, that were closely related to the different denaturation of protein induced by the cooking process.

Results indicated that different steam levels (relative humidities) led to different meat cooking performances and cooked meat quality.

The application of steam in cooking allows for shorter cooking times than dry oven cooking when the temperature of the surface of meat results sufficiently higher than the temperature of the centre. Low steam cooking, characterized by shorter cooking times than those with no steam, resulted in higher cooking yield and greater perceived tenderness of meat than high steam cooking (close to the saturation condition).

The minimum relative humidity values allowing positive effects on meat quality and higher potential water saving at low cooking temperatures (80-150°C), were defined.

The use of low steam quantities at low cooking temperatures could be considered as a valid alternative to saturation cooking, particularly indicated for industrial applications, due to the increased quality of turkey meat and the potential water saving.

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# Introduction

## 1. OVEN COOKING

### 1.1 Aim of cooking foods

The oven cooking of foods is one of the most used operations both in industrial and in domestic applications. It is a unit operation that use heated air, often combined with steam, to make food more palatable, digestible and microbiologically safe (*Bender, 1999; Tornberg, 2005*).

Cooking alters the eating quality of foods: the development of controlled physical-chemical modifications leads to an increase of sensory acceptability from the consumers. Moreover, cooking process increases the bio-availability of several nutrients and improves food preservation by destruction of micro-organisms and reduction of the water activity at the surface of the food (*Fellows, 2000*).

### 1.2 Heat and mass transfer

Cooking involves simultaneous heat and mass transfer; heat is transferred into the food from the hot surfaces and from the air of the oven. Simultaneously the moisture is transferred from the food to the dry air that surrounds it and then it is removed from the oven (*Figure.1*).

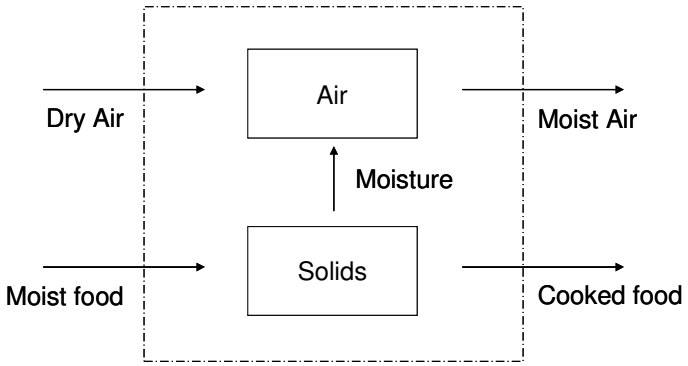



*Figure 1. Diagram of material flow during cooking in an oven (Fellows, 2000)*

#### *1.2.1 Heat transfer*

In an oven, heat is supplied to the surface of the food by a combination of the three mechanisms of **heat transfer**: ***conduction, convection*** and ***radiation*** (*Datta, 2002*). All three types may occur at the same time, and it is advisable to consider the heat transfer by each type in any particular case.

***Conduction*** is the transfer of heat from one part of a body to another part of the same body, or from one body to another in physical contact with it, without appreciable displacement of the particles of the body (*Knudsen et al., 1997*). The transfer of thermal energy between neighbouring molecules in a substance is due to a temperature gradient. It always takes place from a region of higher temperature to a region of lower temperature, and acts to equalize the temperature differences. In solids, it is due to the combination of vibrations of the molecules in a lattice and the energy transport by free electrons. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion. The law of heat conduction, also known as Fourier's law, states that the time rate of heat transfer through a material is proportional to the negative gradient in the temperature and to the area, at right angles to that gradient, through which the heat is flowing (*Datta, 2002*).

$$\frac{q_x}{A} = -k\frac{dT}{dx}$$

Where:

$q_x$: rate of heat flow in the x direction [J/s],

A: is the area perpendicular to the x direction through which the heat flows [$m^2$],

k: thermal conductivity of the medium [W/(m*K)],

dT: absolute temperature difference [K],

dx: space difference (m)

Conductive heat transfer in oven cooking occurs through the pan or tray on which the food is placed to the food and through the food matrix itself (from the heated surface to the geometric centre of the product). Heat passes through the food by conduction in most cases, foods have low thermal conductivity that causes low rates of conductive heat transfer and it has an important influence on cooking time. Conduction of heat through cooking pans or trays increases the temperature difference at the base of the food and increases the rate of cooking compared to the surface crust. The size of the pieces of food is an important factor in cooking time as it determines the distance that heat must travel to cook the centre of the food adequately (*Fellows, 2000*).

***Convection heat transfer*** occurs from one point to another within a fluid, gas, or liquid caused by molecular motion and by the mixing of one portion of the fluid with another. It cannot take place in solids, since neither bulk current flows nor significant diffusion can take place in solids. In natural convection, the motion of the fluid is entirely the result of differences in density resulting from temperature differences; in forced convection, the

motion is produced by mechanical means. When the forced velocity is relatively low, it should be realized that “free-convection” factors, such as density and temperature difference, may have an important influence. (*Knudsen, Hottel, Sarofim, Wankat, & Knaebel, 1997*). The law that describe this phenomenon is reported below.

$$q_{1-2} = hA(T_1 - T_2)$$

Where:

$q_{1-2}$: rate of heat flow from the fluid 1 to the 2 ones [J/s]

A: is the surface of heat exchange [$m^2$]

h: heat transfer coefficient [$W/(m^2*K)$]

$T_1$: fluid/bulk absolute temperature [K]

$T_2$: fluid/surface absolute temperature [K]

In oven cooking the heat from circulating air, other gases and moisture vapour is transferred to the food surface by a convective mechanism. The convection heat transfer coefficient depends on the type of fluid, flow properties and temperature properties (*Knudsen et al., 1997*).

The order of magnitude of the heat transfer coefficient of some typical heat flux/ medium is reported in *Figure 2*.

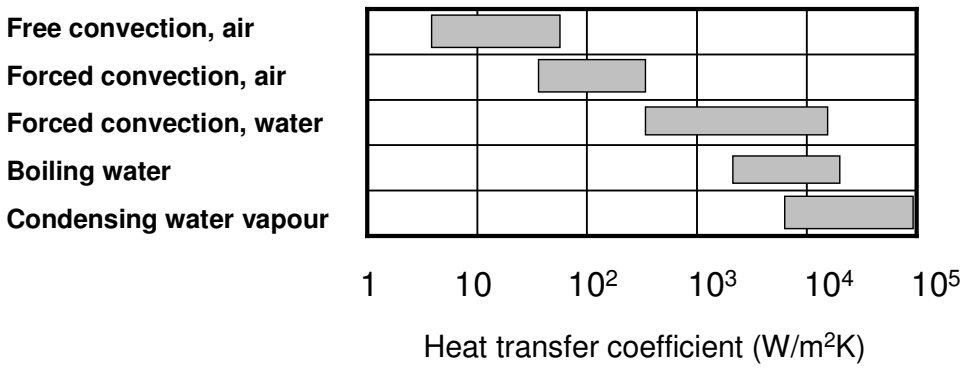



*Figure 2. Order of magnitude estimates of the heat transfer coefficient h for various simulations (Datta, 2002).*

It is important to highlight how condensing water vapour has a heat transfer coefficient three times higher than forced convection air. Hence, the application of steam leads to an acceleration of the heating process; indeed in oven cooking the air forced convection method is often coupled with steam injection in the oven chamber to reduce the cooking time and to prevent surface dehydration *(Belk, Luchak, & Miller, 1993; Murphy, Johnson, Duncan, Clausen, Davis & March, 2001).*

Generally in oven cooking a boundary film of air acts as a resistance to heat transfer into the food and to movement of water vapour from the food. The thickness of the boundary layer is determined mostly by the velocity of the air and the surface properties of the food and in part controls the rates of heat and mass transfer. Convection currents promote uniform heat distribution throughout the oven, and many commercial designs are fitted with fans to supplement natural convection currents and to reduce the thickness of boundary films. This increases heat transfer coefficients and improves the efficiency of energy utilisation (*Fellows, 2000*).

The ***radiative heat transfer*** is the transfer of energy (heat) from one body to another, not in contact with it, by means of wave motion through space (electromagnetic waves, *Knudsen et al., 1997*). The radiative heat transfer is described by the equation following:

$$\frac{q}{A} = \sigma \cdot T^4$$

Where:

*q :* heat-flux density, energy per time [W]

σ : Stefan-Boltzmann constant = $5.67*10^{-8}$ W/($m^2*K^4$)

T : absolute temperature [K]

A: is the surface of heat exchange [$m^2$]

In oven cooking the infrared radiation from the oven walls is absorbed into the food and converted to heat.

### *1.2.2 Mass transfer*

When a food is placed in a hot oven, the low humidity of air in the oven creates a moisture vapour pressure gradient, which causes a moisture depletion at the surface of the food and water evaporate from the surface of the food to the surrounding air. The evaporation of water from the food's surface in turn creates the water diffusion inside the food matrix that is the movement of moisture from the interior of the food to the surface (*Fellows, 2000*).

The molecules of a liquid to evaporate must be located near the surface, be moving in the proper direction, and have sufficient kinetic energy to overcome liquid-phase intermolecular forces. If evaporation takes place in a closed vessel, the escaping molecules accumulate as a vapour above the liquid. Many of the molecules return to the liquid, with returning molecules becoming more frequent as the density and pressure of the vapour increases. When the process of escape and return reaches an equilibrium, the

vapour is said to be "saturated," and no further change in either vapour pressure and density or liquid temperature will occur. For a closed system consisting of vapour and liquid of a pure substance, an equilibrium state takes place (liquid-vapour) that is directly related to the vapour pressure of the substance, as given by the Clausius-Clapeyron relation (*Datta, 2002*):

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{\Delta H_{vap}}{R} \cdot \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

Where:

$P_1$, $P_2$: vapour pressures [Pa] at temperatures $T_1$, $T_2$ respectively [K],

$\Delta H_{vap}$: enthalpy of vaporization, [J/mol],

R: universal gas constant. [J/(mol*K)].

The rate of ***evaporation*** in an open system is related to the vapour pressure found in a closed system. If a liquid is heated, when the vapour pressure reaches the ambient pressure the liquid will boil. The ability for a molecule of a liquid to evaporate is largely based on the amount of kinetic energy an individual particle may possess. Even at lower temperatures, individual molecules of a liquid can evaporate if they have more than the minimum amount of kinetic energy required for vaporization. The water evaporation from the food surface during the cooking process determine a water vapour pressure gradient inside the food matrix that is the driving force of water diffusion from the centre to the surface of the product. ***Diffusion*** is described by Fick's First Law (reported below in the double version for liquid and gasses), it relates flux of a component to its composition gradient, employing a constant of proportionality called diffusivity (*Hallstrom, 1992*).

$$J_A = -D_{AB} \cdot \frac{dC_A}{dx}$$ for the liquids, $$J_A = -D_{AB} \cdot \frac{dP_A}{R \cdot T \cdot dx}$$ for the gases.

Where:

$J_A$: Molar flux of A with respect to mean volume velocity [kmol/($m^2$*s)]

$D_{AB}$ : diffusivity [$m^2$/s].

$dC_A/dx$ : concentration gradient along the axis of diffusion [kmol/m]

$dP_A/dx$: pressure gradient along the axis of diffusion [Pa/m]

R: universal gas constant = 8.31 J/mol K

T : absolute temperature [K]

The extent of moisture loss is determined by the nature of the food, movement of air in the oven and the rate of heat transfer. When the rate of moisture loss from the surface exceeds the rate of movement from the interior, the zone of evaporation moves inside the food, the surface dries out, its temperature rises to the temperature of the hot air and a crust is formed (*Fellows, 2000*). Because cooking takes place at atmospheric pressure and moisture escapes freely from the food, the internal temperature of the food does not exceed 100ºC. These changes are similar to those in hot-air drying, but the more rapid heating and higher temperatures used in cooking cause complex changes to the components of the food at the surface. These changes both enhance eating qualities and retain moisture in the bulk of the food. In contrast with dehydration, where the aim is to remove as much water as possible with minimal changes in sensory quality, in cooking the heat-induced changes at the surface of the food and retention of moisture in the interior of some products (cake, bread, meats, etc.) are desirable quality characteristics. In other products, such as biscuits and crispbread, loss of moisture from the interior is required to produce the desired crisp texture.

The types of mass and heat transfer in the different zones of a food during cooking are described in *Table 1.*

| ***Zone in the food*** | ***Type of mass transfer*** | ***Type of heat transfer*** |
|---|---|---|
| Boundary layer | Vapour diffusion | Conduction, convection, radiation |
| Crust | Vapour diffusion | Conduction, vapour movement (convection) |
| Evaporation zone | Vapour diffusion, surface diffusion, capillary flow | Conduction, movement of vapour and liquid water |
| Interior | Capillary flow | Conduction |

*Table 1.. Heat and mass transfer in food during cooking, adapted from Hallstrom & Skjoldebrand (1983).*

### 1.3 Oven cooking equipment

The cooking procedure (cooking equipment, medium, and process parameters) significantly affect the extent and the entity of the physical-chemical modifications that lead to the characteristics of the final product (*Belk et al. 1993; Fellows, 2000; Ferracane, Pellegrini, Visconti, Graziani, Chiavaro, Miglio,& Fogliano, 2008*).

Ovens are classified into ***direct*** or ***indirect*** heating types. In ***directly heated ovens***, air and the products of combustion are recirculated by natural convection or by fans. The temperature in the oven is controlled automatically, by adjustment of air and fuel flow rates to the burners. Natural gas is commonly used. Gas is burned in ribbon burners

located above and below conveyor belts in continuous ovens, and at the base of the cabinet in batch ovens. The advantages of direct heating ovens include a short cooking times, high thermal efficiencies, a good control over cooking conditions (using the fan speed and the rate of fuel consumption) and a rapid start-up, as it is only necessary to heat the air in the oven. However, care is necessary to prevent contamination of the food by undesirable products of combustion, and gas burners require regular servicing to maintain combustion efficiency. Electro-heating (radio-frequency, microwave and ohmic heating) are another example of direct heating ovens.

In ***indirectly heated ovens*** there are steam tubes that are either heated directly by burning fuel or supplied with steam from a remote boiler. The steam tubes then heat air in the cooking chamber. Heated air is commonly recirculated through the cooking chamber and through a separate heat exchanger. Alternatively, combustion gases are passed through banks of radiator tubes in the cooking chamber, or fuel is burned between a double wall and the combustion products are exhausted from the top of the oven. Electric ovens are heated by induction heating radiator plates or bars. In batch ovens, the walls and base are heated whereas in continuous ovens, heaters are located above, alongside and below a conveyor (*Fellows, 2000*).

## 1.4 Cooking modifications on foods

Cooking causes changes in texture, flavour, aroma, colour and nutritional properties. These main modifications determined by the cooking process on food are reported in the sections below.

### *1.4.1 Texture*

Changes in texture are determined by the nature of the food (moisture content and the composition of fats, proteins and structural carbohydrates -cellulose, starches and pectins-) and by the temperature and duration of heating. A characteristic of many cooked foods is the formation of a dry crust which contains the moist bulk of the food (for example meats, bread, potato). Other foods (for example biscuits) are baked to a lower moisture content, and in these the changes that take place in the crust occur throughout the food. In fruits and vegetables the principal heating modifications are starch gelatinization, cellulose crystallisation and moisture content variations with food consequences as rupture, crack, compression and permanently distort the relatively rigid cells food with a shrunken and shrivelled appearance (*Fellows, 2000*).

When meat is heated, fats melt and become dispersed as oil through the food or drain out as a component of ‘drip losses’. Collagen is solubilised below the surface, to form

gelatine. Proteins become denatured, lose their water-holding capacity and shrunk. This forces out additional fats and water of to be expelled from the meat matrix, and they lead to an increase of toughness of the food. Further increases in temperature cause the drying of the surface, the texture becomes crisper and harder and a porous crust is formed by coagulation, degradation and partial pyrolysis of proteins. A detailed discussion of the physical changes of the meat is following given in *section 4*.

In cereal foods, changes to the granular structure of starch, gelatinisation and dehydration produce the characteristic texture of the crust. Rapid heating produces an impermeable crust which seals in moisture and fat and protects nutrients and flavour components from degradation. A steep moisture vapour gradient is formed between the moist interior (high *a*w) and hygroscopic exterior (low *a*w) of the food.

Slower heating permits larger quantities of moisture to escape from the surface of the food before it is sealed by the crust as observed by *Vittadini, Rinaldi, Chiavaro, Barbanti, & Massini (2005)* in their work on pork meat cooking. This results in a shallower moisture vapour gradient and a drier interior in the food.

### *1.4.2 Flavour, aroma and colour*

Cooking process leads to aroma development and important sensory characteristics of cooked goods. Maillard browning reactions between sugars and amino acids occur on the surface layers of food exposed at high temperatures (especially above about 140°C), so you need to cook meats at high temperatures to develop “meaty” flavours. Details of the chemistry of the Maillard reaction and Strecker degradation are discussed by a number of workers including *Mauron, (1982), Danehy (1986) and Bemiller & Whistler (1996)*. The high temperatures and low moisture contents in the surface layers also cause caramelisation of sugars and oxidation of fatty acids to aldehydes, lactones, ketones, alcohols and esters. The Maillard reaction and Strecker degradation produce different aromas according to the combination of free amino acids and sugars present in a particular food. Each amino acid produces a characteristic aroma when heated with a given sugar, owing to the production of a specific aldehyde. Different aromas are produced, depending on the type of sugar and the heating conditions used (for example the amino acid proline can produce aromas of potato, mushroom or burnt egg, when heated with different sugars and at different temperatures). Further heating degrades some of the volatiles produced by the above mechanisms to produce burnt or smoky aromas. There are therefore a very large number of component aromas produced during cooking. The type of aroma depends on the particular combination of fats, amino acids and sugars present in the surface layers of food, the temperature and moisture content of the food throughout the heating period and the time of heating.

The characteristic golden brown colour associated with roasted foods is due to Maillard reactions, caramelisation of sugars and dextrins (either present in the food or produced by hydrolysis of starches) to furfural and hydroxymethyl furfural, carbonisation of sugars, fats and proteins (*Mitsuo, 1988; Elizalde, Bressa, Dalla Rosa, 1992*)

### *1.4.3 Nutritional value*

Literature shows that the heat treatment of food (common culinary practice) significantly influences cooking losses and content of basic chemical compounds (*Clausen & Ovesen, 2001; Badiani et al. 2002; Fillion & Henry, 1998*). The main nutritional changes during cooking occur at the surface of foods, and the ratio of surface area to volume is therefore an important factor in determining the effect on overall nutritional loss.

In general, water-soluble vitamins and minerals are lost in the cooking water, the amount depending on the surface area– volume ratio, i.e. greater losses take place from finely cut or minced foods. Fat-soluble vitamins are little affected except at frying temperatures. Proteins suffer reduction of available lysine when they are heated in the presence of reducing substances, and further loss at high temperature. Dry heat, as in cooking, results in some loss of vitamin B1 and available lysine. The most sensitive nutrients are vitamins C and B1 (*Fellows, 2000*). In meats, nutrient losses are affected by the size of the piece, the type of joint, the proportions of bone and fat, pre- and post-slaughter treatments and the type of animal. *Cover, Dilsaver, Hays, & Smith (1949)* studied the effect of cooking temperature on vitamin losses in different meats. At 150ºC the meats were well cooked and total thiamine losses were moderate. At higher temperatures the pan drippings were charred and inedible, and total losses were therefore substantially increased. Thiamine is the most important heat-labile vitamin in both cereal foods and meats, and losses are reported in *Table 2* In cereal foods the extent of thiamine loss is determined by the temperature of cooking and the pH of the food. Loss of thiamine in pan bread is approximately 15% (*Bender, 1978*) but in cakes or biscuits that are chemically leavened by sodium bicarbonate, the losses increase to 50–95%.

The loss of amino acids and reducing sugars in Maillard browning reactions causes a small reduction in nutritive value. In particular, lysine is lost in Maillard reactions, which slightly reduces the protein quality. In bread the *protein efficiency ratio* is reduced by 23% compared with that of the original flour (*Bender, 1978*). The extent of loss is increased by higher temperatures, longer cooking times and larger amounts of reducing sugars.

| *Food* | *Thiamin loss (%)* |
|---|---|
| Beef | 40-60 |
| Pork | 30-40 |
| Ham | 50 |
| Lamb | 40-50 |
| Poultry | 30-45 |
| Bread | 15 |
| Cake | 23 |
| Soya bean | 90 |

*Table 2 Thiamin losses during cooking, adapted from Farrer (1955).*

Cooking induces significant changes in chemical composition, influencing the concentration and bioavailability of bioactive compounds in vegetables. However, both positive and negative effects have been reported depending upon differences in process conditions and morphological and nutritional characteristics of vegetable species (*Podsêdek, 2007*). In some cases cooking process improves food nutritional properties as in vegetables, although consumption of fresh unprocessed plant food is widely advocated, evidence is emerging that *in vivo* bioavailability of many protective compounds is enhanced when vegetables are cooked (*Link, & Potter, 2004*).

**1.5 Cook value**

In the optimization / comparison of different cooking treatments the "cook value" parameter can be used as a performance index. The cook value has been used successfully to measure the product quality changes during thermal processing (*Ohlsson, 1980; 1986; 1988*).

The cook value ($C_{Zref}$) is defined, for analogy to the laws concerning the effect of temperature on microbial selection, as the equivalent number of minutes the product would have to spend at a reference temperature (usually $T_{ref}$=100°C) to achieve a given effect on the final product quality, for example, at the time needed to reach a particular degree of tenderness of a piece of meat, rather than at the time when a nutrient probe is degraded to a small percentage. In particular for meat products is considered the time needed to the 3% reduce the content of thiamine (Vitamin $B_1$).

Mathematically it is calculated as:

$$C_{Z_{ref}} = \int_0^t 10^{\frac{(T-T_{ref})}{Z_{ref}}} dt$$

where $Z_{ref}$ is the temperature increment needed to tenfold increase the rate of quality change, generally is used the z-value equal to 33°C. When reference temperature is 100°C with a z-value equal to 33°C the cook value is denoted as $C_0$ (*Pompei, 2009*).
The cook value is calculated by the integrating of the heat penetration curve recorded in a particular position of the product, generally at the surface or at the middle (*Holdsworth, 1985; Vittadini et al., 2005*)., however the surface $C_0$ is considered the more indicative value because the external part of the product is the more degraded position.
The heating treatment time at which the $C_0$ value reach the $C_0$ target for a specific degradation process or transformation (ex. $C_0$=10min for the 3% reduce of thiamine content) can be calculated. Hence, any extension of treatment beyond this time has the effect of increase the cook value, at the expense of degradation of the other product characteristics.
The degree of cooking can be measured in terms of cook value, in the centre and on the surface of each sample, considering only the heating phase (*Poon, Durance, & Kitts, 2001*) or the total thermal process - both the heating and the cooling phase- (*Van Roon, Houben, Koolmess, Van Vliet, & Krol, 1994*).

## 2 AIR - STEAM MIXTURES

### 2.1 Air - Steam mixtures properties

The main physical laws that describe air -steam mixtures performances are following reported (*Spiga, 1999*). Steam or water vapour is the gas phase of water. Water vapour can be produced from the evaporation of boiling liquid water or from the sublimation of ice. The air-steam mixture could be considered as a mixture of perfect gasses: dry air and water vapour. Hence, a brief description of the main laws that describe the perfect gas behaviour is reported below.
The partial pressure of a gas ($p_i$) is the pressure exerted by each gas component ($i$) as if it was occupying the same volume of the mixture, at the same temperature T. The effective partial pressure of the steam can be expressed as:

$$p_i = n_i R \frac{T}{V}$$

The partial pressure of a gas is related to its mole fraction and the total pressure of the mixture:

$$p_i = y_i P$$

Where:

$p_i$: partial pressure of a gas [Pa],

$n_i$ = number of moles of the gas *i* ,

$y_i$: molar fraction of the gas, $n_i/n$,

P: total pressure [Pa],

T: temperature [K],

V: total volume [$m^3$],

R: is the gas constant =8,31 [J/(K*mol)].

The total pressure of an air-steam mixture, considered as a mixture of perfect gases, is made up by the sum of the partial pressures of the components in the mixture as known from *Dalton's law of partial pressures*. Similarly we have that the sum of partial volumes of a mixture of perfect gases result from the total volume of the mixture.

$$P = p_a + p_v$$

Where:
$p_a$ = partial pressure of air [Pa],

$p_v$ = partial pressure of water vapour [Pa],

P: total pressure [Pa]

Moreover is important to indicate the dry air molar mass ($M_a$) and the water vapour molar mass ($M_v$) respectively 28,95 *$10^{-3}$Kg/mol and 18*$10^{-3}$Kg/mol. In a single-phase air–steam the mass of superheated steam and the mass of the system can vary, for example, the vapour can condense, causing a decrease in mass of the system. At the steady state phase, when doesn't seem to happen the evaporation of the water droplets on the surface, there is a dynamic equilibrium between the liquid and the vapour phases; the number of liquid particles that evaporated is the same of the number of gas particles condensed. Applying the *Gibbs Phase rule* to univocally describe the physical equilibrium state of an air-steam mixture (bicomponent and monophase system) three thermodynamic coordinates are necessary (the pressure, the temperature and a coordinate referred to the composition of the mixture).

$$P = p_a + p_v \qquad \begin{aligned} p_a \cdot V &= n_a \cdot R_a \cdot T \quad \text{with} \quad R_a = 287.06\ \mathrm{J/(kg \cdot K)} \\ p_v \cdot V &= n_v \cdot R_v \cdot T \quad \text{with} \quad R_v = 461.52\ \mathrm{J/(kg \cdot K)} \end{aligned}$$

Universal gas constant is R = 8,31 J/(K*mol) and the gas specific constant of a gas ($R_x$) is determined as the universal gas constant divided to the molar mass ($M_x$) of the specific gas or gas mixture.

$$R_x = \frac{R}{M}$$

**2.2 Mixtures parameters**

The relative abundance of the two components of the air-steam mixture (air and water vapour) can be expressed through different parameters (*Spiga, 1999*); the most widely used are:

- **relative humidity *(φ)*,**
- **absolute humidity *(x)*,**
- **degree of saturation ($\psi$ ).**

The three parameters are dependent one to the other, hence only one of them is sufficient to univocally define the composition of the moist air.

***2.2.1 Relative humidity – RH - ($\varphi$)***

The **relative humidity** – **RH - *(φ)*** of an air-water mixture is defined as the ratio between the mass of steam (*Mv*) and the mass of steam that would be present at the saturation condition (*Ms*), at the same total pressure and temperature. In other terms, applying the gas law *pV = nRT*, RH is the ratio of the partial pressure of water vapour ($p_v$) to the saturated water vapour pressure ($p_s$) at a given temperature.

$$\varphi = \frac{Mv}{Ms} = \frac{n_v}{n_s} * \frac{m_v}{m_v} \rightarrow \frac{p_v}{p_s}$$

In a saturated environment $\varphi$ is equal to 1.

RH is dimensionless, and is usually expressed as a percentage (RH%). If a system is isobarically heated (heating with no change in system pressure), by increasing the temperature, the relative humidity of the system decreases, because the saturation pressure of water ($p_s$) increases with increasing temperature. The dependence of saturated vapour pressure on temperature is represented in *Figure 3*. This relation is given by the *Clausius-Clapeyron equation*, which expresses the saturated vapour pressure above a flat surface of pure water. This formula can be approximated experimentally by the *formula of Magnus*:

$$p_{v,sat}\ [kPa] \cong exp[16.6536 - 4030.183 / (T\ [°C] + 235)].$$

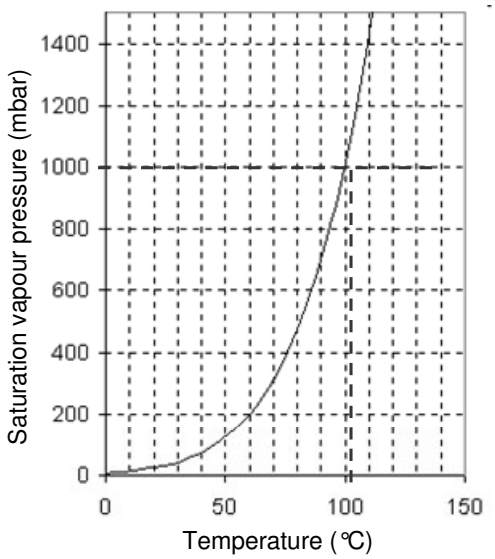



*Figure 3. Relation between saturation vapour pressure and temperature.*

The saturated vapour pressure increases rapidly with temperature. Above the boiling point of water (100°C), the saturation vapour pressure $p_s$ is greater than 1013 hPa (normal atmospheric pressure). Therefore relative humidity cannot reach RH =100% above 100°C in an unpressurized system.

By considering the system at T < 100°C and at atmospheric pressure ($P_{atm}$), it is possible to achieve 100% of relative humidity at any temperature while for T > 100°C, the possibility of reaching the maximum relative humidity drastically falls, being $p_s > P_{atm}$. As an example, pure water steam may reach 100% RH at 100°C, while it will only reach 20% RH at 150°C. The maximum RH values that can be obtained at temperatures above the 100°C (100<T<180°C) are reported in *Table 3*.

| T (°C) | $\varphi_{MAX\cdot T\geq 100°C}$ |
|---|---|
| 100 | 0,995 |
| 110 | 0,702 |
| 120 | 0,505 |
| 130 | 0,370 |
| 140 | 0,276 |
| 150 | 0,209 |
| 160 | 0,160 |
| 170 | 0,124 |
| 180 | 0,098 |

*Table 3. Saturation relative humidity at temperatures above 100°C at atmospheric pressure.*

### *2.2.2 Absolute humidity ( x )*

The absolute humidity (*x)* or humidity ratio, is defined by the ratio between the steam mass (*Mv*) in the system and the mass of the dry air (*Ma*).

$$x = \frac{Mv}{Ma} = \frac{n_v}{na} * \frac{m_v}{m_a} = \frac{18}{29}\frac{p_v V R_0 T}{p_a V R_0 T} = 0{,}622\frac{p_v}{p - p_v} = 0{,}622\frac{\varphi \cdot p_s}{p - \varphi \cdot p_s}$$

Therefore at the saturation condition the absolute humidity is defined as :

$$x_s = 0{,}622\frac{p_s}{p - p_s} \qquad \left[\frac{kg_{steam}}{kg_{dry\_air}}\right].$$

The absolute humidity (x) and the total pressure of the mixture (p) are necessary to calculate the pressure of the air ($p_a$) and of the steam ($p_v$) as following reported:

$$x = \frac{Mv}{Ma} = \frac{R_a \cdot p_v}{R_v \cdot p_a} = 0{,}622\frac{p_v}{p - p_v} \Rightarrow \qquad p_a = \frac{0.622}{0.622 + x} \cdot p \qquad p_v = \frac{x}{0.622 + x} \cdot p$$

In a transformation with a constant total pressure, as generally takes place, $p_a$ and $p_v$ remain separately constant until the absolute humidity (x) is constant.

### *2.2.3 Degree of saturation ($\psi$ )*

The degree of saturation is the ratio between the absolute humidity (x) and the absolute humidity at the saturation condition ($x_s$) at the same total pressure and temperature of the mixture.

$$\psi = \frac{x}{x_s} = \frac{0.622 \cdot \varphi \cdot p_s / (p - \varphi \cdot p_s)}{0.622 \cdot p_s / (p - p_s)} = \varphi\frac{p - p_s}{p - \varphi \cdot p_s} \le \varphi$$

Generally the terms $p_s$ and $\varphi * p_s$ are approximately negligible, hence results that $\psi \cong \varphi$. The degree of saturation is equal to 1 at the saturation condition. The saturation pressure ($p_s$) is function of the pressure and of the temperature of the mixture, hence the absolute humidity at the saturation condition ($x_s$) is function of the thermodynamic conditions.

## 2.3 Psychrometric chart

A psychrometric chart is a graph that describe the thermodynamic properties of moist air at a constant pressure (often equated to an elevation relative to sea level, P=101325 Pa, *Knudsen et al., 1997*). The Mollier psychrometric chart is a shaft whose angular coordinate are dry bulb temperature and enthalpy, it is generally known in ASHRAE style (*Figure 4*). The psychrometric chart depicts the properties reported below and it is thus a graphical equation of state. The represented properties are:

- Dry-bulb temperature ($T_d$) is that of an air sample, as determined by an ordinary thermometer, the thermometer's bulb being dry. It is typically the abscissa (horizontal axis) of the graph. The SI units for temperature are kelvins or degrees Celsius;
- Wet-bulb temperature ($T_{wb}$) is the temperature of adiabatic saturation. This is the temperature indicated by a moistened thermometer bulb exposed to the air flow. $T_{wb}$ can be measured by using a thermometer with the bulb wrapped in wet muslin. The adiabatic evaporation of water from the thermometer and the cooling effect is indicated by a "wet bulb temperature", it is lower than the "dry bulb temperature" in the air. The $T_{wb}$ will be identical to the $T_d$ when the air sample is saturated with water. The rate of evaporation from the wet bandage on the bulb, and the temperature difference between the dry bulb and wet bulb, depends on the humidity of the air. The evaporation is reduced when the air contains more water vapour.
- Dew point temperature ($T_s$) is that temperature at which a moist air sample at the same pressure would reach water vapor “saturation.” At this point further removal of heat would result in water vapor condensing into liquid. The dew point temperature is measured easily and provides useful information, but is normally not considered an independent property of the air sample. It duplicates information available via other humidity properties and the saturation curve.
- Relative humidity ($\varphi$ or $RH$) it has been previously defined in the *section 2.2.*
- Humidity ratio or absolute humidity ($x$) previously defined in the *section 2.2*. It is typically the ordinate (vertical axis) of the graph.
- Specific enthalpy symbolized by $h$, also called heat content per unit mass, is the sum of the internal (heat) energy of the moist air, including the heat of the air and water vapor within. In the approximation of ideal gases, lines of constant enthalpy are parallel to lines of constant $T_{wb}$. Enthalpy is given in (SI) joules per kilogram of air.
- Specific volume, also called *inverse density*, is the volume per unit mass of the air sample. The SI units are cubic meters per kilogram of dry air; other units are cubic feet per pound of dry air.

The versatility of the psychrometric chart lies in the fact that by knowing three independent properties of some moist air (one of which is the pressure), the other properties can be determined. Changes in state, such as when two air streams mix, can be modeled easily and somewhat graphically using the correct psychrometric chart for the location's air pressure or elevation relative to sea level.

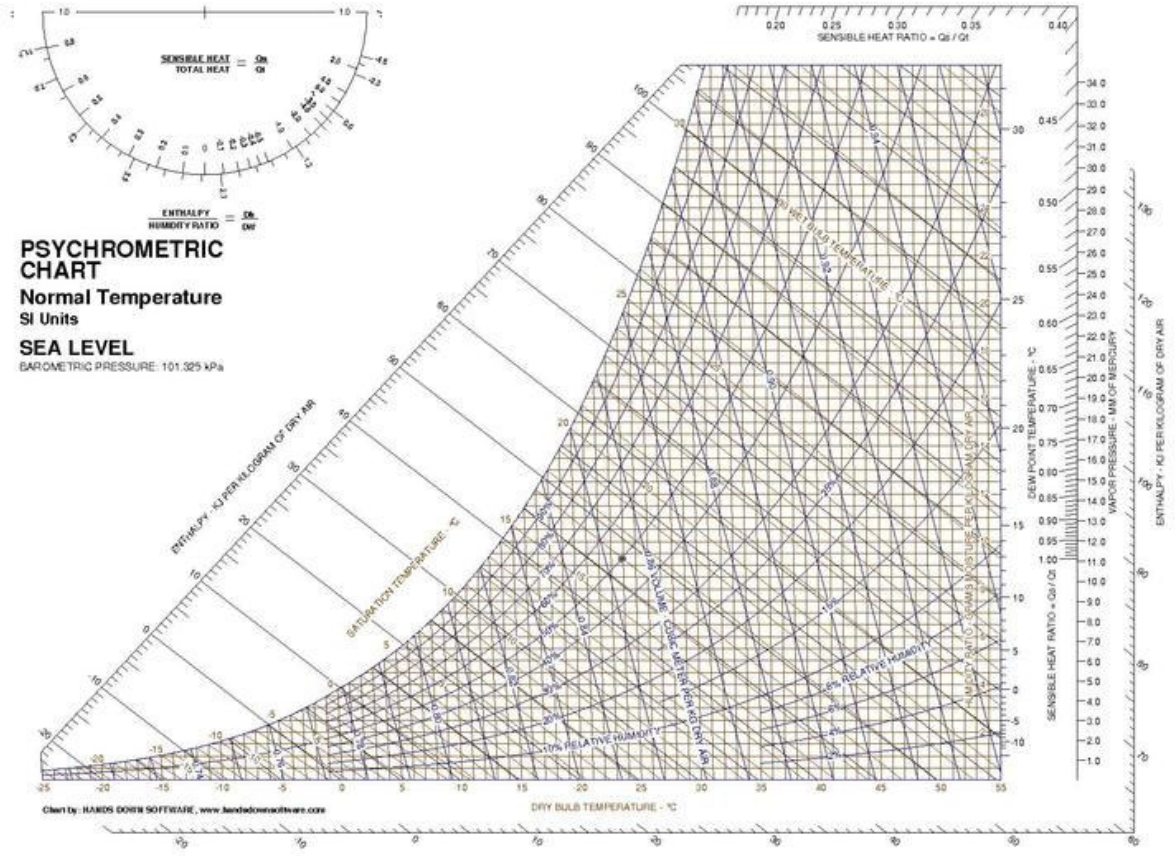



*Figure 4. The psychrometric chart in ASHRAE style.*

### 2.4 Methods of air humidity determination

The most simple method to measure air humidity is the *Assmann psychrometer or hygrometer*. The instrument consists of two thermometers that measure the dry bulb and in the wet bulb temperature. On the basis of the psychrometric chart the instrument give the absolute humidity value of the air-steam mixture and therefore its relative humidity.

The procedure to calculate the RH value from the temperatures of the dry bulb and the wet bulb *(http://home.fuse.netclymer/water/wet.html)* is listed below.

$$RH = \frac{p_v}{p_{s,db}} \cdot 100$$

$$p_{s,db} = \exp\left(\frac{16.78 \cdot T_{db} - 116.9}{T_{db} + 237.3}\right), \qquad p_v = p_{s,wb} - A \cdot P \cdot (T_{db} - T_{wb}),$$

$$p_{s,wb} = \exp\left(\frac{16.78 \cdot T_{wb} - 116.9}{T_{wb} + 237.3}\right), \qquad A = 0.00066 \cdot (1.0 + 0.00115 \cdot T_{wb}).$$

Where:

$T_{wb}$ = wet bulb temperature (°C),

$T_{db}$ = dry bulb temperature (°C),

$p_{s, wb}$ = saturation vapour pressure at $T_{wb}$ (kPa),

$p_{s, db}$ = saturation vapour pressure at $T_{db}$ (kPa),

$p_v$ = vapour pressure (kPa),

P = air pressure (kPa).

In addition to this method there are three major types of hygrometers (*Morris, 1998*): mechanical, electrical (resistive, electrolytic -$P_2O_5$ -, capacitive and with detection by impedance -$Al_2O_3$-), and cold-spot or dew-point (condensing with optical sensing or condensing with saturated salts –LiCl-).

*Capacitive hygrometers* are electrical hygrometers, these relative humidity and temperature sensors showed high performances in a miniature format with the possibility to measure air humidity over than 100°C. Non-contact capacitive sensors work by measuring changes in an electrical property called capacitance. The capacitive hygrometers have a function similar to a capacitor where the dielectric is a hygroscopic material (usually polymer or ceramic). Usually one electrode is permeable to the water vapour. The humidity balance established between the insulation and the environment, change the relative dielectric permittivity. The result is a variation of capacity of the sensitive information that becomes representative of the relative humidity of the air. This type of device is sensitive to the relative humidity as it is in equilibrium with the environment to characterize.

## 3. MEAT

### 3.1 Structure of muscle

Because muscle is converted to meat post slaughter it serves as a raw material for the meat industry and hence its composition and structure are likely to influence the overall meat quality. It is therefore important to understand the structure and composition of muscle (*Lawrie, 1998*).

Based on such specializations there are three different types of muscles in a meat animal (striated voluntary or skeletal muscles, striated involuntary or cardiac muscles and smooth muscles or involuntary muscles).

As now we know that skeletal muscles constitute the bulk of a slaughtered animals muscle mass therefore special emphasis shall be laid upon the structure and organization of ***skeletal muscles***.

***Muscle fibre*** (*Figure 5*) is the structural unit of skeletal muscle. Muscle fibre constitutes 75-92% of skeletal muscle volume, the rest is contributed by nerve fibres blood vessels, connective tissue.

In the muscle important layers holding different structural elements together:

- ***Epimysium*** is connective tissue sheath surrounding the entire muscle,
- ***Perimysium*** a layer beneath epimysium which divide the muscle fibres into small groups or fascicule. These groups are also known as primary bundles. When few primary bundles come together they form secondary bundles and secondary bundles coming together leads to formation of tertiary bundles.
- ***Endomysium*** a layer beneath perimysium with surrounds each muscle fibre individually. These are very thin strands. The endomysium should not be confused with sarcolemma or muscle cell membrane.

The epimysium, perimysium and endomysium serve as the structural basis for skeletal muscles. They conduct the vascular and neural supply to and from the muscle. Larger nerves and blood vessels lie at the periphery of perimysium and between the adjacent fasciculi. The size of fasciculi, in fact, has bearing on the texture of the muscle i.e. muscles engaged in lighter activities have fine texture and it is reverse for the heavier muscles or muscles which have to work more.

Each ***fibre*** (muscle cell) present several cell nuclei. The muscle tissue, with a polarizing microscope vision, show an alternating light and dark areas that take place regularly and that are the muscle functional unit: the ***sarcomeres***, contractile elements that join in thin filaments (myofibrils). The reason for appearance for these light and dark bands of myofibrils is a different behaviour under polarized light of the different bands. The *Light bands* are a singly refractive when viewed under polarized light, they are therefore isotropic and derives name ***I - bands*** or isotropic bands. Whereas, the *Dark bands* are doubly refractive or anisotropic thus they are known as ***A –bands*** (*Figure 6*).

In the *I- band* there is a dense line called ***Z-line***, each sarcomere is in-between two *Z-lines*. Sarcomeres are divided into bands of thin and thick filaments respectively made of ***actin*** or ***myosin.*** In the *I- band* there are the thin filaments (actin) whereas in the *A-band* both the thin (actin) and the thick filaments (myosin) are present. During muscle contraction, the filaments slide over each other to cause shortening of the sarcomere.

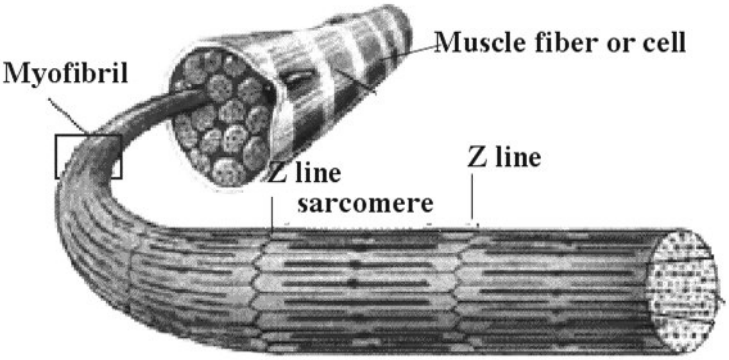



*Figure 5. Muscle fibre structure.*

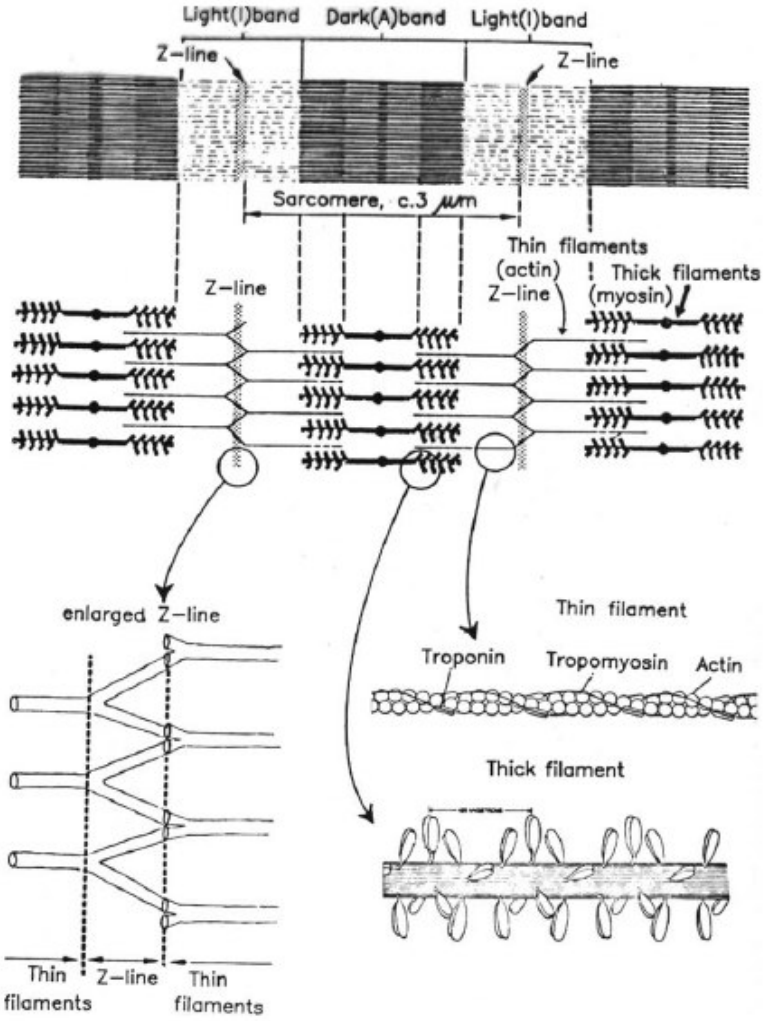



*Figure 6. The structural build-up of the sarcomere, the thin and thick filaments (Tornberg, Olsson, & Persson., 1990).*

## 3.2 Composition of meat

The meat muscle consists of 75% water, 20% protein, 3% fat and 2% soluble non-protein substances. Out of the latter 2%, metals and vitamins constitute 3%, nonprotein nitrogen-containing substances 45%, carbohydrates 34% and inorganic compounds 18% (*Tornberg, 2005*).

### *3.2.1 Water*

Water serves as a vehicle for transport of nutrients in the body. It constitutes about 75% of fresh meat (*Cavani & Bianchi, 2004*). Water content varies inversely with the fat content in meat and with the age of the animal. The ratio of water to protein is relatively constant 3.6 or 3.7 to 1. The retained water contributes to the juiciness and palatability of meat. Water within muscle is attached to protein as water is bipolar. Water is present in muscle in three forms:

***i) Bound water*** – about 4-10g/100g of protein. It is the water directly bound to the protein molecules through interactions with amino acid polar chains and it isn't available as solvent. This kind of water is tightly bound and remains so even during application of severe mechanical or any other physical force.

***ii) Immobilized water***– about the 20-60g/100g of protein. The water molecules are slightly away from the protein molecules and are attached to the bound water molecules but the binding force (hydrogen bounds) is weaker as compared to bound water and became more and more weak as the distance from proteins polar groups increases.

***iii) Free water*** – 300-600g/100g of protein. The water is held by the surface forces i.e. capillary forces. The orientation of free water molecules is independent of the charged groups. It is the water category with the major technological importance because it tends to be lost during processing. The ability of meat to retain its water during application of external forces such cutting, heating, grinding and pressing is quantified by the water holding capacity (WHC) parameter that will be thoroughly discussed in the *section 4.2.2.*

### *3.2.2 Proteins*

Muscle proteins represent about the 20% of meat muscle, they can be divided into three groups based on their solubility characteristics: ***sarcoplasmic proteins***, the metabolic proteins that are soluble in water or dilute salt solutions; ***myofibrillar proteins***, the contractile proteins that are soluble in concentrated salt solutions; and ***stromal proteins***, the connective-tissue proteins that are insoluble both in water and in concentrated salt solutions (*Lawrie, 1998*).

*3.2.2.1 Sarcoplasmic Proteins*

Sarcoplasmic proteins represent 30-35% of the total muscle proteins or about 5% of the muscle weight (*Asghar, Samejima, & Yasui, 1985*). There are around 200 different proteins known to be present in the sarcoplasmic fraction, many of which are glycolytic enzymes responsible for the control of enzymatic reactions in muscle (*Kijowski, 2001*). Despite the various biological functions in muscle, sarcoplasmic proteins exhibit many common physicochemical characteristics: relatively small molecule size, globular or rod-shaped structure, low viscosity (*Asghar et al., 1985*), poor water holding properties and weak /fragile gels formation (*Miyaguchi et al., 2000*).

***Myoglobin*** is the most important sarcoplasmic protein, it is responsible of meat colour (the major pigment in well-bled meat) which is associated with product quality (*Kijowski, 2001*). Myoglobin consists of a protein portion and a non-protein porphyrin ring with a central iron atom (*Figure 7*), it has the function to store oxygen for aerobic metabolism in the muscle. The iron atom is an important player in meat colour. The defining factors of meat colour are the oxidation (chemical) state of the iron and which compounds (oxygen, water or nitric oxide) are attached to the iron portion of the molecule. Because muscles differ greatly in activity, their oxygen demand varies. Consequently different myoglobin concentrations are found in the various muscles of the animal. Also, as the animal gets older there is more myoglobin. With a greater myoglobin concentration yields a more intense colour. Muscle pigment concentration also differs among animal species. For example, beef has considerably more myoglobin than pork or lamb, thus giving it a more intense colour.

As reviewed by *Lawrie (1998),* the colour of the meat depends not only on the quantity of myoglobin present, but also on the type and chemical state of the myoglobin molecule. The colour of meat is largely determined at the meat surface by the relative amounts of three forms of myoglobin, i.e. deoxymyoglobin (DeoxyMb, purplish-red), metmyoglobin (MetMb, brownish-red), and oxymyoglobin (OxyMb, cherry-red; *Bemiller & Whistler*, 1996; *Kinsman, Kotula, & Breidenstein, 1994; Lawrie, 1998; Zhu & Brewer, 1998*).

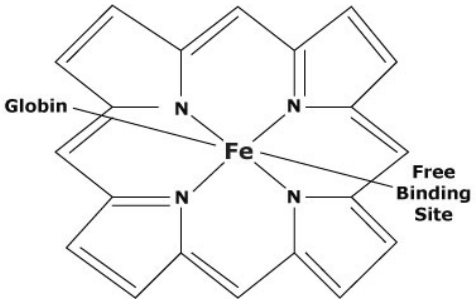



*Figure 7. Myoglobin: chemical structure.*

*3.2.2.2 Myofibrillar proteins*

Myofibrillar proteins constitute about 55-60% of the total muscle protein, or 10% of the weight of the skeletal muscle *(Asghar et al., 1985*). It is well known that myofibrillar proteins are largely responsible for the textural properties of processed meat products (*Asghar et al., 1985; Yasui, Ishioroshi, & Samejima, 1980*).

They are generally extracted in intermediate or high ionic strength buffer, so are referred to as salt-soluble proteins. The adequate extraction of myofibrillar proteins is particularly important for promoting gel formation in meat products (*Li-Chan, Nakai, & Wood,,1987*). Myosin and actin are two major proteins of the myofibrillar proteins, they are responsible for muscle contraction in the living animal, as well as many functional characteristics in processed meat products.

The thick myofilaments of the sarcomeres are mainly composed of ***myosin***, which comprises 43-45% of the myofibrillar proteins in the muscle of mammals, birds, and fish (*Maruyama, 1985; Robson, 1995; Yates & Greaser, 1983*). Myosin is a large fibrous molecule (~ 500 kDa), composed of two large subunits called myosin heavy chains and four small subunits called myosin light chains. The two heavy chains form the rod portion and a large part of the myosin head. The two light chains are located in each of the myosin heads (*Bechtel, 1986*). In living muscle, myosin exhibits important biological properties: myosin molecules can assemble themselves and build filaments, the myosin head has the catalytic site for ATPase activity whose action provides the energy for muscle contraction and myosin forms natural complexes with actin. This interaction is critical for the generation of the force that moves the thick and thin filaments on each other (*Stryer, 1995*). Myosin can be extracted with salt (e.g., NaCl, KCl) solutions of concentrations higher than 0.15 M. The isoelectric point of myosin is ~5.3, which means under normal meat processing conditions where the pH value is around 6, the myosin molecule will be negatively charged and have the ability to bind water (*Harrington, 1979*). Salt will further enhance the water-binding ability of myosin by increasing the effective net negative charge and breaking ionic bonds, causing molecular swelling and water uptake (*Acton, Ziegler, & Burge., 1983*). The presence of myosin is essential in protein gel formation of meat systems, while other myofibrillar proteins (actin, titin, tropomyosin, troponin and nebulin) are supposed to have a strong influence on the viscoelastic properties of gels by influencing the formation of the myosin gel matrix. Gaining an understanding of the gelation properties of myosin and meat gel systems is beneficial for the development of processed meat products as well as maintaining quality in meat products (*Westphalen, Briggs, & Lonergan, 2005*).

***Actin*** is the major constituent of the thin myofilaments and accounts for 22% of the myofibrillar protein (*Yates & Greaser, 1983*). Actin is a globular protein (G-actin), under physiological conditions, G-actin molecules polymerize into a double-stranded fibrous form (F-actin) (*Huxley, 1963; Steiner, Laki, & Spicer, 1952*). The F-actin forms the backbone of the thin filament and also provides binding sites for tropomyosin and troponin complex which regulates the activity of myosin ATPase. Actin also has a binding site to myosin. When calcium is present, F-actin comes into contact with the myosin heads of the thick filaments and there is a rapid breakdown of ATP, ultimately resulting in muscle contraction (*Bechtel, 1986*).

Actin alone does not exhibit any binding property (*Fukazawa,* Hashimoto, & Yasui*, 1961; Samejima,* Hashimoto, Yasui, & Fukazawa*, 1969*), however, in the presence of myosin, actin exerts a "synergistic effect". The formation of the actomyosin complex in the system determine an high ability to form strongest gel.

*3.2.2.3 Stromal proteins or connective tissue proteins*

Stromal proteins are a salt insoluble protein fraction. Collagen, elastin, and lipoproteins of the cell membrane, are among the most important connective tissue proteins in the muscle. They have a fibrous structure, and in the majority of tissues, ***collagen*** quantitatively predominates. Collagen is generally associated with the toughness of the meat. Collagen is made of three helically twisted polypeptide chains stabilized by intramolecular and intermolecular bonds (e.g., hydrogen bonds). As animals age, more covalent bonds are formed inside and between collagen molecules, which contribute to the toughness of the meat (*Asghar et al., 1985; Kijowski, 2001*). The stromal proteins have no gelation ability, as the fraction only coagulated upon heating to 80 °C (*Ziegler and Acton, 1984*).

### *3.2.3 Lipids*

Lipid content present an high variability because is affected by several animal factors such as species, age, feed, breeding, muscle type, etc. (*Cavani & Bianchi, 2004*). The lipid fraction could be classified in three main types:

- ***adipose tissue*** that is represented by deposition of fat at the muscle surface or in the abdominal cavity, hence it is easily separable. The adipose tissue is mainly constituted by the triglyceride and saturated fat acids. This tissue is very important in the ham productions.
- ***intermuscolar fat or marbling,*** the fat localized between muscle bundles of a particular anatomic area. It is difficult to remove. A certain degree of marbling have a positive effect because it improve meat sensory properties such as tenderness and flavour.

- ***intramuscular fat*** is the less likely to variability (1-4%) because it is mainly composed by phospholipids of cell membranes. Hence the intramuscular fat in general is characterized by a major polyunsaturated fat content than the intermuscolar fat and the adipose tissue (*Cavani & Bianchi, 2004*).

### *3.2.4 Carbohydrate, minerals and vitamins*

In meat other than water, proteins and lipids there are:

- ***carbohydrate***, mainly ***glycogen***. The energy required for muscle activity in the live animal is obtained from the glycogen of the muscle. In the healthy and well-rested animal, the glycogen content of the muscle is high. After the animal has been slaughtered, the glycogen in the muscle is converted into lactic acid, and the muscle and carcass becomes firm (rigor mortis). This lactic acid is necessary to produce meat, which is tasteful and tender, of good keeping quality and good colour. If the animal is stressed before and during slaughter, the glycogen is used up, and the lactic acid level that develops in the meat after slaughter is reduced. This will have serious adverse effects on meat quality (*Chambers, & Grandin, 2001*).
- ***minerals***: about 1%, mainly Na, K in the ionic state and Ca and Mg associate to proteins and phosphorylated compounds,
- ***vitamins***: mainly of the B group (B1 and B2), and liposoluble ones (A, D, E, K) principally in the fat cuts and in the guts,
- ***non protein nitrogen compounds*** (*Cavani & Bianchi, 2004*).

## 3.3 Poultry meat: Turkey

Poultry meats are currently receiving increasing interest from both consumers and industries. Poultry meat consumption is drastically increased in the last ten years, particularly for turkey meat: the per capita turkey meat consumption in the U.S. increased from 3.5kg in the 1970 to 7.5kg in the 2009, with a stable trend in the last twenty years (*http://www.eatturkey.com/consumer/stats/stats.html*).

The increasing demands of turkey products by consumers have shifted turkey sales from whole birds, just for holidays, to further processed products (pre-cooked, refrigerated ready-to-eat) bought year-round that now compose a large proportion of the turkey market (*Owens, Hirschler, McKee, Martinez-Dawson, & Sams, 2000*). Relatively low and competitive pricing of poultry meat compared to the other meat, the absence of cultural or religious obstacles, and in particular the dietary and nutritional qualities are the main factors explaining its attractiveness.

The chemical composition of turkey meat is characterized by an high protein content (higher than the 20g/100g of edible part –e.p.- ) and a low collagen content compared to

pork and beef meat. Moreover turkey meat has a low fat quantity: the breast muscles is characterized by a very low fat content (1-4 g/100g of e.p), while the turkey thigh have a major lipid content (3-9 g/100g of e.p). The lipid fraction of turkey meat presents a relatively high quantity of polyunsaturated fatty acids (0.34 g/100g of e.p.), with a favourable balance between polyunsaturated and saturated fatty acids (P:S = 0.9), and a low cholesterol content (50 mg/100g of e.p., *http://www.inran.it/646/tabelle_di_composizione_degli_alimenti.html?idalimento=106850&quant=100*), all strongly desirable attributes from a nutritional standpoint.

## 4. QUALITY OF COOKED MEAT PRODUCTS

Meat undergoes many changes during cooking, both physical and chemical, including protein denaturation, weight loss (up to 40% of its weight), muscle fibres shrinkage, aroma development and modifications of water holding capacity, texture and colour.

Quality characteristics of cooked meat products are strongly dependent both on the inherent composition and characteristics of the muscles and on the method of heating as well as on the time/temperature combinations applied (*Bouton, Harris, & Ratcliff, 1981; Christensen, Purslow & Larsen, 2000*).

Proteins undergo substantial structural changes on heating and, therefore, the quality of the meat product, which is mainly governed by the meat structure, also changes drastically after cooking (*Tornberg, 2005*). Changes of meat induced by cooking have been studied for many years and extensively discussed (*Hamm, 1977; Offer, 1984; Tornberg, 2005*); however few reports have specifically dealt with turkey meat (*Sammel & Claus, 2007; Mielnik, Sem, Egelandsdal, & Skrede, 2008*).

### 4.1 Physical properties

The evaluation of physical characteristics of meat, like water-holding capacity, tenderness and colour, is necessary to assess meat quality within a processing operation, and/or on final products. Moreover, in a research tool, the determination of the physical properties of meat is fundamental for structural studies of muscle and meat.

#### *4.1.1 Colour*

Colour is the visual characteristic of meat that is the critical initial impression a consumer gets of a product, hence it is a very important parameter with an high impact on the purchase decision. Because colour is of paramount importance, it has received the

attention of the food industry and numerous investigators. There have been many reviews on colour and meat (*Hunt and Kropf, 1987; Cornforth, 1994*).

As previously described (*section 3.2.2.1*) meat colour is determined by the quantity of myoglobin present, by the type and chemical state of the myoglobin molecule (*Lawrie, 1998*) and on muscle micro-structure (*Cornforth, 1994*). Moreover it is influenced by the ultimate pH, the rate of pH decline post-mortem, the physical characteristics of muscle and the presence of some ingredients in elaborated meat products such as nitrates and nitrites.

During external processes such as cooking, storage, and irradiation, the three forms of myoglobin i.e. deoxymyoglobin (DeoxyMb, purplish-red), metmyoglobin (MetMb, brownish-red), and oxymyoglobin (OxyMb, cherry-red) interconvert and are degraded through oxygenation, oxidation and reduction reactions, ultimately influencing the appearance of meat colour. Moreover, myoglobin could be transformed into other forms such as sulfmyoglobin (green) by the specific activity of some bacteria (*Nicol, Shaw, & Ledward, 1970*).

Meat colour can be measured both subjectively (sensory analysis) and instrumentally. Guidelines for human evaluation of meat colour have been published by *Kinsman et al. (1991)* and the "Guidelines for Meat Color Evaluation" (Hunt et al.,1991) has been a valuable source of information to encourage uniformity in collecting colour data. There are several methods to meat colour evaluation: from the measure of the concentration of heme pigments and colour cards to the use of an image analysis software (*Warriss, 2000*).

The analysis of ***visible absorption*** characteristics with a reflectance colorimeter is the most applied method for meat colour quantification (*Liu & Chen, 2000; Nanke, Sebranek, & Olson, 1998; Swatland, 1989*). This is a non-destructively and sensitively measure of colour. Colour data could be processed using the ***colour scale L*a*b**** or ***reflectance spectrophotometry.***

The ***colour scale L*a*b**** is the method of measure meat colour most applied (Commission International de l'Eclairage, 1976): colour is measured with a reflectance colorimeter, where the recommended parameters are a light source of D65 with the illumination/viewing system as 45/O or O/45 or diffuse/8 (d/8), the recommended standard observer angle is 10° (*Honikel, 1998*). The CIELAB system is the system based on L*a*b* colour scale (*Warriss, 2000*).

The ***reflectance spectrophotometry*** (spectral features in the visible region) allows to explain colour changes during the cooking of meat due to the degradation of the myoglobin protein through oxygenation, oxidation and reduction reactions, influencing the appearance of meat colour (*Figure 8*) as reported by several authors (*King, & Whyte,*

*2006; Varnam, & Sutherland, 1995; Warren, Hunt, Kropf, Hague, Waldner, Stroda, & Kastner, 1996; Baron, & Andersen, 2002*).

This measures the reflectance of light from the meat surface, the changes in reflectance at different wavelengths enabling calculation of the relative proportion of myoglobin, oxymyoglobin an methmyoglobin (*Solberg, & Franke,, 1971*). Four bands around 445, 485, 560, and 635 nm have been previously identified and associated to DeoxyMb (purplish-red), MetMb (brownish-red), OxyMb (cherry-red) and sulfmyoglobin (green), respectively (*Liu & Chen, 2001*).

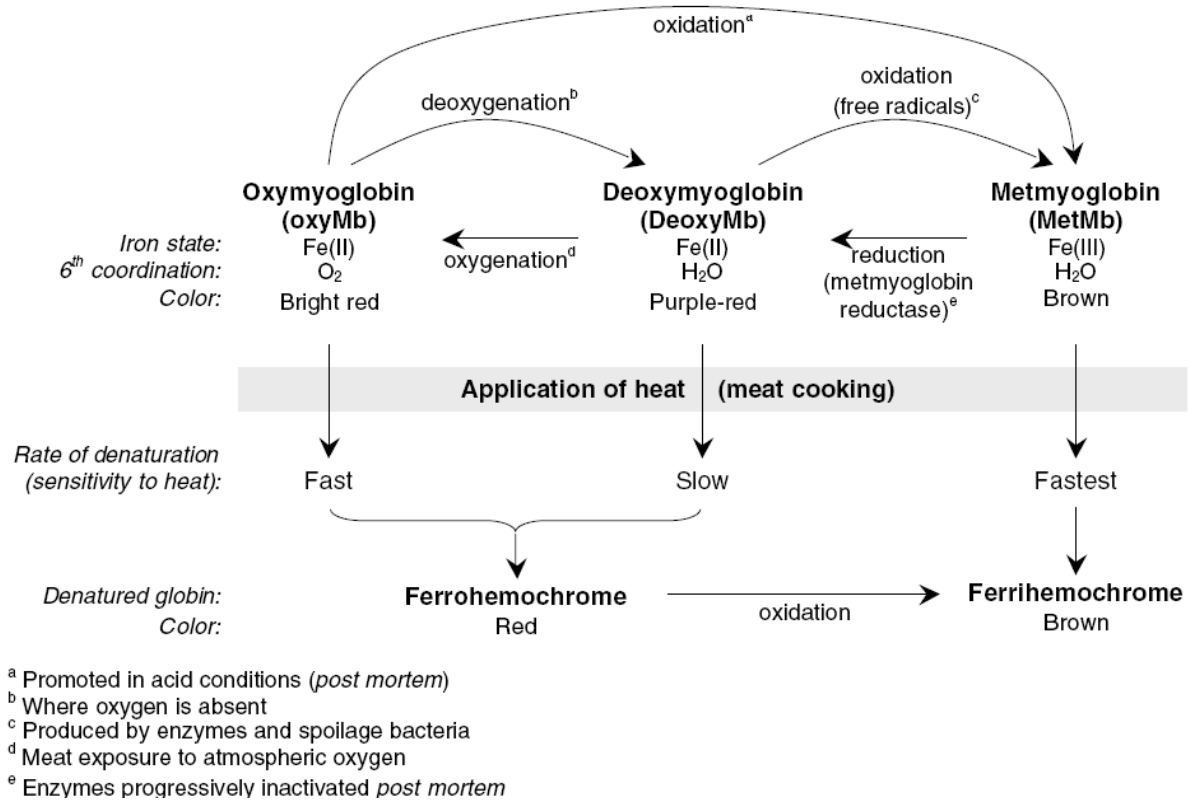



*Figure 8. Characteristics of the myoglobin pigments in meat, their dynamic relationship, and the denatured products formed during cooking.* (*King, & Whyte, 2006*).

### *4.1.2 Texture*

Three main factors are known to influence inherent meat texture. These are sarcomere length, the amount of connective tissue and its degree of cross-linking, and the extent of the proteolytic changes that occur during conditioning post-mortem. Additionally, large amounts of intra-muscolar (marbling) fat will make meat more tender because fat is softer than muscle (*Warriss, 2000*). The texture of cooked meat products is highly dependent on the gelation of myofibrillar proteins. Moreover, lipid and water retention contribute to the

yield, texture, and cohesion of the final product and both are influenced by the gelling capacity of these proteins (*Foegeding, 1987*).

Cooking drastically influence meat tenderness. Myofibrillar and connective tissue proteins undergo several temperature and time dependent structural changes during cooking which impact directly on product yield, texture and overall eating quality. Cooking causes denaturation of the myofibrillar components which results in toughening. Conversely, it may also promote structural alterations and solubilization of collagen which results in more tender meat (*Christensen, Purslow, & Larsen, 2000; Sims & Bailey, 1992*). Thus, cooking can cause either tenderization or toughening of meat with the net effect being dependent on the inherent composition and characteristics of the muscles, the method of heating and the time/temperature combination employed (*Bouton, Harris, & Ratcliff, 1981; Christensen et al., 2000; Laakkonen, Wellington, & Sherbon, 1970; Lawrence, King, Obuz, Yancey, & Dikeman, 2001; Obuz, Dikeman, & Loughin, 2003*).

The most diffuse instrumental techniques to measure meat texture carried out on cooked meat are: ***Warner-Bratzler test, tensile test method and penetrometer measure – TPA (Texture profile analysis).***

***Warner-Bratzler test*** also called compressive or shear test is a very common and widely used method to measure the tenderness of both raw and cooked meat. Meat samples should have a specific fixed shape and size with the grain of muscle running parallel to the long axis. Each sample is cut through by a metal blade about 1mm thick. The force required to move the blade to shear through the sample is measured, the blade being moved by a geared electronic motor and the force measured using a scale.

The ***tensile test method*** is best suited for structural investigations (*Purslow, 1985*) rather than to predict sensory evaluation of tenderness. It is a useful test in conjunction with other methods. The test can be carried out on raw or cooked meat. Results will be affected by sample size and by strain rate, but this latter effect is small. The standard thickness of the slices is 3-5 mm but for some species and some muscles thinner slices may be required. Testing may be conducted either transverse or parallel to the fibre direction. A load deformation curve to complete rupture should be obtained. Criteria for the acceptance of test results is that fracture should occur in the parallel-sided region of the specimen. Breaking stress is calculated as the ratio between the peak force and the measured width multiplied by thickness. The total energy to fracture (area under the curve) and breaking strain (breaking strain = extension of peak force/original gauge length) could be also determined. Larger amounts of connective tissue in the samples tested cause high variability. Problems with gripping the samples are a major cause of measurement failure, especially with raw meat. Cyanacrolate adhesives or freezing grips can be employed (*Lewis and Purslow, 1991*).

The ***penetrometer measure – TPA (Texture profile analysis)*** is a simply mechanical reproduction of the chewing process of meat. In TPA test a cylindrical flat ended plunger (diameter 1-3,5 cm) in a test frame. The plunger is driven with a constant speed vertically for a fixed distance, generally 50-80% of the sample thickness, through meat sample with a constant thick so that the fibre axis is perpendicular to the direction of the plunger penetration. The plunger is driven twice into the meat at each location (*Honikel, 1998*).
A minimum of eight to ten samples should be measured for each texture test.
When testing is used to evaluate consumer products it is strongly recommended that the methods should be validated against sensory panels. (*Honikel, 1998*)

### *4.1.3 Shrinkage*

Meat cooking shrinkage is very important meat quality parameter to the consumer (*Barbera, & Tassone, 2006*). During cooking, the consumer observes some shrinkage often thought to be an indicator of poor meat quality and/or the effect of hormone treatments. The consumer buys a steak with a certain appearance and size; the size or weight determining the cost. The alteration in size due to meat shrinkage strikes the consumer unfavourably. The cooking loss, tenderness and shrinkage, despite being different expressions of the same phenomenon, are perceived by the consumer as different events because they are observed in different time frames.
During heating, at varying temperatures (37–75°C). the different meat proteins denature causing meat structural changes, such as the destruction of cell membranes (*Rowe, 1974*), transversal and longitudinal shrinkage of meat fibres, the aggregation and gel formation of sarcoplasmic proteins and the shrinkage and the solubilisation of the connective tissue (*Tornberg, 2005*). Changes in muscle fibres, observed by *Palka and Daun (1999)* confirm the opinion of *Offer, Restall, and Ick (1984)*, that meat shrinkage during cooking in the 45–90°C range occurs in two phases. At a temperature of about 45–60°C the shrinkage is primarily transverse to the fibre axis (transverse shrinkage) and at 60–90°C primarily parallel (longitudinal shrinkage). At a higher temperature of about 121°C there may be a third shrinkage of meat which is transversal to the fibre axis (*Barbera, & Tassone, 2006*). Most of the water in the living muscle is held within the myofibrils and any large changes in the distribution of water within the meat structure originate from changes in this spacing. Shrinkage on cooking causes the greatest water loss at 60–70°C and it is presumed that water is expelled by the pressure exerted by the shrinking connective tissue on the aqueous solution. (*Barbera, & Tassone, 2006*).
Shrinkage of meat could be measured and calculated by different methods from the most simple (manual calliper) to the new generation ones using a digital video camera to obtain images and an image processing software to elaborate them.

### *4.1.4 Cooking yield*

Water loss in cooked whole meat is a fundamental meat quality parameter for both sensorial and economic aspects. Among different methods to evaluate cooking effects on meat, the cooking loss measurement represents the most rapid and important to estimate some correlated quality characteristics, such as juiciness, and evaluate some economic aspects (*Barbera, & Tassone, 2006*).

During heating, the different meat proteins denature at varying temperatures (37-75°C). Denaturation causes structural changes such as the destruction of cell membranes, transverse and longitudinal shrinkage of muscle fibres, the aggregation of sarcoplasmic proteins and shrinkage of the connective tissue. All these events, particularly the connective tissue changes, result in cooking losses in meat. Relevant reviews on the effect of heat on muscle proteins and structure have been given by *Hamm (1977*) and *Offer (1984).*

The cooking conditions must be defined and controlled (heating rate and the end-point temperature at the thermal centre) as the dimension and the geometry of the sample.

## 4.2 Water properties of meat

Water plays a key role in defining the properties of fresh and cooked meat (Van *Oeckel, Warnants, & Boucque, 1999; Bertram, Engelsen, Buska, Karlsson, & Andersen, 2004*) as well as the development of the cooking process and it is, therefore, very important to characterize the status of water in meat and its dependence on the cooking process. Many analytical techniques have been used to study water status in meat.

### *4.2.1 Moisture Content*

The determination of moisture content is very often carried out to characterize water status in meat, especially as an indicator of water loss upon cooking and, therefore, it doesn't provide an insight of water interactions in the meat matrix.

### *4.2.2 Water Holding Capacity*

Water in meat can also be characterized by the water holding capacity (WHC), that is one of the most important quality parameters used in meat industries. WHC defines the quality of fresh meat and its capability to retain water (free water), that are related to drip loss, technological performance and also to the quality of the final product (*Offer et al., 1989*). Low WHC is associated with high drip or purge loss and subsequently reduces profitability in meat production.

Water losses originate from volume changes of myofibrils induced by pre-rigor pH fall and the attachment of myosin heads to actin filaments at rigor where myofibrils shrink owing to pH fall.

Numerous and complex factors contribute to the considerable variability in WHC of meat. Genotype (*Hamilton, Ellis, Miller, McKeith, & Parrett, 2000*), different stunning methods (*Stoier, Aaslyng, Olsen, & Henckel, 200*1), aging (*Kristensen & Purslow, 2001*), chilling rate (*Maribo, Olsen, Barton-Gade, Moller, & Karlsson, 1998*) and even protein oxidation (*Rowe, Maddock, Lonergan, & HuV-Lonergan, 2004*) may all affect the WHC of meat. Recently, several authors have shown that degradation of cytoskeletal and other structural proteins plays an important role in drip loss (*Huff-Lonergan & Lonergan, 2005*).

There are a very large number of ***methods*** that have been used ***to measure WHC*** (*Warriss, 2000*). WHC is not definable in absolute units since each method measures slightly different things. Working definition of WHC as "the ability of meat to hold its own or added water during the application of any force" (*Hamm, 1986*), or as "the ability of meat to retain its water during application of external forces, such as cutting, heating, grinding or pressing" (*Lawrie, 1998*).

Methods of measure WHC can be divided into three categories: those in which the only force applied is that of normal gravity ***the drip loss method*** (Honikel bag method - *Honikel, 1987*), those in which a greater force is applied (press, centrifuge or capillary) called ***enhanced force methods*** and ***indirect methods***.

The ***gravity method*** or ***drip loss method*** is the simplest method: sample joints or stakes are stored for a period of time and the loss of drip measured. It is common to suspend whole "chops" (slice of meat) inside polyetilene bags (to prevent evaporative losses) at 1 to 5℃ for 48-72 hours. Results for whole chops are affected by the fat : lean : bone ratio but the advantage is comparability with actual practice. An improvement is to use always the same muscle and to use defined-geometry samples of it.

***Enhanced force methods*** include ***filter paper, centrifugation*** and ***capillary methods.*** In the ***filter paper*** method originally develop by *Grau and Hamm (1952)* a small (0,2g) piece of meat is pressed on a filter paper between two clear plastic plates to form a thin film. Water is squeezed out and absorbed by the filter paper to form a ring of expressed juice. The area of this ring relative to the area of the meat is an index of WHC. Meat with an high WHC forms a larger area on pressing than meat with a low WHC. In fact, the area of meat is more variable than that of the expressed juice and can be used alone to asses WHC. A major advantage of the press method is that it can be employed with ground or processed meat. The pressure exerted can be controlled with a hydraulic press or tensile test machine (***filter paper press method***) but there appears to be little improvement in precision over that in methods where pressure is exerted manually. The ***centrifugation***

***methods*** involve centrifuging small samples of meat at high speed and under high gravitational forces (60-100,00g) for long periods (*Bouton et al., 1971*). The exudate forma as a supernatant and can be poured off and weighed. ***Capillary methods*** engage the use of absorbent material such as gypsum ($CaSO_4$) or filter paper. A sample of meat is pressed between a plate and a block of gypsum. Air is displaced from the block by exudates and rises up capillary tube, in turn displacing a coloured liquid. The volume of exudates is read off a scale.

An example of ***indirect methods*** is protein solubility quantification to asses WHC. The contractile (myofibrillar) proteins are extracted only at high ionic strength, e.g. by 1,1M KI in 0,1 M potassium phosphate at pH 7,4. Non-structural (sarcoplasmic) proteins are extracted by low ionic strength buffers, e.g. by 0,04 M potassium phosphate at pH 7,4. The correlations with drip loss measured directly are higher with sarcoplasmic than with myofibrillar or total protein concentrations and only sarcoplasmic protein concentrations reliably differentiate between normal and DFD (Dark, firm, dry) pork. (*Lopez-Bote, Warriss, & Brown., 1989*).

### *4.2.3 Molecular mobility - Proton Magnetic Resonance*

In the past two decades proton nuclear magnetic resonance (NMR) relaxometry has also been applied to describe water status in meat. This technique can provide direct information about the interactions between water and proteins and it has been extensively applied in meat science (*Cope, 1969; Hazlewood, Nichols, & Chamberlain, 1969; Belton, Jackson, & Packer, 1972; Hazlewood, Chang, Nichols, & Woessner, 1974; Pearson, Duff, Derbyshire, & Blanshard, 1974; Bertram & Andersen, 2004*) and also coupled with WHC (*Bertram, Donstrup, Karlsson, & Andersen, 2002; Tornberg, Andersson, Göransson, & von Seth, 1993; Brøndum, Munck, Henckel, Karlsson, Tornberg, & Engelsen, 2000; Brown, Capozzi, Cavani, Cremonini, Petracci, & Placucci, 2000; Bertram, Andersen, & Karlsson, 2001*), Differential Scanning Calorimetry (*Bertram, Wu, van den Berg, & Andersen, 2006*), microscopy (*Mortensen, Andersen, Engelsen, & Bertram; Bertram, Wu, Straadt, Aagard, & Aaslying, 2006*) and sensory analysis (*Bertram, Aaslyng, & Andersen 2005*). NMR relaxometry has also been used to investigate the modifications occurring in meat during cooking, as water status and cooked meat properties are strongly dependent on the nature of meat and on the processing parameters (e.g. cooking temperature, movement of air in the oven, amount of steam present) that will determine the rate of heat transfer (*Fellows, 2000*) and consequently affect cooked meat properties. Water status changes related to the cooking of meat have been studied with NMR to verify the effect of different temperatures, in relation to protein denaturation and shrinkage of the muscle fibres (*Bertram et al.; 2004; Micklander, Peshlov, Purslow, & Engelsen, 2002*). Most of the

studies published in scientific literature have been carried out on pork meat (*Bertram et al.; 2004; Micklander, et al., 2002*) and they were performed simulating the cooking process in the NMR tube, without considering the mass transfer and the changes that samples undergo in the oven environment (e.g., surface dehydration). These studies reported the presence of different types of water that are physically compartmentalized and characterized by multiple $^1H$ $T_2$ relaxation times (*Cole, LeBlanc, & Jhingran, 1993; Yamada, 1998; Lillford, Clark, & Jones1980; Bertram, Karlsson, Rasmussen, Pedersen, Dønstrup, & Andersen, 2001*). Few literature is available on NMR relaxometry studies on other types of meat, such as chicken (Rongrong, & Li, 2000; Sharifudin, Nott, & Hall, 2006) and turkey (Bianchi, Capozzi, Cremonini, Laghi, Petracci, Placucci, & Cavani, 2004).

The denaturation of protein and its relation to water status and distribution among the different domains has been investigated by means of $^1H$ NMR ($^1H$ $T_2$) and differential scanning calorimetry (DSC) by *Bertram et al. (2006).* They reported that the denaturation of myosin and actin were correlated to changes in water distribution and mobility and also to the expulsion of water from meat. Different cooking processes may result in a different degree of denaturation and, therefore, affect water mobility and distribution.

### 4.3 Sensory properties

Sensory properties are the characteristic that can be detected by the sense organs, for foods used particularly of the combination of taste, texture and stringency (perceived in the mouth) and aroma (perceived in the nose, *Bender, 1999*) .

During cooking, a complex series of thermally induced reactions occur between non-volatile components of lean and fatty tissues resulting in a large number of reaction products which contribute to the flavour of cooked meat (*Mottram, 1998*). Lipid oxidation and other degradation reactions lead to the formation of low molecular compounds, which contribute to sensory profile. Hydroperoxides and secondary oxidation products can react with protein and amino acids during processing, heat treatment and storage period affecting the flavour, odour and texture of meat products (*Frankel, 1998*).

The overall eating quality is strongly related to temperature and time dependent structural changes that occur during cooking in particular those involving the protein fraction (myofibrillar, sarcoplasmatic and connective tissue proteins, *Walsh, Martins, O' Neill, Kerry , Kenny & Ward, 2010*).

The sensory properties of meat perceived by the consumer are the result of both physical and water properties of meat, for example, a sample characterized by higher WHC presents a higher juiciness perception (*Omojola et al., 2009*).

Instrumental assessment of the components of eating quality can only be approximations to the true measure of particular attribute, because no machine can measure the range of interacting characteristic that contribute to eating quality and palatability. Sensory perception is a complex task that depends at the same time from many quality of the food. We don't perceive tenderness in isolation, we perceive it in relation to juiciness and "mouth feel" and perhaps even apparently unrelated attributes such as flavour and odour. For some assessments there is therefore no alternative to the use of a taste panel (*Warriss, 2000*).

Test panelling and sensory evaluation can be made by trained or consumer panels (8-10 panelists), the former is composed by individuals screened and trained while the latter include selected members of the general public that asses the meat in less controlled conditions.

There are different types of methods available to evaluate the sensory properties of meat, the appropriate method to apply must be choose in relation to the specific properties to assess and to the aim of the analysis. The are four many type of tests: ***difference or discrimination tests***, ***ranking tests***, ***category scaling*** and ***sensory profiling***. In ***difference or discrimination test*** panellists are asked to make a choice between two or more samples in regard to either witch they prefer or which is less or greater for some characteristic. Examples of difference tests are Triangle test and Paired-Comparison consumer tests. In ***ranking test*** more than two samples can be compared, with the aim to rank a series of samples according to some characteristic.

The ***category scaling*** give information on how the samples are different from one other. It is a descriptive test (*ISO, 1985*) that though category scales enable samples to be categorized in regard to specified characteristics such as texture, juiciness and flavour (*Warriss, 2000*). Prior to the analysis, the panel have to be trained in the definition and intensities of attributes. An example of descriptive test is reported by *Mielnik et al. (2008),* they showed as descriptive characteristics for turkey meat: odours (turkey, acidic, spicy, rancid), flavours (turkey, acidic, salty, spicy, bitter, metallic, rancid), colour (whiteness, hue, intensity) and texture attributes (hardness and juiciness). In ***sensory profiling*** testing the assessors develop a unique set of descriptors to define the characteristic of the sample. This leads to quite subtle descriptions of sensory characteristics of the sample than category scaling. (*Warriss, 2000*)

# 5. STEAM OVEN COOKING

## 5.1 Effect of steam on foods

Steaming is one of the methods most used in Oriental cuisine but also in Occidental countries has had a lot of success and nowadays is widely diffuse with various applications. Steamed foods are appreciated because they retain their original flavour, without this being affected by other substances (water, oil, butter, etc.), they have a reduced fat content, for the loss of melt fats during cooking and to the absence of condiments, and furthermore they show a smaller lost of water-soluble components (vitamins, mineral, proteins, etc.) compared to boiled foods.

In particular for meat based foods steam cooking is reported to retain more proteins and less fat than traditionally cooked samples. Foods cooked with steam are characterized by a valuable retention of substances with attractive sensory properties (*Choubert & Baccaunaud, 2010*) and recognized nutritional value i.e. vitamins and antioxidants (*Ferracane et al. 2008*). *Miglio, Chiavaro, Visconti, Fogliano, & Pellegrini (2008)* in their study on the effects of different cooking methods on nutritional characteristics of vegetables, observed that, for carrots and courgettes, steaming determined a lower loss of total phenols than boiling and frying. Moreover, they found that steaming was the only cooking method that completely preserved glucosinolates and even significantly increased by 30% of their initial concentration.

Nevertheless the scientific literature that analyzes the effect of different cooking treatments on food properties is limited and moreover often the cooking conditions aren't clearly defined, making difficult the comparison between different processes.

All the steam cooking techniques exploit the high capacity of the water vapour to transfer heat that leads to a speeding up of the cooking process (improvement of the efficiency of the treatment). Steam cooking can be classified in function of the pressure which the process is carried out in high pressure steam cooking (in pressure cookers), where temperature reached by the steam is higher than boiling water, and room pressure steam cooking traditionally conduct in steamers or in steam convection ovens.

## 5.2 Steam ovens

**Steam ovens** operating by steam and air-convection (commonly known as "combi" ovens), are appliances who gained popularity since their introduction about twenty years ago (*Barbanti & Pasquini, 2005*). "Combi" ovens combine the accurate heat control of an air-convection oven with the efficiency of steam that can be used individually, sequentially

or in combination to give the operator multiple cooking choices in a single appliance (*Vittadini et al., 2005; Chiavaro, Rinaldi, Vittadini, & Barbanti, 2009*).

Mainly two types of steam ovens are available on the market: the first type, commonly used in catering services, has the steam generator external to the oven cavity, while in the second one, mainly for domestic use, the steam is produced inside the oven cavity.

Whatever the type, ovens do not normally allow an accurate humidity control inside the cooking chamber. Ovens with an external steam generation have the possibility to apply alternating air-steam cycles and some models present a modulation system of the RH of the air that allow to create different RHs, but with a rough control of the steam quantity. These type of ovens have considerable dimensions and require a connection to the water network of the building.

Ovens with a steam generation directly inside the oven cavity have a water tank and the steam is created by the injection of nebulised water on the heating coil. In this kind of ovens there isn't the possibility to control air RH; there are only two possible modulations: presence/absence of steam, that is no steam injection -dry air- or steam injection, corresponded to the steam saturation condition. It is important to specify that above 100°C the saturation condition don't correspond to 100% RH but at different RH values as reported in *table 3* and thoroughly explained in *section 2.2.1.*

### 5.3 Effect of steam oven cooking on meat at low temperatures

**Steam oven cooking** is widely used both in industrial processing and domestic cooking for several foods (e.g., cooked ham, ready-to-eat meals, various vegetables and seafoods).

In oven cooking the air forced convection method is often coupled with steam injection in the oven chamber to reduce the cooking time and to prevent surface dehydration (*Belk, Luchak, & Miller, 1993; Murphy et al., 2001*). Steam oven cooking of meat, and in particular of turkey meat, is widely used in commercial processing and foodservice operations.

Operators gain several advantages in the steam oven cooking of meat, such as improved yields and lower energy consumption (*Danowska-Oziewicz, Karpinska-Tymoszczyk, & Borowski, 2007*). Nevertheless, the effect of steam on cooking parameters (cooking yield, surface temperature) and on texture, colour and sensory properties (juiciness, tenderness, palatability) of the cooked meat has not yet been clearly explained. Published data about the use of steam-convection oven and its effects on the quality of the final products are still rather limited and contradictory, making harder to understand the effect of different cooking methods on meat.

Moreover, it is quite difficult to compare results of different research papers on air-and-steam cooking mainly because of (i) different experimental conditions (e.g. oven temperatures or different cooking end point temperatures) and in particular (ii) unsatisfactory definitions of the thermodynamic conditions of steam (*Skog, Eneroth, & Svanberg, 2003, Barbanti et al., 2005, Danowska-Oziewicz et al., 2007, Białobrzewski et al., 2010). Danowska-Oziewicz et al. (2007)* found that weight losses in chicken cooked in oven with/without steam were comparable, while *Barbanti, & Pasquini (2005)* reported that the presence of steam in oven cooking resulted in an higher weight loss of chicken breast.
Few papers are published on steam oven cooking and most of them considered only the steam saturation condition, that is the most diffused and simple steam cooking method and is often compared to dry oven cooking (*Vittadini et al., 2005; Chiavaro et al.2009*).
*Vittadini et al., (2005)* compared samples of pork meat cooked in a commercial oven using different cooking conditions: natural convection, forced convection or combined forced convection/steam (FC/S) heating. FC/S treatment showed shorter cooking times compared to natural and forced convection methods. FC/S samples also had significantly higher weight loss than samples cooked by the other methods and resulted in a paler colour on the meat surface.
*Chiavaro et al. (2009)* reported that saturated steam cooking proved to be particularly attractive for pork meat compared to dry oven cooking at 100 and 110°C rather than 120 and 140°C: at lower temperatures the presence of steam resulted in similar or better cooked meat quality (texture, colour, water holding capacity) in a shorter time.
Only little information is available on the use of steam quantities lower than saturation that identify different relative humidity in the oven chamber. It was previously reported that the heat flux is closely related to the relative humidity of the oven air and results in different meat heating profiles (*Murphy et al. 2001*). *Murphy et al., (2001)* analyzed the effects of different RHs (range, 40-95%) during oven cooking of chicken breast patties by means of the evaluation of heat transfer properties and product yield between 149 and 218°C.
Heat transfer, cooking time and meat modifications during steam cooking were reported to be strongly different from traditional oven cooking. They reported increased heat flux and heat transfer coefficient (shorter cooking time) with increasing RH. An increased product yield was achieved by reducing oven temperature or final internal temperature of the product, and increasing RH.
The heating profile during cooking affects the sequence and the extent of meat protein denaturation in the cooking process and, consequently, the physical and sensory properties of the final product: a higher heating rate was previously associated to the production of a leathery material where collagen and actomyosin underwent aggregation almost simultaneously (*Riva & Schiraldi, 1994*).

Changes occurring in the cooking process were associated to structural modifications due to the denaturation of proteins and to the loss of water (*Tornberg, 2005*).

In particular the application of a heating profile characterized by a slow cooking rate has been reported to have a desirable effect on meat cooking characteristics in terms of higher cooking yield and tenderness (*Lawrence et al., 2001*).

Studies of treatment at low temperature also have nutritional relevance because it has been shown that the presence of steam reduced the mutagenic activity, except when high temperature was used in combination with high air velocity." (*Skog et al. 2003*).

# Objective

The objective of this work was to study the effect of cooking with different steam quantities (different relative humidities) on physical characteristics, water status and sensory properties of turkey meat samples. The minimum relative humidity value that allows to obtain a positive effect on meat quality and a higher potential water saving at low cooking temperatures (80-150℃) has also been evaluated.

# Set up of the experimental trials

## 1. COOKING EQUIPMENT: SET-UP OF AN EXPERIMENTAL STEAM CONVECTION OVEN WITH CONTROLLED STEAM INJECTION (CONTROLLED HUMIDITY)

### 1.1. Design and development of the experimental steam cooking device

An improved steam cooking device was developed to investigate the relationship between the application of different steam quantities/RH (different from the saturation condition) and turkey cooking performances in terms of instrumental quality, sensory properties and water status. The experimental cooking device was expressly designed to maintain fixed air RH conditions. The apparatus allowed online monitoring and data-logging of air RH, and temperature profile of both oven and samples during cooking.

The experimental set-up *(Figure 9)* consists of two major components, the cooking unit (1), and the automated data acquisition system (2). The cooking unit consists of a domestic electric convection oven (*Whirlpool AKZ 190/IX*) modified by connecting an external steam generator (*Tosca 100, Parma, Italy*) to its cavity. Steam was injected inside the oven chamber through a tube set in the centre of the vertical right panel, towards the bottom of the cavity, to maximize and homogenize the steam diffusion. A capacitive humidity-temperature sensor (*Rotronic HygroClip HC2-IC302, Zurich, Switzerland*), characterized by a humidity accuracy of ±3% over the 80-150°C operating range, was fixed in the centre of the vertical right panel in the oven cavity. The steam generator had an on-off steam injection switch allowing to set the relative humidity in the oven on the basis of the relative humidity measured by the sensor. The steam generator was weighed before and after each cooking trial with an electronic bench-top balance (*Tamagnini, EP series, Parma, Italy*), in order to estimate the water consumption.

Wire thermocouples (*type K, Ni/Al–Ni/Cr)* were placed inside the oven cavity to measure dry and wet bulb temperatures as described by *Chiavaro et al., (2009*) and to calculate the RH value (principle of the Assmann psychrometer, *as reported in the introduction section 2.4*). Temperature of each sample was recorded on the surface and at the geometric centre during cooking using wire thermocouples (type K*,* Ni/Al–Ni/Cr*)*.

(2) The computer based data acquisition system consisted of a personal computer associated to a DAQ acquisition device (National Instruments, Austin, Texas*)*, connected to the thermocouples and the capacitive humidity-temperature sensor. A *LabVIEW 8.0* graphical interface software (*National Instruments, Austin, Texas*) was used to develop a graphical interface for the real–time measurement and recording of time/temperature and humidity data profiles (*Figure 10*).

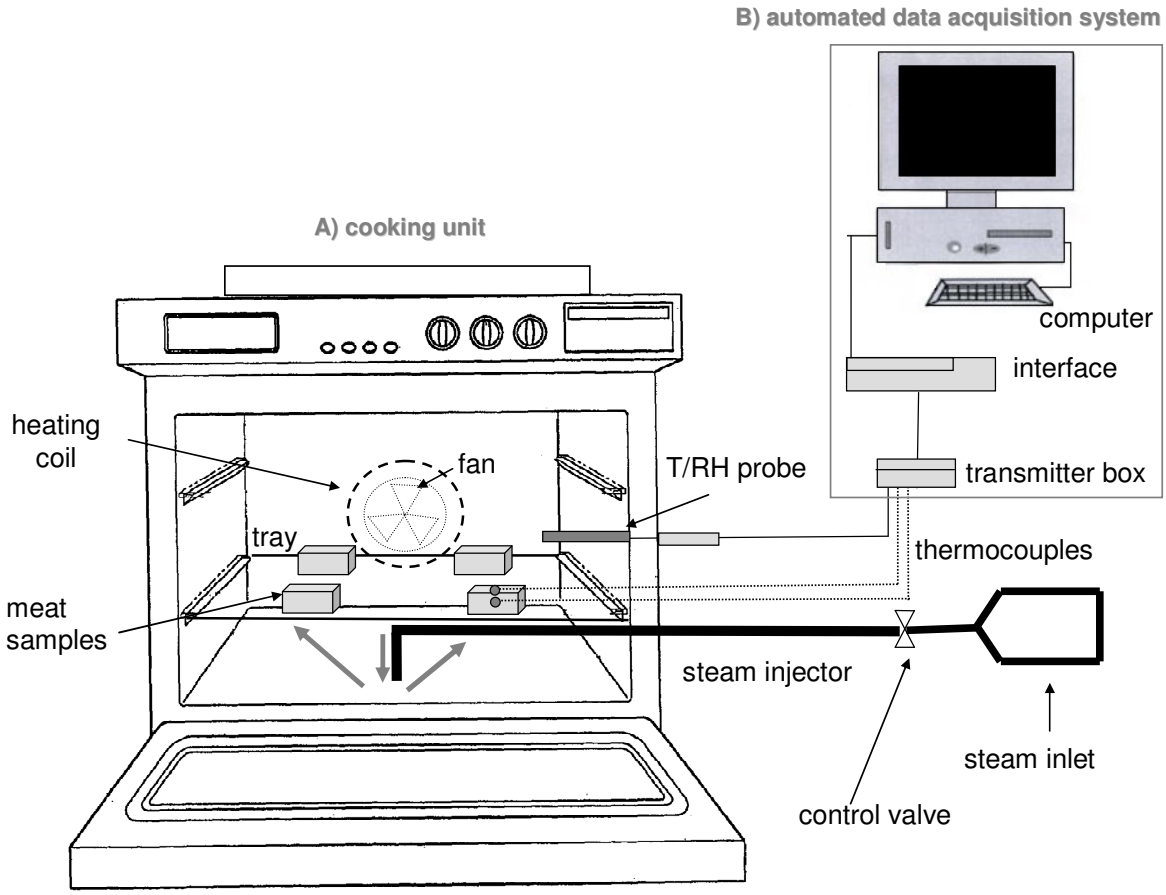



*Figure 9. Steam cooking device.*

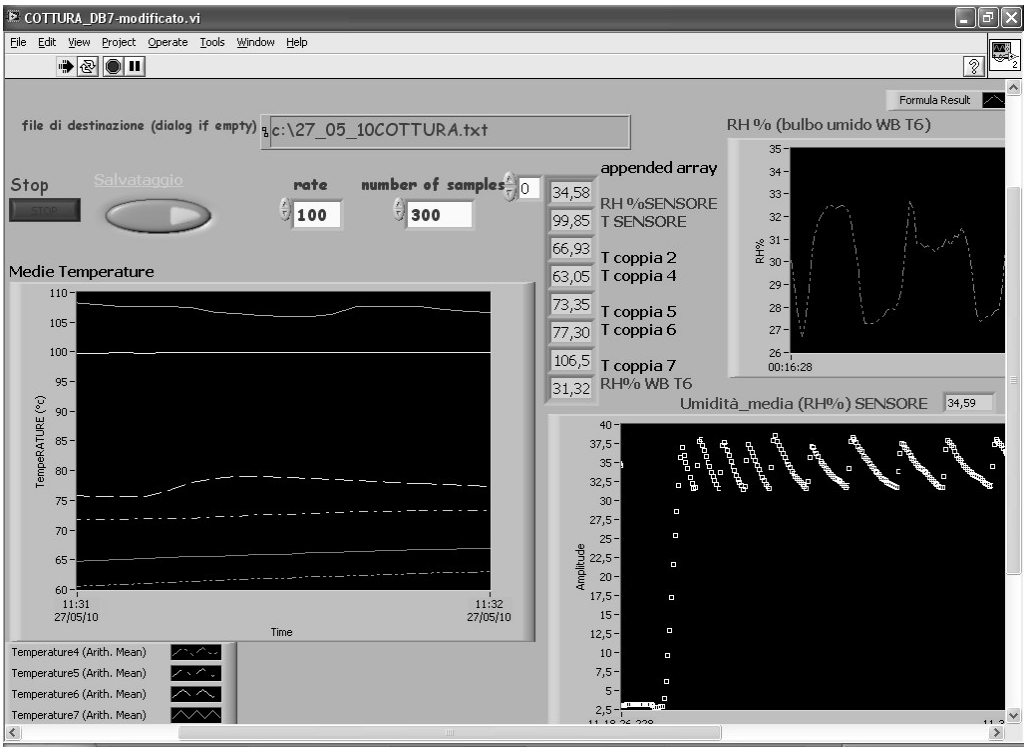



*Figure 10. Graphical interface for the real–time measurement and recording of time/temperature and humidity data profiles.*

**1.2. Experimental steam cooking device performance and optimization**

Preliminary cooking experiments were carried out to characterize the performances of the oven and to select the better cooking procedure.

A brief description of the **performance parameters** of the cooking equipment is reported below.

- ***Heating condition***: the "*thermo-ventilation*" was chosen among the several heating conditions of the oven (natural convection/no ventilation, ventilation with two heating coils, one in the upper part of the oven and another one in the lower, etc.) in order to minimize the heating time and quickly reach the set cooking temperature. The thermo-ventilation heating condition consisted of a forced convection cooking where the air was heated by a circular heating coil located around the fan of the oven. The oven temperature resulted very stable during the entire the cooking trial.

- ***Air speed measure***: the airflow was measured with an air velocity probe *(Testo, Milan Italy*) Air speed was 0,90 +/- 0,13m/s in thermo-ventilation cooking condition and the flux variation of was about 14%.

- ***Oven's thermal inertia***: the time necessary to reach the target cooking temperature was about 20 minutes for all the temperatures considered. Hence, the samples were inserted in the oven after this time.

- ***Quantification of steam flux*** at different steam generator settings (from SET1 to SET9, 13.2-56.6 g/min). Steam flux uniformity is reached after only 3-4 minutes of continue steam injection. SET3 -16.3±3.3g/min- and SET5 (only for the condition of 110°C at 62%) -31,6±1.41g/min- were chosen for the trials in order to have a controlled steam injection with adequate on-off time breaks.

A low and a high steam cooking of hygroscopic samples (white bread, 3x3x6cm) were considered (100°C RH:24%, 110°C RH:62% -the saturation condition-) in order to quantify the temperature/humidity ***reproducibility*** and ***uniformity*** of the treatments. The heating profile in the geometric centre of each sample was monitored with wire thermocouples and sample weight loss was recorded after cooking in order to evaluate the heat and mass transfer of the samples. Three trials of each treatment were carried out to assess the reproducibility of the system. Samples were put in different positions on the cooking tray to quantify the uniformity of each treatment. The obtained results are reported below.

- ***Heating reproducibility*****:** a good reproducibility was recorded with a maximum standard deviation between treatments of ±0.9°C.

- ***Humidity reproducibility:*** a maximum difference of ± 1.5 - 2% of the mean weight loss value between the samples in the same position was obtained. The system allowed for a good reproducibility.
- ***Heating uniformity:*** the temperature difference between samples was high in the first 3-4 minutes of the cooking process, while it reached at most 1°C at the end of the warm up and the device was correctly working at full capacity (corresponding to a coefficient of variation percentage (C.V.%) of about 1.5%). The recorded temperature difference was considered negligible.
- ***Humidity uniformity:*** samples in different positions of the cooking tray, after the steam treatment, showed a maximum weight difference of 4-5% (corresponding to a coefficient of variation percentage (C.V.%) of about 10-15%). This humidity uniformity has been considered a good standard.

The apparatus (a common electric oven) could not be considered a close system nor an open one from a thermodynamic point of view, but rather a semi-open system. Hence, the only feasible regulation of the air relative humidity was the "*on-off steam injection" (Figure 11).* Different RH target levels and the corresponding RH ranges were identified (*Table 4*) with several experimental trials. A maximum RH variation of ±5% from the target level was considered a tolerable variation in order to create different RH ranges clearly separated among each other and to have a manageable process (the on-off regulation was manually performed).
The RH ranges, clearly separated and well centred on the target levels were obtained and they are showed in *Figure 12*.

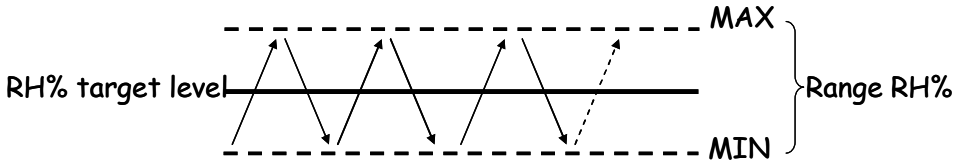



*Figure 11. On-off steam injection*

| **RH % level** | **0-10** | **19-29** | **30-40** | **38-48** | **57-67** | **83-93** |
|---|---|---|---|---|---|---|
| **RH % centre of the level** | **5** | **24** | **35** | **43** | **62** | **88** |
| **ON**-OFF | - | 21.5 | 31 | 40.5 | 59.5 | 83 |
| ON-**OFF** | - | 24 | 34 | 43 | 62 | 93 |

*Table 4. Experimental trials:*
*RH target levels, the corresponding RH ranges and the ON-OFF applied.*

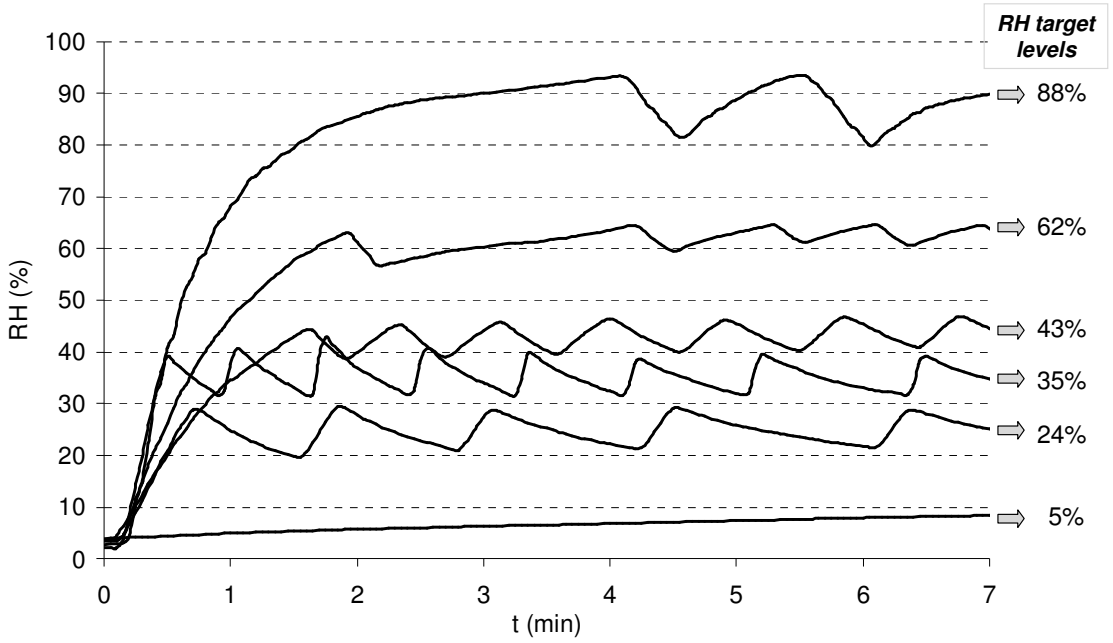



*Figure 12. Examples of the time/RH profiles at the cooking temperature of 100°C.*

## 2. MUSCLE PREPARATION

Turkey (*Meleagris gallopavo)* breast samples (*pectoralis major*), from the same processing plant and stored at 4°C, were purchased from a local supermarket 72 hours after slaughter and analyzed within 8 hours. Two slices (3 cm thick) were obtained from halved breasts and four samples of 3x3x6 cm (about 50g each) with muscle fibres running parallel to the major dimension were taken from each slice (*Figure 13*) . A total of 200 g of turkey meat was used in each cooking trial (4 pieces of 50 g). Meat samples were extracted from the fridge, equilibrated at room temperature (20-25°C) for 15 minutes until they reached an ultimate temperature of about 13-15°C of the geometric core of the samples prior to cooking.

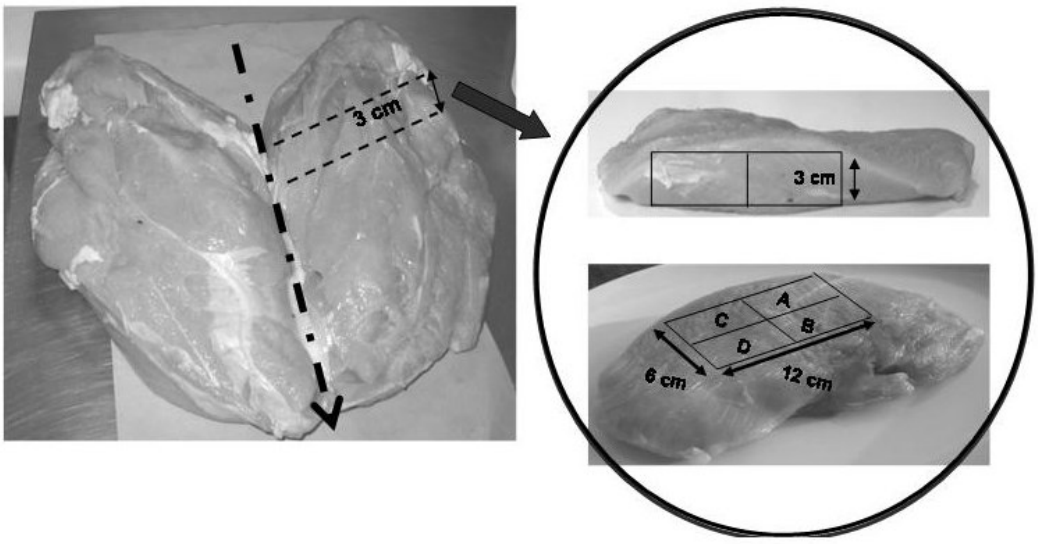



*Figure 13. Preparation of the turkey meat samples.*

## 3. COOKING TREATMENTS

The specific cooking conditions will be described in the following sections (*A, B, C*).

Three cooking trials for each treatment were carried out placing 4 meat samples positioned on the tray located in the middle height of the oven. The four meat samples were placed on the cooking tray at the same distance from each other and the oven walls, symmetrically. A total of 12 samples were analyzed for each cooking condition.

Temperature of each cooked sample was recorded during cooking using wire thermocouples (*type K, Ni/Al–Ni/Cr)* which were placed on the surface and at the geometric centre of each sample.

Cooking treatments finished when meat samples reached 74°C at their thermal centre, that is the recommended safety temperature for turkey meat (*United States Department of Agriculture, 2006*). Cooked samples were then cooled at room temperature for 30 minutes to reach a temperature of 27±2°C in the geometric core of the samples.

The degree of cooking in the centre and on the surface of each sample was expressed in terms of ***cook value***, considering only the heating phase (*Poon et al. 2001*). The cook value was calculated by integrating the heat penetration curve in the centre and on the surface of meat samples, as previously reported (*Holdsworth, 1985; Vittadini et al., 2005*).

# Methods of analysis

*The specific application of each method is described in the following sections (A, B, C).*

## 1. PHYSICAL PROPERTIES

### 1.1 Colour

Colour of fresh and cooked samples was measured by means of a Minolta Colorimeter (*CM 2600d, Minolta Co., Osaka, Japan*) with the standard illuminant D65 at 10° position of the standard observer (*CIE, 1976*). 16 readings for each sample at different positions (8 at the surface and 8 at the centre) were taken. Colour data were processed using the ***colour scale L*a*b**** and the analysis of the ***VIS reflection spectra***.

***L*(lightness), a*(redness), b*(yellowness), C*(chroma), h* (hue angle)*** parameters and colour difference ***ΔE*** between cooked and raw sample (*Sosa-Morales et al., 2006*) were considered.

The ***VIS reflection spectra*** (400÷700 nm) were also recorded and the spectral data were converted to log (1/R) units, (where R is reflectance), as reported by *Brùndum, Byrne, Bak, Bertelsen, & Engelsen (2000).*

### 1.2 Texture

Objective texture was measured on raw and cooked meat with a Texture Analyser (*TA-XT2, Stable Micro Systems, Goldalming, UK*) equipped with a 25 kg load cell. The performed tests were: *shear force test* and *texture profile analysis (TPA).*

***Shear force test***

For the ***shear force test***, fresh and cooked meat samples (n = 8) were cut perpendicularly to muscle fibers with a Warner–Bratzler blade (3 mm thickness) moving down at 2 $mm*s^{-1}$ (test speed). Shear (maximum) force and the work after the maximum force were measured. The shear force (N) was then normalized to the shear surface ($N/m^2$) and the work after the maximum force (J) to the shear section ($J/m^2$).

***Texture profile analysis (TPA)***

The TPA, double compression test, was performed on 2x2x2 cm samples of fresh and cooked meat. The test was carried out perpendicularly to muscle fibres by means of a cylindrical probe (code P35) at 5 $mm*s^{-1}$. The contact area was 4 $cm^2$, the final strain was set at 50% and the time interval between the first and the second compression was 1 s. Hardness (N) was calculated as reported by *Cheng, Sum, & Scannell., (2005)* as peak force required for the first compression. All experimental data were collected and analysed by Texture Expert software version 1.22.

### 1.3 Shrinkage

Length (L), width (W) and height (H) of each sample were measured by means of a manual calliper before and after each cooking trial and the total volume (V) of the meat sample was calculated. Each parameter was expressed as the ratio (dimensionless) between raw (i) and cooked value (f), identified, respectively, with Lf/Li, Wf/Wi, Hf/Hi, and Vf/Vi.

### 1.4 Cooking yield

Cooking weight loss percentage (WL%) was calculated by weight difference between uncooked and cooked samples on weight of uncooked samples * 100 as reported by *Vittadini et al. (2005).*

## 2 WATER PROPERTIES OF COOKED MEAT PRODUCTS

### 2.1 Moisture Content

Moisture content of samples was determined for raw and cooked samples by weight loss at 105°C (*ISCO NSV 9035, ISCO, Milan, Italy*) to constant weight, 4 measurements for each sample were carried out. In particular moisture content of cooked samples were evaluated both in the external (EXT) and internal (INT) positions.

### 2.2 Water holding capacity (WHC)

WHC for raw and cooked samples was obtained following the method of *Bouton et al. (1971)*, with few modifications. After equilibration at room temperature, meat samples of about 0.25–0.35 g taken from the external (EXT) and the internal (INT) positions of each sample were weighed and centrifuged at 4°C at 14000 rpm for 30 min (*Centrifuge 5810R, Eppendorf AG Barkhausenweg, Hamburg, DE*). Meat WHC was expressed as the percentage fraction water lost referred to 100 g of water in raw samples (*Chiavaro et al., 2009*). Six determinations were performed for EXT and INT for each cooking trial. Eight pieces were analyzed for the raw sample.

### 2.3 Low resolution nuclear magnetic resonance ($^1$H NMR)

A low resolution (20 MHz) $^1$H NMR spectrometer (the minispec, *Bruker Biospin, Milano, Italy*) operating at 25°C was used to study proton molecular mobility by measuring the free induction decay (FID), transverse ($T_2$) and longitudinal ($T_1$) relaxation times. 24 NMR determinations for RAW, cooked (INT and EXT) and post- centrifugation samples ($RAW_{WHC}$ and INT cooked samples – $NS_{WHC}$, $LS_{WHC}$, $HS_{WHC}$) were carried out. Samples were placed in the NMR tube that was then sealed with Parafilm® to prevent moisture loss

during the NMR experiment. Recycle delays for all experiments ranged from 1 to 3 s, depending on the sample $^1H$ $T_1$. $^1H$ FIDs were acquired using a single 90° pulse, followed by dead time of 7 µs. $T_2$ (transverse relaxation times) were obtained with a CPMG pulse sequence (*Carr, & Purcell, 1954; Meiboom, & Gill, 1958*) and an interpulse spacing of 0.15 ms and a number of data points varying from 3000 to 6000, depending on the sample relaxation time. $^1H$ $T_1$ (longitudinal relaxation times) were determined by the inversion recovery pulse sequence with a log-spaced interpulse ranging from 1 ms to 6000 ms depending on the sample relaxation time and 20 data points were collected. $^1H$ $T_2$ and $^1H$ $T_1$ curves were analyzed as quasi-continuous distributions of relaxation times using a UPEN software (*Borgia, Brown, & Fantazzini, 1998; 2000*).

**3. SENSORY ANALYSIS**

All sensory tests were performed by a semi-trained panel. Cooked turkey samples were halved to evaluate both the internal and the external parts of the sample and equilibrated at room temperature for at least 30 minutes prior to be evaluated by the assessors.

Cooked samples were ranked for liking of overall aspect and flavour (taste and oral texture) by a panel of 10 people.

Three additional sensory tests were carried out to thoroughly evaluate the effect of low and high steam on the sensory properties of cooked meat:

- A triangle test was carried out to assess if the subjects (n=9) could perceive a sensory difference in terms of aspect and tenderness (by handling the samples).
- A ranking test was performed with 20 subjects, as described above, to assess the overall liking for aspect and flavour.
- A paired-comparison consumer tests (two sided) with 17 subjects was carried out to assess the sensory perception of tenderness.

Data analysis was carried out as previously reported (*Jellineck, 1985*).

**4. STATISTICAL ANALYSIS**

Means and standard deviations (SD) of experimental data were calculated with SPSS (*Version 16.0, SPSS Inc., Chicago, Illinois, USA*) statistical software. One-way-analysis of variance (ANOVA) with a Tukey-*high significant difference test*, at a 95% confidence level ($p < 0.05$) was applied to identify significant differences among the different cooking conditions.

# Section A

## OVEN COOKING OF TURKEY MEAT AT DIFFERENT RELATIVE HUMIDITIES

*B. Mora, D. Barbanti, G. Betta, F. Bozzoli*

### 1. Abstract

Some selected physical characteristics of turkey meat (weight loss, texture, colour, volume shrinkage and cook value) were evaluated after oven cooking at 100 and 110°C. For each cooking temperature, dry air (only air convection, RH = 5%) and three predetermined relative humiditiy values (RH = 24, 43 and 62%, respectively) were obtained inside the oven cavity by means of a steam generator.

Significant cooking time decrement of about 70-90% (compared to air convection condition) was achieved by using steam, both at 100 and 110°C with the exception of the treatment at 100°C and RH= 24%. Moreover, the steam presence during cooking increased the cooking yield when steam treatments were shorter than the dry air convection treatment. About 10% cooking yield increase (as compared to air convection condition) was found at 100°C (at RH = 43% and 62%) and at 110°C (at RH = 62%). An additional cooking yield increase up to +15% was measured at RH = 24% and 43% at 110°C. Steam cooking lead to a noticeable decreases of shrinkage, shear force and hardness of meat samples both at 100 and 110°C. The best cooking conditions, in terms of short cooking time, high cooking yield, high tendernss and minor chewiness were obtained at 100°C with RH = 62% and 110°C with RH = 43%.

### 2. Aim of the Work

The objective of this work was to study the effect of cooking with diffferent steam quantities on some physical characteristics of turkey meat samples.

The cooking trials were carried out at three relative humidities (24, 43 and 62% RH) and two cooking temperatures (100 and 110°C) in an air-and-steam convection oven. The standard cooking trials at 100 and 110°C were carried out without steam injection (RH = 5%). In order to verify the experimental relative humidities and temperatures, a continuous check and control of these parameters were carried out. The effects of the different cooking trials on the selected physical characteristics of turkey meat samples were evaluated by means of analyses of cooking yield, hardness, shear force, shrinkage and colour.

## 3. Materials and Methods

### *3.1 Sample Preparation*

Turkey breast samples were obtained as reported in the section *Set up of the experimental trials*.

### *3.2 Cooking trials*

Turkey breast samples were cooked at two air temperatures (100 and 110°C) and three relative humidities (RH = 24, 43 and 62%) under forced air circulation with the cooking equipment described in the section *Set up of the experimental trials*. Another cooking treatment was carried out without steam injection (RH = 5%, convection cooking, coded as CC). The other conditions (RH = 24, 43 and 62%, ± 5%) were maintained by means of manual on-off control of the steam generator. These steam convection cooking were coded as 24SCC, 43SCC and 62SCC respectively, and all the steam convection cooking treatments were coded as SCC.

Temperature of the surface and at the geometric centre of the sample were recorded during cooking in order to obtain the *thermic profiles* of the samples. The *cook value* was calculated both at the surface and in the centre of the samples as reported in the section *Set up of the experimental trials*. The *final surface temperatures* and the *cooking time* were also recorded.

### *3.3 Analyses*

Turkey meat samples were characterized for the following physical properties: *volume shrinkage ($V_f/V_0$), weight loss, texture properties –Shear Force test and Texture Profile Analysis – and colour scale L*a*b* parameters*. The detailed procedures of the analysis were reported in the section *Methods of analysis*.

### *3.4 Statistical Analysis*

Statistical analysis were performed as described in in the section *Methods of analysis*.

## 4. Results and Discussion

### *4.1 Thermal profiles*

In order to have constant temperature and RH inside the oven cavity and also to reach 74 °C at the thermal centre of each sample, a continuous check of these parameters for each cooking trial was carried out. In *Figure A/ 1* an example of the evolution of dry and wet bulb temperatures and RH inside the oven cavity and the temperatures of meat sample surface and centre were reported (110 °C, RH = 24%). The set oven temperature resulted very stable all along the cooking trial.

Surface and centre temperatures of meat samples increased with time during cooking with different rates, as expected. Surface temperature of meat samples was affected by the on-off steam injection: the on-off steam injection caused little variations of the temperature of the surface of samples during cooking. When the steam was injected it condensed on the surface of the samples and the latent heat produced by condensation was given up to the surface that increased its temperature.

In *Figures A/ 2a and A/ 2b*, the temperature profiles of sample surface and wet bulb at 100 and 110 °C and different RH were reported. Each cooking treatment was considered finished when meat samples reached 74 °C at its thermal centre, hence different cooking lenghts were obtained. SCC and CC treatments resulted in different heating kinetics of the sample surfaces, both at 100 and 110 °C. SCC treatments always showed an initial rapid increase of surface temperature; this behaviour was due to the latent heat of condensation transferred from the steam to the meat samples surface, about 2260kJ*kg$^{-1}$, (*Perrot, 1998*) and to the higher heat transfer coefficient of condensing water vapour (h=$10^4$-$10^5$ W m$^{-2}$ K$^{-1}$) compared to that of forced convection air (h=$10^2$ W m$^{-2}$ K$^{-1}$) (*Datta, 2002*). Moreover, at the beginning of the cooking process (after about 10 min) the sample's heating rate was directly proportional to the relative humidity of the air, as already reported by *Murphy, Johnson, Duncan, Clausen, Davis & March (2001).* The relation between the heating rate of samples and the RH of the air in the oven was quantified considering the surface temperature of the samples after 10 minutes. At both the examined cooking temperatures (100-110°C) the surface temperatures of samples were proportional to the RH of the air with a second degree relation:

| | | |
|---|---|---|
| 100°C: | $T(°C) = -0.0055\ RH^2 + 1.06\ RH + 44.237$ | $R^2=0.99$ |
| 110°C: | $T(°C) = -0.0052\ RH^2 + 1.1317\ RH + 46.985$ | $R^2=0.99$ |

After an initial phase characterized by a surface temperature increase a constant temperature period was observed at 100 °C, 24% and 43% RH and at 110 °C, 24% RH. These conditions allowed sample surfaces to behave like a wet-bulb, in terms of mass transfer and temperature, according to the drying theory (*Fellows, 2000*). The temperature equilibrium is reached at the surface of the food if it is maintained perfectly wet by the migration of water from the interior of the food itself; when this condition occurs, the surface shows constant temperature, equal to wet bulb temperature and it is a function of cooking T and RH. At other SCC conditions (100 °C, 62% RH, 110 °C, 43 and 62% RH) meat sample surfaces reached 74 °C at the thermal centre in few minutes (about 10 min) hence the constant temperature period did not appear.

During CC treatment, a continuous increase of surface temperature both at 100 and 110 °C was observed: the surface temperature did not behave like a wet bulb and a slow and constant surface temperature increase during the entire cooking trial occurred. It was due to the dehydration caused by the vapour partial pressure gradient between the food and the surrounding air, in agreement with the second phase of drying theory (*Fellows, 2000*).
In *Table A/ 1*, a summary of final surface temperature, cooking time, cook values, moisture content and volume shrinkage has been reported. The final surface temperature of meat samples always turned out lower than 100 °C because of water evaporation and consequent cooling effect at the meat surface. Nevertheless, the increasing of RH values (both at 100 and 110 °C) reduced the vapour pressure gradient between the food and the surrounding air, thus resulting in a lower water evaporation and in an increase of meat surface temperature.

### *4.2 Cooking time*

In SCC treatments the cooking time was in inverse proportion to the RH value, both at 100 and 110 °C. At 100 °C a significant cooking time reduction in comparison with CC condition was observed: -82 % for 43SCC and -89% for 62SCC, with no significant differences between them. These values depended on the faster initial heating kinetic of SCC, as previously described.
An "apparent" abnormal value of cooking time was repeatedly observed at 24SCC and 100 °C, significantly higher than CC at 100 °C (+17.7%). Taking into account that during the 24SCC trials the wet bulb temperature ($T_{wb}$) was about 74.5 °C, the extension of cooking time depended on the low temperature gradient between sample surface and centre until the end of cooking (T=74 °C at sample's thermal centre).
At 110 °C, 24SCC, 43SCC and 62SCC showed a noticeable cooking time reduction in comparison with CC: -72, -86 and -87%, respectively.

### *4.3 Cook value*

Surface and centre cooking values ($C^z_{Tref}$ ) are the measure of the cumulative heat impact of the time/temperature history on a food quality attribute (*Poon, Durance, & Kitts, 2001*). The surface $C^z_{Tref}$ value of SCC, except 24SCC at 100 °C, resulted three to four times lower than CC at both temperatures of 100 and 110 °C, mainly due to their respective shorter cooking time. By considering the limit threshold of thermal damage of 13,56 minutes at 100°C, defined as the time necessary to reduce thiamine content by 3% (*Pompei, 2009*), the surface $C^z_{Tref}$ of CC treatments and 24SCC at 100 °C exceeded this value, while at the other SCC treatments a limited nutritional quality degradation of meat ($C^z_{Tref}$ <13,56 min) can be hypothesized. The centre $C^z_{Tref}$ value, both at 100 and 110 °C

was always lower than surface $C^z_{Tref}$ value, due to the lower temperature reached in the centre of the sample (74 °C).

### *4.4 Moisture content*

The moisture content of heat treated samples with steam injection (at 100 °C) decreased with the decrasing of RH. The lowest MC value was obtained at 24SCC because of the longest cooking time, while the highest MC value was measured at 62SCC (2,18 $kg_{water}/kg_{dry\ matter}$). At 110 °C the higher MC decreasing was observed for the CC condition (1,56 $kg_{water}/kg_{dry\ matter}$), while for 24SCC, 43SCC and 62SCC the shorter cooking times reduced MC decrease (2,13, 2,1 and 2,06 $kg_{water}/kg_{dry\ matter}$, respectively).

### *4.5 Shrinkage*

The cooking process induced a volume reduction of meat samples; the volume shrinkage value ($V_f/V_0$) of SCC meat samples was always higher (hence their volume reduction was lower) than the corresponding CC samples both at 100 and 110 °C. In details, at 100 °C the $V_f/V_0$ value of 43SCC samples was the highest (+20%) in comparison with CC sample. At 110 °C the shrinkage value of all SCC samples resulted significantly higher than CC samples (+20-27%), but no significant differences were found among SCC samples.

### *4.6 Weight loss*

Weight loss (WL) is the measure of the product cooking yield, the higher weight loss the lower cooking yield.. The average WL values obtained at 100 and 110 °C have been reported in *Figure A/ 3*. The presence of steam significantly reduced meat sample WL (with the exception of 24SCC at 100 °C), in comparison with CC both at 100 and 110 °C. At 100 °C, 43SCC and 62SCC the WL of meat samples resulted to be of about 20% (+10% of cooking yield compared to CC at the same temperature), whereas at 100 °C, the WL of 24SCC was greater than CC mainly because of the long time needed for this cooking condition. The lowest WL were observed at 110 °C, 24SCC and 43SCC, where they were about 15% lower than CC. At 110 °C the sample's WL at RH = 62% (corresponding to the pure steam condition at this temperature) was higher than the WL at lower relative humidities probably due to the highest cooking rate of this particular thermo-hygrometric condition compared to the other ones. The presence of steam reduce the vapour pressure gradient between the surface of the sample and the air, hence steam cooked samples with a cooking length lower than CC presented a lower weight loss than the ones cooked without steam. However, when the cooking length of steam cooked samples resulted greather that CC (24SCC at 100 °C) we obtained the opposite result: an higher WL in steam cooked samples, because the crust formation in CC samples obstacle

water evaporation from sample surface to the air as previously described by *Vittadini, Rinaldi, Chiavaro, Barbanti, & Massini (2005).*

### *4.7 Texture properties*

The shear force test is the most widespread method normally used as an indicator of meat tenderness, the shear force values (N) of raw and cooked meat samples are shown in *Figure A/ 4*. Under our experimental conditions the injection of steam during cooking generally determined a shear force reduction of meat samples compared to ones cooked without steam. Only the samples cooked at 62SCC at 110°C (cooked at the pure steam saturation condition) presented the same shear force value of the ones of CC at 110°C. Some significant differences of shear force were found among steamed samples, in particular, at 100 °C, 62SCC resulted significantly more tender than 24SCC and 43SCC. A different behaviour was observed at 110 °C, where the tenderest samples were the 24SCC and 43SCC (no significant difference between them). Considering only the SCC treatments at 110°C the lowest RH values (lowest cooking rate) lead to the lowest shear force value, whereas the application of an higher steam quantity (highest cooking rate) determined a tenderness reduction in agreement with *King, Dikeman, Wheeler, Kastner, & Koohmaraie (2003).*

Concerning texture profile analysis of cooked and raw samples hardness, cohesiveness, springiness, gumminess and chewiness were evaluated, these parameters were reported in *Table A/ 2*. At 100°C the most hard sample was the 24SCC, no significantly different from CC, whereas the 62SCC resulted the most tender sample, not significant different from 43SCC. Samples cooked at 24SCC, 100 °C resulted the highest in hardness if compared both to SCC and CC conditions because they have an extended cooking time that lead to an higher samples dehydration as previoulsly described. At 110°C the difference between the hardness of the different samples was minor than that at 100°C and only 43SCC samples resulted significantly tenderer than CC ones.

The cohesiveness was very similar among different cooked samples both at 100 °C and 110 °C. At 100°C the only significant difference was between 43SCC and 62SCC, the former was higher than the latter. Tendentially the higher RH lead to the lower cohesiveness (at 100°C 62SCC and at 110 °C 43SCC and 62SCC). No differences in springiness value were found among all samples. At 100 °C the less gummy sample was the 62SCC, significantly different from the others, while at 110 °C the lower gumminess was observed at 43SCC not statistically different from 62SCC. The chewiness of cooked samples was lower at 43SCC and 62SCC than the other treatments at both temperatures. However at 110 °C the chewiness of meat samples cooked at 62SCC weren't statistically different from CC and 24SCC.

Hardness, gumminess and chewiness at 100°C resulted linearly related in inverse proportion to the moisture content of samples with a $R^2$ higher than 0,93 (correlations not reported). At 110°C the same tendency was observed however the presence of an outlier (the sample 24SCC) made difficult any relation between texture parameters and moisture content. No relation between moisture content of samples and shear force data was observed ($R^2$ ~0,3).

Sensorial quality of meat is strongly affected by its moisture content, hence, since TPA results were better related to the moisture content of samples than shear force results, it could be hypothesized that TPA analysis could better relate to the sensorial quality of meat than shear force test in agreement with *Ruiz De Huidobro, Miguel, Blàzquez, & Onega (2005)* which affirmed that texture profile analysis (TPA) seems to be the most useful and accurate method for predicting sensory texture of cooked meat.

### *4.8 Colour*

The differences of colour parameters between cooked and raw samples (Δ) are shown in *Table A/ 3*. The surface colour parameters of the uncooked meat was characterized by lightness L* = 49.2 ± 2.9, redness a* = -0.7± 0.6, yellowness b* = 3.1 ± 1.1. Cooking caused an increase of the sample's surface colour in terms of L*, a* and b*, consequently cooked meat sample's surfaces were brighter (higher L*), more red (higher a*) and yellow (higher b*) than the raw uncooked samples.

SCC samples compared to CC samples showed a paler colour: they resulted in lower a* and b* than CC sample and also by higher L*. Significant differences in terms of surface colour increase between SCC (with short cooking times) and CC were found. In SCC samples with short cooking times the presence of steam prevented surface dehydration thus reducing Maillard reactions while, as expected, under CC condition a uniform brown crust formation was clearly observed and instrumentally detected. No color differences were found between steam cooked samples at different RH with short cooking times. Meat samples cooked at 24SCC, 100 °C (steam cooking with long cooking time) showed an increased a* values (browning degree) in-between CC and SCC samples: a non uniform crust formation, localized on edges and corners, the more dehydrated areas, was observed.

Concerning the colour of the internal part of meat samples contrasting results between the two temperatures were obtained. At 100°C the higher ΔE value was recorded in CC sample, while at 110°C in absence of steam the ΔE value was the lowest, and the same behaviour was observed for ΔL* values. An high Δa* value was observed at 24SCC at 100°C no significantly different from CC at the same temperatures.

## 5. Conclusions

In this study the attention has been focused to the control of the relative humidity under different cooking conditions. Important information have been obtained from the analysis of the heating profiles of samples during cooking: at the beginning of the cooking process the presence of steam increased the heating rate of meat samples with increasing relative humidity of the air.

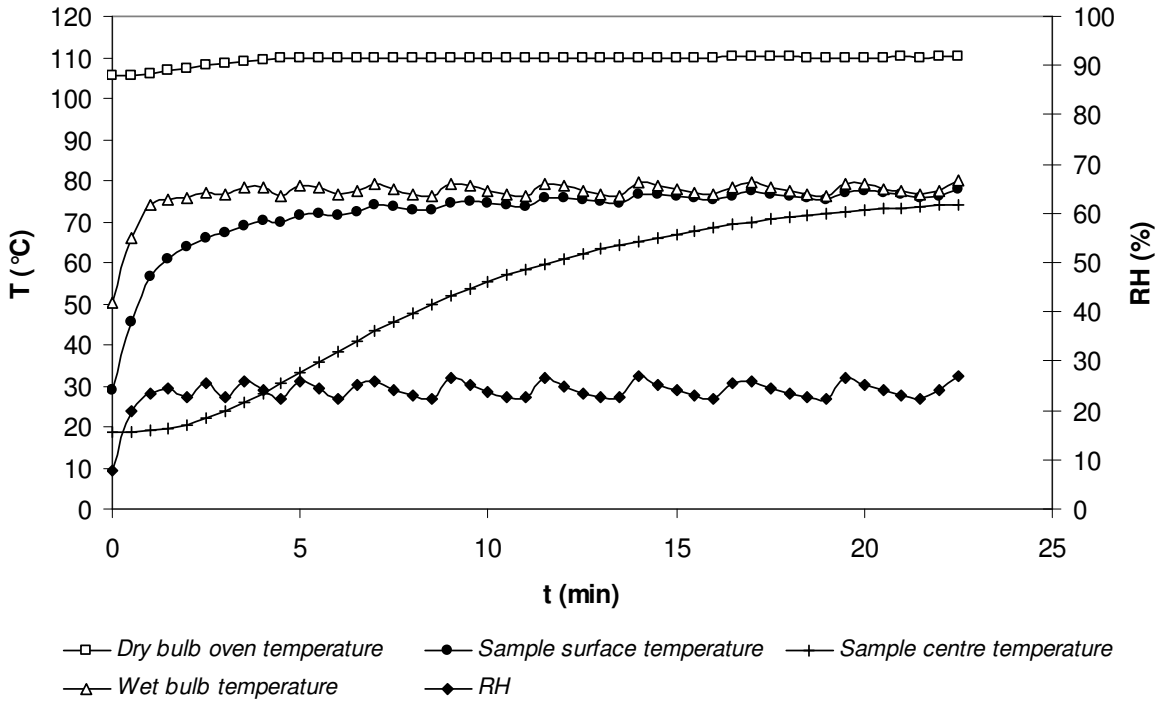
Different relative humidities led to different meat cooking performances. The presence of steam significantly reduced meat sample weight loss, increased their tenderness and prevented high volume reductions when cooking times were shorter than dry oven cooking. Whereas, when longer cooking times occurred (100°C, 24%) the steam presence led to a worsening of the selected quality parameters of turkey meat.

The best cooking performances (maximum cooking yield, highest tendernss, minor chewiness, etc) were found at RH = 62 % at 100 °C and at RH = 43 % at 110°C. At 110°C relative humidities lower than saturation allowed to obtain better quality characteristics of cooked meats with a potential energy saving.

A good knowledge of cooking behaviour under different relative humidities could be usefull to improving food quality and reducing energy consumption.

## 6. List of Figures

***Figure A/ 1.*** *Thermal profile of a turkey meat sample during steam-convection cooking at oven's air temperature of 110°C and relative humidity of 24 %.*



***Figures A/ 2.*** *Sample surface temperature and wet bulb temperature evolution at 100℃ (a) and 110℃ (b) at the different relative humidity conditions (RH= 5%, 24%,43% and 62%).*

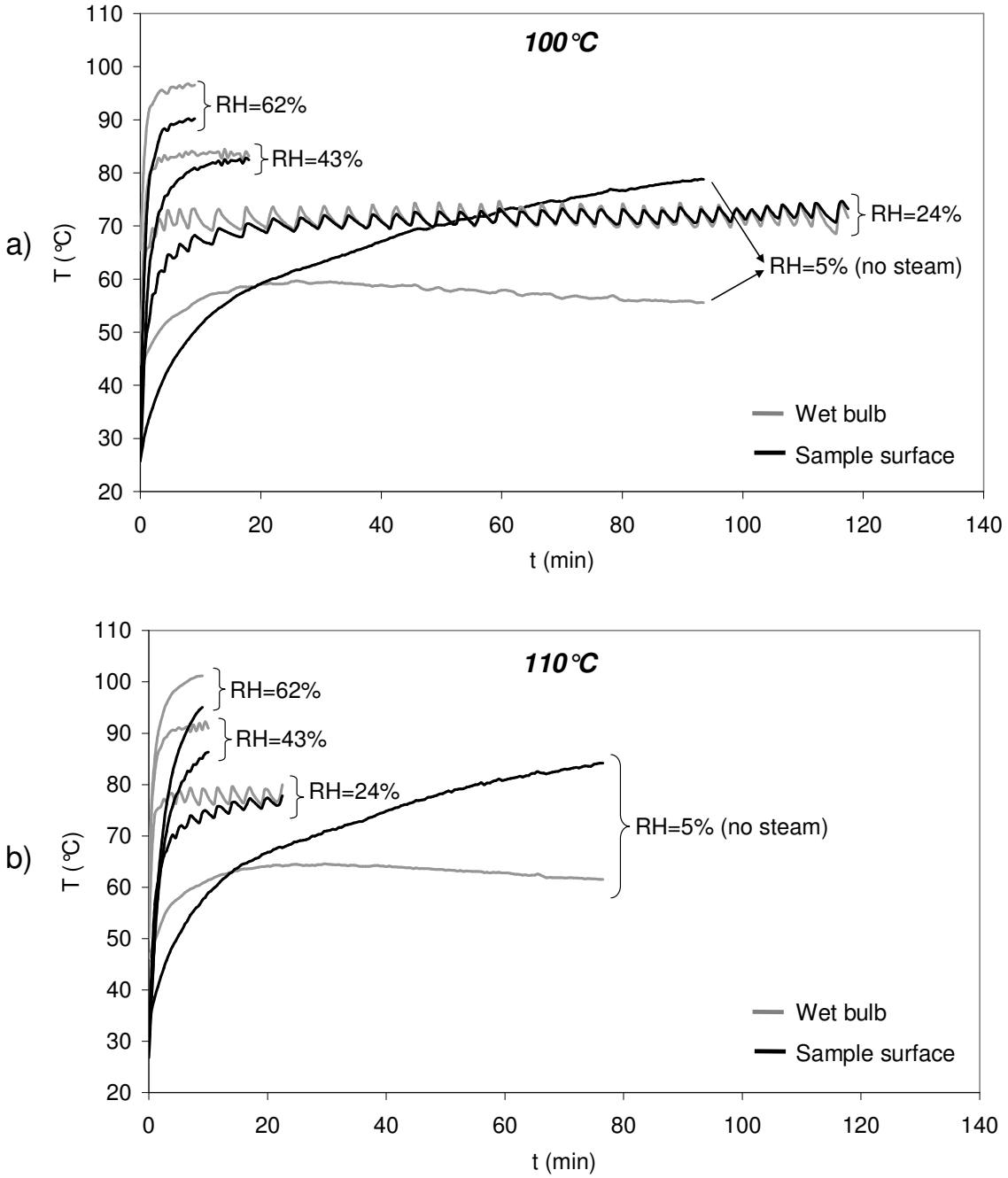


***Figure A/ 3.*** *Weight loss values of meat samples cooked at the different T/RH conditions, (weight loss difference between fresh and cooked samples) expressed as percentage on fresh sample weight (WL%).*

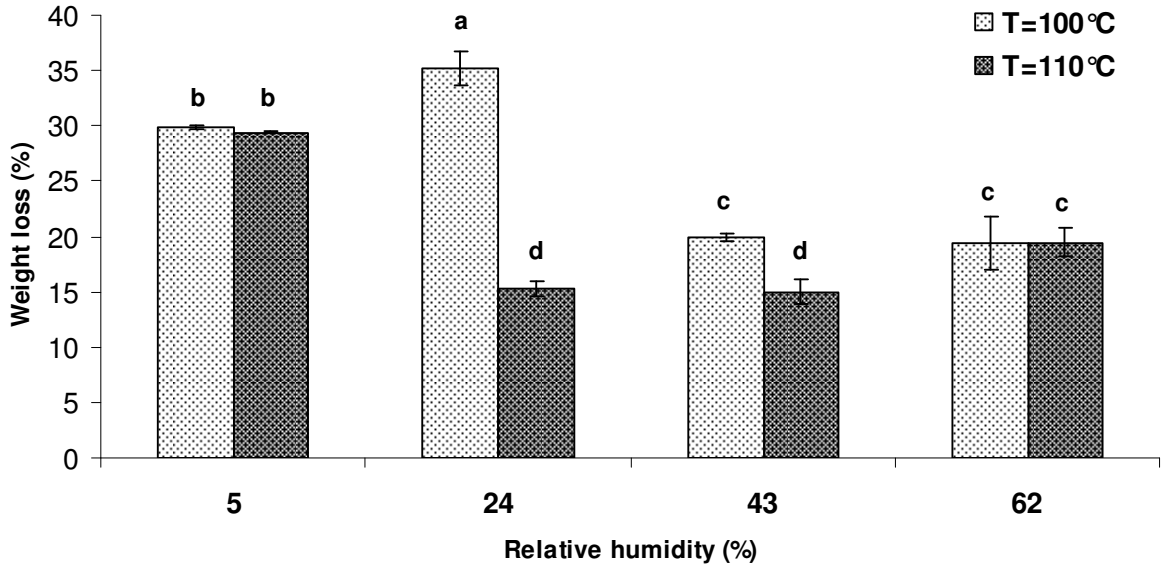
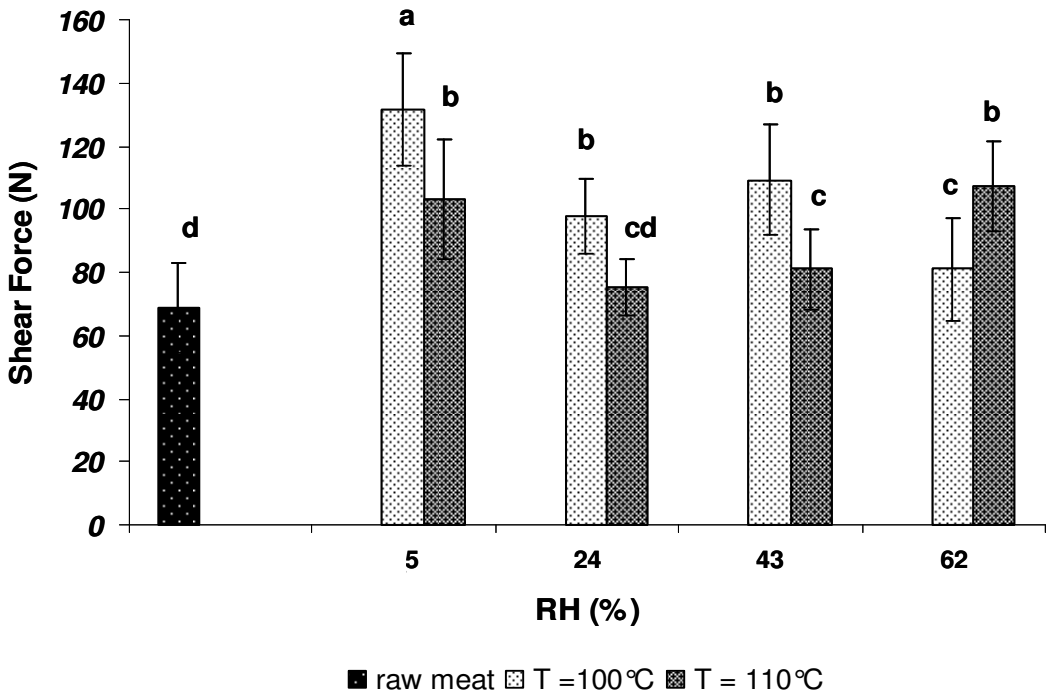


***Figure A/ 4.*** *Shear force results (expressed as N*cm$^{-2}$) for uncooked turkey meat samples and cooked samples at 100 and 110°C under different relative humidity conditions.*



## 7. List of Tables

***Table A/ 1.*** *Meat cooking results at the different temperatures and hygrometric conditions: samples' final surface temperature (°C), cooking time (min), surface and center cook values (min), moisture content (kg water/kg dry matter) and volume shrinkage (dimensionless). Numbers in parenthesis are the standard deviation of the mean (+/-). Samples' final surface temperature, cooking time, surface and center cook values n=2, moisture content n=4, shrinkage n=8. Means with the same letter are not significantly different (p<0.05).*

| Treatment | Final surface temperature (°C) | Cooking time (min) | Cook values (min) | | MC (kg water/kg dry matter) | Shrinkage ($V_f/V_0$) |
|---|---|---|---|---|---|---|
| | | | Surface | Center | *raw meat: 2.7 (0.06) a* | |
| **100°C** | | | | | | |
| **CC** | 80.1 (1.7) de | 98.2 (5.5) b | 12.4 (1.7) a | 8.1 (0.1) b | 1.52 (0.02) d | 0.69 (0.08) c |
| **24SCC** | 74.5 (2.2) e | 115.7 (3.2) a | 15.8 (0.7) a | 14.2 (0.1) a | 1.38 (0.07) e | 0.73 (0.07) bc |
| **43SCC** | 82.8 (0.4) cd | 17.6 (0.6) de | 3.9 (0.2) b | 0.9 (0.1) e | 2.08 (0.04) c | 0.83 (0.09) a |
| **62SCC** | 90.4 (0.3) ab | 10.6 (1.8) e | 3.4 (0.1) b | 0.6 (0.1) e | 2.18 (0.05) b | 0.76 (0.08) abc |
| **110°C** | | | | | | |
| **CC** | 82.2 (2.8) cd | 79.9 (4.7) c | 12.1 (1.3) a | 7.1 (0.3) c | 1.56 (0.04) d | 0.67 (0.05) c |
| **24SCC** | 76.6 (1.2) e | 22.3 (0.5) d | 3.3 (0.3) b | 1.5 (0.1) d | 2.13 (0.08) bc | 0.81 (0.06) ab |
| **43SCC** | 87.4 (1.6) bc | 11.3 (1.6) de | 3.0 (1.3) b | 0.6 (0.1) e | 2.1 (0.06) c | 0.80 (0.09) ab |
| **62SCC** | 95.0 (0.2) a | 10.1 (1.3) e | 3.0 (0.9) b | 0.4 (0.1) e | 2.06 (0.03) c | 0.85 (0.13) a |

***Table A/ 2.*** *TPA results of raw and cooked meat samples at the different temperatures and hygrometric conditions: hardness, cohesiveness, springiness, gumminess and chewiness values are reported. Numbers in parenthesis are the standard deviation of the mean (+/-). n=8. Means with the same letter are not significantly different (p<0.05).*

| Treatment | Hardness (N) | Cohesiveness | Springiness | Gumminess (N) | Chewiness (N*mm) |
|---|---|---|---|---|---|
| ***raw meat*** | *47.0 (20.5) f* | *0.40 (0.08) c* | *0.56 (0.12) a* | *17.77 (7.08) f* | *9.61 (3.83) f* |
| **100°C** | | | | | |
| **CC** | 103.3 (41.5) ab | 0.45 (0.04) ab | 0.57 (0.04) a | 46.17 (15.70) ab | 26.39 (8.64) ab |
| **24SCC** | 113.0 (30.7) a | 0.46 (0.05) ab | 0.59 (0.04) a | 51.43 (14.87) a | 30.34 (9.99) a |
| **43SCC** | 66.0 (21.6) cde | 0.49 (0.06) a | 0.53 (0.03) a | 32.03 (10.47) cd | 16.99 (5.99) de |
| **62SCC** | 48.9 11.4) ef | 0.43 (0.04) bc | 0.57 (0.03) a | 20.54 (3.40) ef | 11.72 (2.30) ef |
| **110°C** | | | | | |
| **CC** | 84.5 (29.1) bc | 0.45 (0.03) ab | 0.60 (0.05) a | 38.22 (15.06) bc | 22.96 (9.37) bc |
| **24SCC** | 78.5 (21.5) cd | 0.45 (0.08) ab | 0.60 (0.05) a | 36.14 (14.34) c | 22.01 (9.95) bcd |
| **43SCC** | 61.7 (13.5) def | 0.43 (0.04) bc | 0.58 (0.04) a | 26.69 (7.25) de | 15.45 (4.18) e |
| **62SCC** | 65.3 (15.9) cde | 0.43 (0.06) bc | 0.61 (0.02) a | 28.77 (10.60) cde | 17.46 (6.27) cde |

***Table A/ 3.***

*Meat cooking results at the different temperatures and hygrometric conditions: external surface and centrals section colour parameters. Differences (Δ) are between cooked and uncooked samples. Numbers in parenthesis are the standard deviation of the mean (+/-). n=32. Means with the same letter are not significantly different (p<0.05).*

| Treatment | Surface | | | |
|---|---|---|---|---|
| | **Δ E** | **Δ L*** | **Δ a*** | **Δb*** |
| **100℃** | | | | |
| **CC** | 24.4 (3.3) c | 17.7 (4.3) c | 6.6 (1.8) a | 15.0 (2.3) a |
| **24SCC** | 22.0 (5.0) c | 17.7 (6.7) c | 4.7 (1.8) b | 11.2 (2.0) b |
| **43SCC** | 29.8 (2.6) b | 27.7 (2.7) b | 1.9 (0.6) c | 10.4 (1.8) b |
| **62SCC** | 33.3 (2.6) a | 31.5 (2.8) a | 1.3 (0.6) c | 10.6 (1.4) b |
| **110℃** | | | | |
| **CC** | 24.4 (2.9) c | 18.3 (3.5) c | 6.6 (1.6) a | 14.3 (2.5) a |
| **24SCC** | 32.1 (3.0) ab | 30.2 (3.4) ab | 1.9 (0.9) c | 10.5 (1.3) b |
| **43SCC** | 31.4 (3.3) ab | 29.6 (3.5) ab | 1.9 (0.8) c | 10.1 (1.6) b |
| **62SCC** | 32.8 (3.9) a | 30.8 (4.0) ab | 1.7 (0.9) c | 11.1 (1.7) b |

| Treatment | Central section | | | |
|---|---|---|---|---|
| | **Δ E** | **Δ L*** | **Δ a*** | **Δb*** |
| **100℃** | | | | |
| **CC** | 36.3 (2.1) a | 35.0 (2.2) a | 1.6 (0.5) ab | 9.3 (1.0) ab |
| **24SCC** | 32.8 (2.1) de | 31.9 (2.0) bc | 1.9 (0.6) a | 7.4 (1.1) d |
| **43SCC** | 31.9 (1.8) e | 30.9 (1.8) c | 1.4 (0.5) b | 7.7 (1.0) d |
| **62SCC** | 33.5 (2.8) cd | 32.0 (3.1) bc | 1.4 (0.6) b | 9.8 (1.6) a |
| **110℃** | | | | |
| **CC** | 34.1 (2.0) bc | 32.8 (2.1) b | 1.6 (0.5) b | 9.1 (1.2) b |
| **24SCC** | 35.2 (2.3) ab | 34.1 (2.4) a | 1.4 (0.6) b | 8.4 (1.3) c |
| **43SCC** | 35.7 (3.2) a | 34.5 (3.2) a | 0.9 (0.6) c | 9.1 (1.4) b |
| **62SCC** | 35.7 (3.1) a | 34.3 (3.1) a | 1.4 (0.5) b | 9.4 (1.4) ab |

# Section B1

## EFFECT OF DIFFERENT AIR/STEAM CONVECTION COOKING METHODS ON TURKEY BREAST MEAT. PART 1. INSTRUMENTAL QUALITY AND SENSORY PROPERTIES.

*B. Mora, E. Curti, E.Vittadini, D. Barbanti*

### 1. Abstract

Turkey breast samples were cooked using a forced convection oven at three relative humidity levels (RH= 8, 35 and 88%) at the same temperature (100°C). Cooking temperatures, cook value, yield, texture, colour and sensory properties of cooked turkey samples were evaluated.

The application of different RH levels resulted in different cooking performances and cooked meat quality. Longitudinal shrinkage was proportional to the heating rate with significant differences among treatments. Low steam cooking conditions (RH=35%) significantly increased cooking yield (7% higher than the high steam cooking) and had a positive effect on perceived tenderness, as shown by sensory analysis, where steam cooked samples were recognized to be more tender.

Low steam cooking resulted in a higher quality cooked turkey breast meat and in a reduced water consumption, making this process an attractive cooking method as compared to high steam.

### 2. Aim of the Work

The objective of this study was therefore to evaluate the effect of different cooking treatments on turkey meat, comparing forced convection oven cooking (dry air, RH= 8%), low steam (RH= 35%) and high steam (RH= 88%) oven cooking at the same temperature (100°C). In particular the effect of the two steam cooking conditions was evaluated in relation to cooking rate, cooking yield, surface temperature, meat texture, colour and sensory properties of the final product.

### 3. Materials and Methods

#### *3.1 Sample Preparation*

Samples of turkey breast were obtained as reported in the section *Set up of the experimental trials*.

All the experiments have required a total of 36 turkey breast samples (3x3x6 cm).

### *3.2 Cooking treatments*

Turkey breast samples were cooked at 100°C under forced air circulation with three different cooking conditions:

- dry air RH=8% – No Steam injection; NS,
- moist air RH=35%+/-5% - Low Steam injection; LS,
- moist air RH=88%+/-5% (the saturation condition) - High Steam injection; HS.

The procedure of the cooking treatment and the water consumption determination were already described in the section *Set up of the experimental trials*.

Temperature of each turkey breast sample was recorded during cooking using wire thermocouples (type K, Ni/Al–Ni/Cr) which were placed on the surface and at the geometric centre of each sample.

Sample *cooking rate* was calculated (both for surface and centre positions) as the ratio between temperature gradient and time variation (°C/min).

The degree of cooking in the centre and on the surface of each sample was expressed in terms of cook value, considering only the heating phase (*Poon, Durance, & Kitts, 2001*). The cook value was calculated by integrating the heat penetration curve in the centre and on the surface of meat samples, as previously reported (*Holdsworth, 1985; Vittadini, Rinaldi, Chiavaro, Barbanti, & Massini,, 2005*).

### *3.3 Physical Analyses*

- *Cooking yield* determination as reported by *Vittadini et al. (2005*).

- *Objective texture* measurement with the shear force test. Fresh and cooked meat samples (n = 8) were cut perpendicularly to muscle fibres with a test speed of 2 mm/s. Shear (maximum) force and the work after the maximum force were obtained. The shear force (N) was then normalized to the shear surface ($N/m^2$) and the work after the maximum force (J) to the shear section ($J/m^2$).

- *Shrinkage* characterization as the ratio (dimensionless) between raw (i) and cooked value (f) of the length (Lf/Li), width (Wf/Wi) height (Hf/Hi) and the total volume (Vf/Vi) of each sample.

- *Colour* of fresh and cooked samples was measured and colour data were processed both using the *colour scale L*a*b** and the analysis of the *VIS reflection spectra.*

The detailed procedures of the analysis were reported in the section *Methods of analysis*.

### *3.4 Sensory analysis*

The sensory analysis are described in the section *Methods of analysis*.

### *3.5 Statistical analysis*

In addition to the statistical analysis described in the section *Methods of analysis* in this section were also applied other tests listed below.

A paired sample student t-test was used to identify differences between the surface and centre positions for cooking rate and cook values of samples that underwent the same cooking process. Similarly the differences between the two steam cooking processes (LS and HS) for cooking time and cook values of samples at the same position (surface and centre) were evaluated with an independent t- test.

## 4. Results and discussion

### *4.1 Cooking treatments*

#### *4.1.1 Water consumption*

Water consumption data are shown in *Table B1/ 1*. In our cooking equipment the water quantity used to produce steam in LS cooking was approximately half of that necessary in HS cooking. Hence, the application of LS cooking implies a significant water saving compared to the saturation condition (HS cooking), that is currently the most applied industrial steam cooking processes.

#### *4.1.2 Cooking rates and temperatures*

Cooking times and the average cooking rates of surface and centre of all samples (NS, LS and HS) are shown in *Table B1/ 1*.

The injection of steam (LS and HS) significantly reduced the cooking time as compared to NS, as expected (*Gardes, Burg, & Fraile, 1995; Murphy, Johnson, Duncan, Clausen, Davis & March, 2001, Vittadini et al. 2005*). Low and high steam cooking (LS and HS) had cooking times 6 and 12-fold lower than no steam cooking respectively: HS resulted in the fastest cooking with a 50% time reduction as compared to HS (10 minutes v.s. 20 minutes).

Heat flux increased as the RH increased as previously reported (*Murphy et al., 2001*). The increase in the heat flux in steam cooking was due to the higher convective heat transfer coefficient of moist air ($h = 10^4$-$10^5$ W/m$^2$K) as compared to dry air ($h = 10^2$ W/m$^2$K) (*Datta, 2002*) and to the condensation of steam on the meat surface in the steam cooking treatments (steam latent heat of condensation ~ 2260kJ/kg) (*Roos, 1992*).

It is important to highlight that the low steam injection (LS) drastically increased the sample heating rate as compared to NS. Both surface and centre average cooking rates were 5-fold faster with increasing RH of the oven air from 8% (NS) to 35% (LS). The rise

in RH from 8 to 88% increased the average cooking rate 12- fold in the centre and 16-fold on the sample surface.

Surface temperature progressively rose in NS samples during the entire cooking time causing surface dehydration, while in LS and HS the surface remained always wet and the temperature asymptotically tended to a constant value equal to the wet bulb temperature, that is a function of the air thermo-hygrometric conditions (*Bengtsson, Jakobsson, & Dagerskog, 1976, Fellows, 2000*).

The different cooking conditions induced different meat heating rates and consequently different final surface temperatures. The surface temperature reached a significantly higher temperature in HS samples (97.7 ± 2.3 °C) as compared to LS (75.7 ± 0.3 °C) and NS samples (79.1 ± 0.2 °C).

*4.1.3 Cook value*

Cook values of the surface and the centre were calculated for all samples and are reported in *Table B1/ 1*.

In all treatments surface cook value was higher than the centre value, as expected.

Cook values (surface and centre ) of NS samples were about 4-fold higher than steam cooked samples (LS and HS). In particular the cooking value of the surface of NS was higher than the limit of thermal damage of 13 minutes at 100°C, defined as the time necessary to reduce thiamine content by 3% (*Pompei, 2009*), suggesting a higher reduction of the nutritional quality of NS sample as compared to the steam cooked samples LS and HS.

Surface cook values were not significantly different between LS and HS, while centre cook value of HS samples was significantly lower than LS. A lower cook value difference between the surface and the centre might be associated to a more uniform heating: the difference between surface and centre cook values was smaller in LS cooking, followed by HS and NS respectively.

### *4.2 Physical analyses*

*4.2.1 Cooking yield*

Cooking yield of all samples are shown in *Table B1/ 1*. Meat samples cooked with low steam (LS) showed the highest cooking yield, 7% higher than HS. The NS samples, instead, showed the lowest cooking yield as compared to the other samples. These samples (NS) were characterized by a higher surface dehydration that was induced both by the higher vapour pressure gradient between the product and the air and by the longer cooking time. Meat surface dehydration led to the development of an uniform crust and to non-enzymatic browning in NS samples.

A lower cooking yield had been hypothesized in LS samples than in HS samples, due to the higher gradient of water vapour pressure between the product and the low moist air of the oven, but opposite results were observed. A higher cooking yield was observed in LS samples as compared to HS. This phenomenon could be related to the lower longitudinal shrinkage observed in LS samples. This hypothesis is consistent with some previous studies (*Cross, Stanfield, & Koch, 1976; King, Dikeman, Wheeler, Kastner, & Koohmaraie, 2003*), that reported that faster heating rates resulted in a lower cooking yield. The distance between proteins became smaller with increasing cooking rates and a higher amount of water was expelled from the meat.

*Davey & Gilbert (1974)* found that the temperature at which cooking yield decreased in meat corresponded to the temperature at which isolated collagen shrunk. It may be therefore reasonably concluded that the differences in cooking yield values observed in our study could be due to a difference in the force generated by the collagen shrinkage on the myofibrils. The collagen shrinkage before its solubilization may have been not severe enough in the slow-cooked meat (LS) to generate a force able to expel water (*King et al., 2003*).

Moreover HS collagen could have undergone a more severe coagulation/dehydration due to the protein unfolding and refolding into a more compact matrix as indicated by the cooking rate and the cook values.

*4.2.2 Shrinkage*

Shrinkage measurements of cooked turkey meat samples referred to volume (Vf/Vi), length (Lf/Li), width (Wf/Wi) and height (Hf/Hi) are shown in *Figure B1/ 1*.

The total volume reduction of cooked turkey meat samples (Vf/Vi) was not significantly different among the three treatments. An anisotropic volume reduction of meat was observed, evaluating separately the contribution of each dimension to overall shrinkage, as previously reported (*Wang, Ngadi, & Adedeji, 2010*). The shrinkage in meat is known to depend on temperature history (*Fowler, & Bejan, 1991*) and on the denaturation of proteins, that occurs over a large range of temperature (37–75°C), inducing transversal and longitudinal shrinkage of muscle fibres and connective tissue shrinkage (*Barbera, & Tassone, 2006*). Longitudinal shrinkage of fibres (Lf/Li) was proportional to the cooking rate with significant differences among the treatments.

The fastest cooked samples (HS) showed the highest reduction in the sarcomere length, as already found by *King et al. (2003),* whereas LS and NS samples showed an intermediate reduction as compared to HS samples. These results could be due to the higher surface temperature reached in HS samples (~100°C) than LS (~76°C) and NS (~80°C) samples; the connective tissue network and the muscle fibres cooperatively

shrank longitudinally at 60–70°C and the extent of shrinkage increased with temperature. The larger the shrinkage, the greater the water loss during cooking. It is therefore hypothesized that water may be expelled by the pressure exerted by the shrinking connective tissue on the aqueous solution in the extracellular void (*Tornberg, 2005*).

Transverse shrinkage to the fibre axis was represented by Wf/Wi and Hf/Hi. A significantly higher height reduction (lower Hf/Hi) was observed in NS (slowest cooking process) than in steam cooked samples (LS, HS). These results could be due to the longer time that NS samples were subjected to 40–60°C temperature range as compared to the steam cooked samples. The transverse shrinkage of the fibre axis mainly occurs in this temperature range, widening the gap already existing between the fibres and their surrounding endomysium at rigor (*Tornberg, 2005*). However a different behaviour was observed in the transverse shrinkage of the width dimension: no difference were found among NS, LS and HS meat samples. Moreover the shrinkage of the width dimension was reduced: although the mean Wf/Wi values for each treatment were lower than 1, Wf/Wi data often resulted higher than 1 for cooked samples, showing the same tendency reported in other works, where meat could shrink in two dimensions and expands in the third dimension (*Offer, Restall, & Trinck, 1984; Rowe, 1974*). The difference in the transverse shrinkage relative to width and height dimensions is possibly due to the action of the force of gravity, that may have enhanced the shrinkage of the height dimension at the expense of the width dimension.

*4.2.3 Texture*

Shear force tests results are reported in *Figure B1/ 2*. Shear force is indicative of the sample surface consistency while the area under the texturogram after the maximum force (work) is indicative of texture properties of the meat inner portion of the sample.

The NS samples were found to require a significantly higher shear force and work after the maximum force than the steam cooked samples (LS and HS). It was due to the surface crust formation and the higher centre dehydration that the samples underwent during cooking.

No significant differences were found between LS and HS texture parameters. This result is in contrast with other studies where slower cooking rates were reported to improve tenderness (*Bayne, Meyer, & Cole, 1969; Cross et al., 1976; Lawrence, King, Obuz, Yancey, & Dikeman, 2001*), but it must be taken into consideration that no steam was used during the cooking process in these studies. Higher heating rates determine protein unfolding immediately followed by the simultaneous aggregation of collagen and actomyosin, resulting in meat with leathery consistency, as previously reported by differential scanning calorimetry studies (*Riva & Schiraldi, 1994*). The tenderizing effect of

slow cooking is also commonly attributed to the solubilization of collagen (*Bayne et al., 1969; Penfield & Meyer, 1975*), that mainly takes place in the 60-80°C temperature range (*Møller, 1981*). In slow cooking treatments (NS and LS) the time at which meat was subjected to this temperature range was longer. Moreover connective tissue content is related to the differences observed in tenderness, as previous works on beef meat reported; texture of muscles with a low collagen content was not influenced by different cooking rates (*King et al., 2003*) and a similar behaviour could be hypothesized for turkey meat.

*4.2.4 Colour*

The major colour change due to cooking is the discoloration of meat, from red/pink to greyish/brown colour due to complex reactions such as denaturation of myoglobin, Maillard browning and formation of denatured globin nicotinamide hemichromes. (*Swatland, 1989*).

A strongly visible surface colour difference was observed between NS and steam cooked samples (LS-HS) due to the non-enzymatic browning (Maillard reaction) that occurred on the surface of NS samples. These were characterized by higher a* and b* values (red and yellow, respectively) and lower L* values (brightness) due to the minor surface water content (data not shown).

In the centre NS samples differed from other samples only for lower b* and C* values.

LS and HS samples were not significantly different between each other for all colour parameters (L*, a*, b*, C* and h*). The only significant differences were found between the surface and the centre of cooked meat in all treatments (data not shown).

The changes in the appearance of meat due to the heating processes were thoroughly studied by visible spectroscopy analysis. The spectral features in the visible region allowed us to observe colour changes during the cooking of meat due to the myoglobin protein degradation by oxygenation, oxidation and reduction reactions, thus influencing the appearance of meat colour. Representative VIS spectra of the surface and the centre of raw and cooked samples are shown in *Figure B1/ 3*. Three well-defined chromophores at 420, 550 and 580nm were identified in all samples. The first one was previously associated to deoxymyoglobin (DeoxyMb) (purplish-red), while the others to oxymyoglobin (OxyMb) (cherry-red); moreover the band at 485nm was attributed to the metmyoglobin (MetMb) (brownish-red) reflectance (*Liu & Chen, 2001*). Only in cooked samples a fourth chromophore at 650nm was observed corresponding to sulfmyoglobin (green) (*Liu & Chen, 2001*).

The surface of NS samples was characterized by a lower decrease of DeoxyMb, MetMb and OxyMb peaks intensity; it was also hypothesized that this result might not be due to these species but to the presence of non-enzymatic browning reaction products.
The samples cooked with a low steam presence (LS) showed a lower decrease of DeoxyMb and OxyMb peak intensity with a higher difference from the other samples especially in the centres in correspondence to DeoxyMb wavelength. A lower loss of reddishness was observed in LS samples, that were characterized by a more pink colour. The normally expected colour for cooked poultry breast meat is grayish brown; therefore, the pink colour observed in LS samples might be considered a defect because consumers could think that meat is undercooked or contaminated (*Nam & Ahn, 2002*).
The pinker colour observed in LS samples was not expected, due to their higher internal cook value as compared to HS samples, in contrast with the results of *Ryan Seyfert, Hunt, & Mancini (2006)* on beef meat. The pinker colour of LS samples could be due to the incomplete denaturation of myoglobin or oxymyoglobin and/or to the reactivity of endogenous meat compounds with the production of denaturated globin hemochromes characterized by many authors as pinking pigments of well cooked meats (*Holownia, Chinnan, & Reynolds, 2003*).

### *4.3 Sensory analysis*

A ranking test was carried out to assess the overall liking for aspect and flavour (taste and oral texture) of the NS, LS and HS samples. The rank sums were 17 for NS, 22 for LS and 21 for HS for aspect and 21 for NS, 18 for LS and 21 for HS for flavour. All these values fell within the 15-25 range (*Jellineck, 1985*) and therefore, samples were equally liked by the panel ($p < 0.05$). The differences between LS and HS were further investigated with a triangle test. The sample NS was not considered because of its roasted appearance. The samples LS and HS were compared for aspect and tenderness (by handling) and the different sample was recognized by 6 out of 9 subjects, indicating a significant difference ($p < 0.05$) between the two steam cooked samples (*Jellineck, 1985*).
A second ranking test was performed with 20 subjects to assess the overall liking for aspect and flavour of LS and HS samples. The rank sums were 29 and 31 for LS and HS respectively for both the aspect and the flavour. The values fell within the 26-34 range (*Jellineck, 1985*) and therefore, samples were equally liked by the panel ($p < 0.05$). The samples cooked with low steam (LS ) were expected to be the less liked when compared to HS for their more pink colour but the ranking test did not indicate any preferred sample between LS and HS for aspect and flavour. Moreover the scored preferences were equally distributed between the two samples, that were, therefore, considered equally appreciated.

A paired-comparison consumer tests (two sided) using 17 subjects was carried out to asses which sample was more tender, LS or HS. The majority of consumers (13 out of 17) identified LS samples to be more tender ($p < 0.05$) than HS samples (*Jellineck, 1985*). It is noteworthy to mention that samples with similar shear force values were perceived significantly different in terms of tenderness. This result could be explained by the fact that tenderness is a very complex perception that originates from several factors and it is strongly affected by the moisture content. Water can have a plasticizing/lubricant effect that increases the perception of tenderness. The samples LS had the highest cooking yield (i.e. highest moisture content) and were perceived to be the most tender.

**5. Conclusions**

The different heating conditions (dry air, low moist air, high moist air) at the same cooking temperature (100°C) led to strongly different heating rate profiles and consequently to different properties of cooked turkey breast.

The presence of steam drastically reduced cooking time, in agreement with previous studies. Dry air cooking showed the highest cooking time compared to the other treatments and the relative samples resulted parched, with an uniform crust formation and a non-enzymatic browning (Maillard reaction). The heat flux and heat transfer coefficient increased with increasing RH.

The most visible change in sample structure was observed in the longitudinal shrinkage, that was proportional to the cooking rate with significant differences among treatments.

Low steam cooked samples were significantly different from high steam samples, showing a higher cooking yield and a higher perceived tenderness, probably due to a lower meat longitudinal shrinkage that led to lower water loss upon cooking.

Low steam cooking resulted in a pinker colour of samples, but the difference did not affect the product acceptance for the aspect; these samples were appreciated equally in comparison to the high steam cooked ones.

Low steam cooking could be considered as a valid alternative to steam saturation cooking, especially in industrial applications, due to the appreciable quality of turkey meat and the markedly reduced water consumption.

## 6. List of Figures

***Figure B1/ 1.*** *Shrinkage of cooked turkey meat.*

*Total volume (Vf/Vi), length (Lf/Li), width (Wf/Wi) and height (Hf/Hi) of NS, LS and HS samples. Shrinkage values (n=12) are expressed as means±S.D.; means with the same letter are not significantly different (p<0.05).*

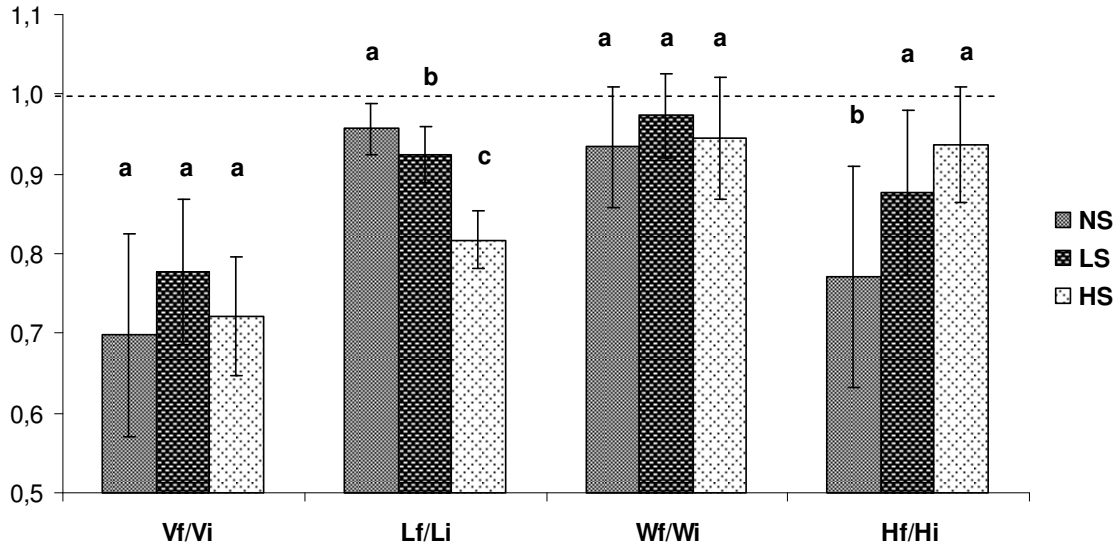


***Figure B1/ 2.*** *Texture of turkey meat.*

*Warner–Bratzler shear force values (A) and work after the maximum force (B), raw meat (R) and cooked meat samples (NS, LS and HS). Values are expressed as means±S.D. (n=8); means with the same letter are not significantly different (p<0.05).*

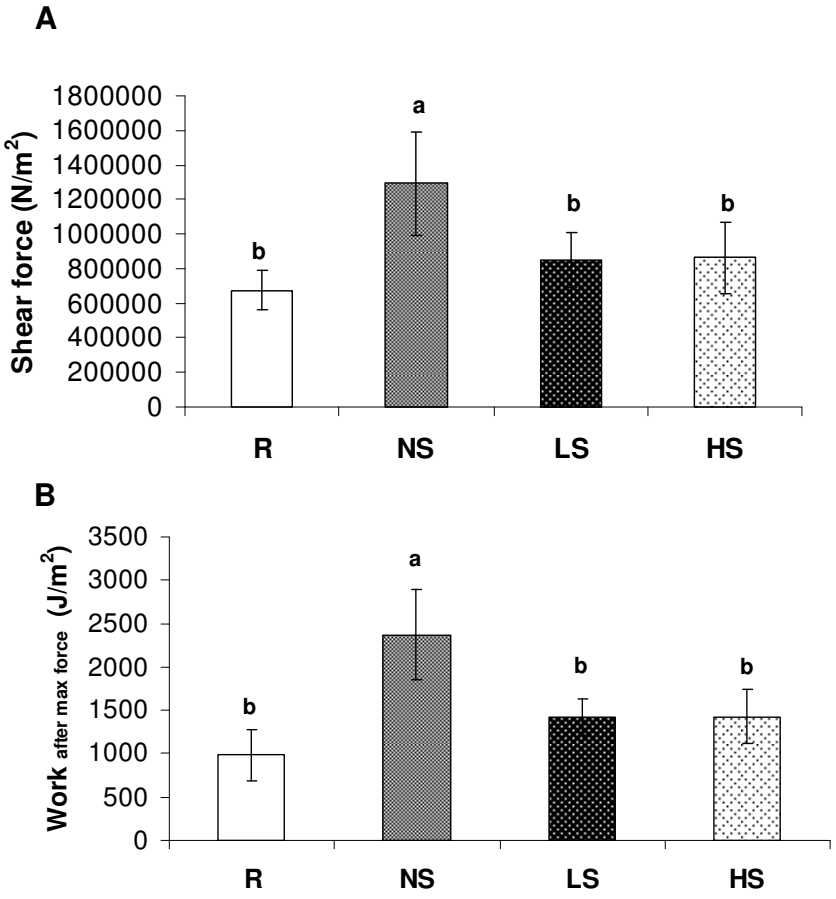
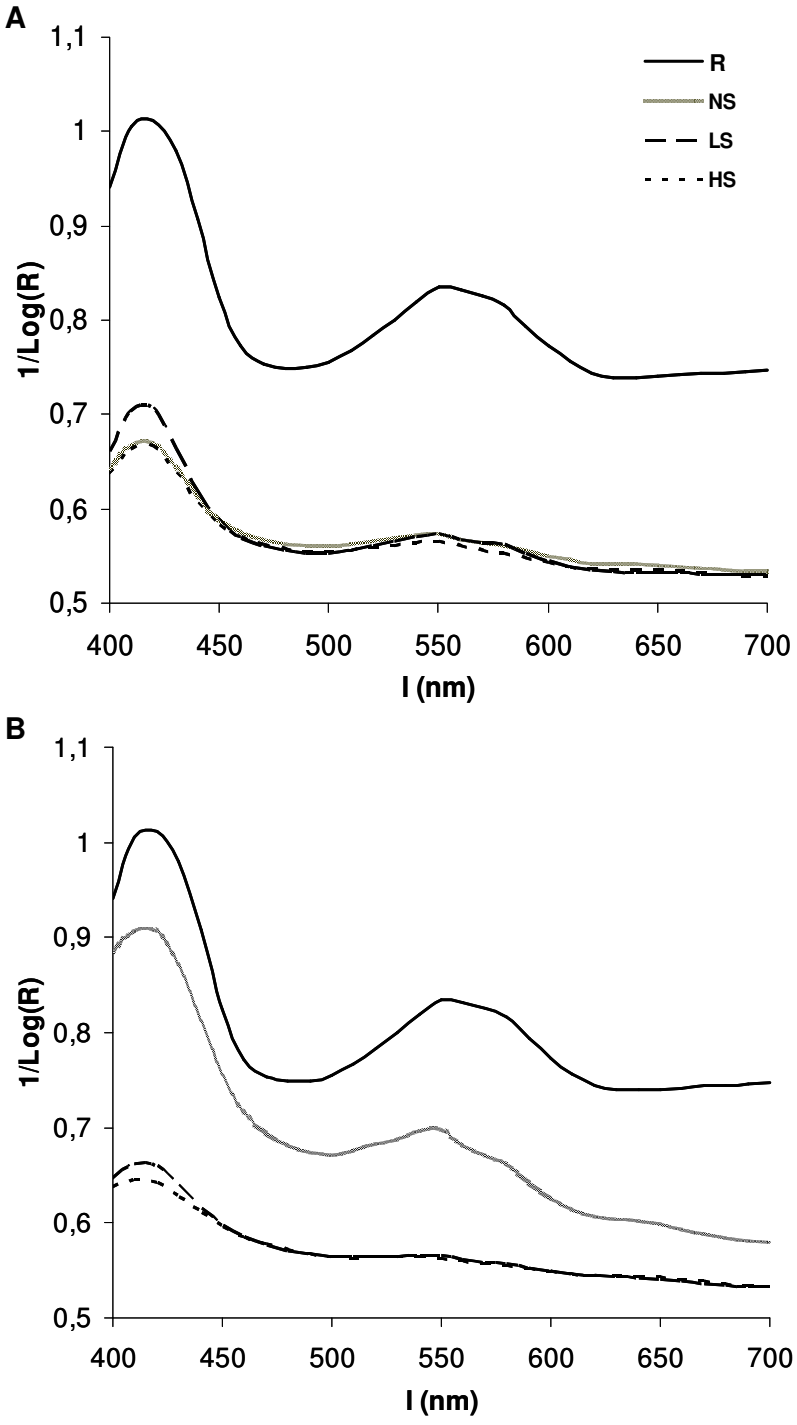


***Figure B1/ 3.*** *Turkey meat colour: VIS spectra.*

*Representative VIS spectra (400<λ<700nm) (n=32) of the external (A) and the central parts (B) of raw (R) and cooked samples (NS, LS and HS).*



## 7. List of Tables

***Table B1/ 1.*** *Turkey meat cooking performance parameters of NS, LS and HS: water consumption for the steam generation (g), cooking time (min), cooking rate (°C/min) and cook values (equivalent min at 100°C, z=33) of surface and centre positions and cooking yield (%).*

| Treatment | | NS | LS | HS |
|---|---|---|---|---|
| **Water consumption (g)** | | absent | 423,5 (54,4)[A] b[B] | 715,7 (112,5) a |
| **Cooking time (min)** | | 119,3 (18,1) a | 24,0 (2,5) b * | 10,4 (0.9) b |
| **Cooking rate (°C/min)** | ***Surface*** | 0,5 (0,1) c | 2,4 (0,2) b | 7,8 (0,7) a # |
| | ***Center*** | 0,5 (0,1) c | 2,5 (0,2) b | 5,9 (0,6) a |
| **Cook values (min)** | ***Surface*** | 13,9 (2,2) a # | 2,8 (0,2) b # | 3,5 (0,7) b # |
| | ***Center*** | 9,5 (2,3) a | 1,7 (0,1) b * | 0,4 (0,1) b |
| **Cooking yield (%)** | | 67,8 (3,0) c | 84,1 (1,3) a | 77,2 (3,1) b |

[A] *Numbers in parenthesis are the standard deviation (+/-) of the mean, n=3 for all parameters reported, except cooking yield where n=12*

[B] *Means with the same letter are not significantly different with ANOVA, Tukey-high significant difference test (p<0.05)*

# Significant difference with paired samples student t-test ($p < 0.05$) between surface and centre of samples of the same cooking process

* Significant difference with independent student t-test ($p < 0.05$) between LS and HS samples in the same position

# Section B2

## EFFECT OF DIFFERENT AIR/STEAM CONVECTION COOKING METHODS ON TURKEY BREAST MEAT. PART 2. WATER STATUS

*E. Curti, B. Mora, D. Barbanti, E.Vittadini*

### 1. Abstract

Cooking turkey meat at 100°C by forced convection with low steam air (relative humidity, RH=35%) resulted in interesting quality attributes as compared to forced convection oven with dry (RH=8%) and high steam (RH=88%) air. Quality attributes of cooked meat are related to water status; consequently, moisture content, water holding capacity (WHC) and NMR water mobility were investigated in low steam, high steam and dry air cooked samples.

Low steam cooked samples showed a higher moisture content and higher WHC. Low and high steam cooked samples showed an overall higher water mobility (slower $^1H$ FID decays, $^1H$ $T_2$ distributed data extended to higher relaxation times and higher $^1H$ $T_1$ relaxation times) as compared to the dry air samples. In particular, $^1H$ $T_2$ distribution data in low steam samples (reduced presence of protons relaxing at times longer than 1 s) were related to the higher perceived tenderness.

### 2. Aim of the work

In the preceding section (*Section B1*) the effect of different heating/cooking conditions (dry air, low steam, high steam) at the same cooking temperature (100°C) on turkey meat has been evaluated: low steam cooking (low cooking rate) resulted in samples with a higher cooking yield and a higher perceived tenderness as compared to high steam cooking. The different properties of low steam cooked meat were associated to a lower water loss upon low steam cooking related to a different protein denaturation and to the lower longitudinal shrinkage of these samples.

The present work was undertaken to study how water and proton mobility of turkey meat samples were affected by forced convection oven cooking (dry air, RH= 8%), low steam oven cooking (RH= 35%) and high steam oven cooking (RH= 88%), close to the saturation condition at the same temperature (100°C).

The presence of steam is expected to strongly affect water status and its interactions with protein in cooked meat. The external and internal positions of samples were investigated

to understand how water distributes across the sample. Turkey samples were analyzed in the NMR spectrometer after the cooking process, to consider the water loss and the changes the samples underwent in the oven environment that would not be taken into account in in-tube NMR cooking. Moreover, $^{1}$H NMR was carried out on the samples after they were subjected to centrifugation to better investigate water interactions in the cooked meat matrix.

## 3. Materials and Methods

### *3.1 Muscle preparation and cooking treatments*

Details about samples preparation and cooking treatments were thoroughly described in the section *Set up of the experimental trials*. Briefly, samples were cooked at 100°C, under forced air circulation, according to the following cooking conditions:

- dry air RH=8% – No Steam injection; NS,
- moist air RH=35% - Low Steam injection; LS,
- moist air RH=88% (the saturation condition) - High Steam injection; HS.

The central section (2x3x3 cm) of the sample was identified. From this, two samples (0.8x0.8x2 cm) were extracted (with the major dimension parallel to muscle fibres) from either the external part (EXT) and the internal part (INT) of the sample and separately analyzed.

### *3.2 Analysis of the water properties of cooked meat products*

The analysis performed on turkey meat to characterized the water status were: *moisture content*, *water holding capacity* through the centrifugation method and *low resolution nuclear magnetic resonance ($^{1}$H NMR).* The procedures of the analysis were described in the section *Methods of analysis*.

### *3.3 Statistical analysis*

In addition to the One-way-analysis of variance (ANOVA), reported in *Methods of analysis,* in this section data were also analyzed with a Student t-test ($p < 0.05$) to identify differences between EXT and INT of each cooked sample**.**

## 4. Results and Discussion

### *4.1 Moisture content*

Moisture content of all turkey samples are shown in *Figure B2/ 1*. Raw turkey meat had a moisture content of ~ 74% (g $H_2O$ / 100 g sample). Cooking significantly decreased

moisture content of samples, as expected, from ~ 74% to ~ 68% (g $H_2O$ / 100 g sample). Moisture content of cooked samples was found to be dependent on the cooking process (*Figure B2/ 1*). The cooking length was reduced in steam cooking processes as previously reported (*Section B1*), resulting in a higher moisture content of the steam cooked samples LS and HS (both EXT and INT). The significantly lower moisture content observed in NS (both EXT and INT) was linked to longer cooking time needed for turkey samples to reach the selected temperature (74°C at their thermal centre) as previously reported in *Section B1*.

The different cooking conditions affected water distribution across the sample: moisture contents of EXT and INT in NS and LS samples were found to be significantly different between each other (*Figure B2/ 1*).

Low steam cooking (LS) resulted in a higher water retention (higher moisture content) than HS, both EXT and INT. This result was not expected as the water pressure gradient between meat surface and oven air was higher in LS cooking, probably indicating that water evaporation from turkey meat is not the sole effect contributing to water loss during cooking. Previous studies reported that the cooking profiles and longitudinal shrinkage of muscle fibres could affect water loss (*Bouton, Harris, & Shorthose, 1975*). In *Section B1* a lower longitudinal shrinkage was observed in low steam cooked samples (LS), characterized by a lower heating rate, that resulted in a lower release of water from the myofibrils, in agreement with some previous studies (*Cross, Stanfield, & Koch, 1976; King, Dikeman, Wheeler, Kastner, & Koohmaraie, 2003*). Moreover, the similar moisture distribution in HS (comparable moisture content between EXT and INT) could be probably associated to the higher longitudinal shrinkage of HS samples (*Section B1*).

### *4.2 Water holding capacity (WHC)*

WHC of turkey meat was measured for RAW and cooked samples and it is shown in *Figure B2/ 2*. WHC was ~ 76% (g of lost water / 100 g water in raw samples) in RAW and it was almost halved in cooked samples due to the structural changes that decrease both the moisture content and the water-holding capacity of meat (*Offer, 1984; Tornberg, 2005*).

WHC of EXT was not affected by the different cooking condition as WHC were comparable in all EXT samples while WHC of INT was significantly higher in LS.

In this work WHC was measured as the quantity of extra-myofibrillar water that can be expelled from the meat matrix by means of centrifugation and the results were in agreement with a previous study on pork meat where the presence of steam significantly affected WHC (*Chiavaro, Rinaldi, Vittadini, & Barbanti, 2009*).

WHC results have been also related to the instrumental quality attributes of the samples (cooking heating rate, cook value, yield, shrinkage, shear force value, perceived tenderness) that were discussed in *Section B1*.

In our study the higher WHC observed in INT of LS, as compared to HS, could be attributed to the lower longitudinal shrinkage of LS in agreement with *Offer (1984)* and *Tornberg (2005)*. Moreover, WHC is strongly dependent on how proteins are denaturated during cooking (*Bertram, Wu, Straadt Aagard, & Aasling, 2006*), and hence, it has been hypothesised that protein denaturation was affected by the different heating rates in LS and HS cooking processes (average cooking rate of ~2.5°C/min and ~ 7°C/min respectively). WHC results have been related to the instrumental quality attributes of the samples, that were discussed in *Section B1*.

However NS samples, that were characterized by a higher cooking loss as compared to HS, as discussed in the preceding paper, showed WHC values comparable to HS. WHC values in NS samples may be attributed to a higher denaturation of sarcoplasmic proteins, due to their higher cook value and the lower cooking yield, that was previously associated to a decrease in WHC (*Monin, & Laborde, 1985*). The lower values of WHC observed in HS samples, as compared to LS samples, could be due to the higher longitudinal shrinkage of HS samples that promoted the loss of water retained in the spaces between the thick and thin filaments (*Offer et al., 1989*). WHC is also related to the eating quality (texture/tenderness and juiciness) of meat: LS samples, showing higher values of WHC, were, in fact, recognized significantly tenderer than HS by a semi-trained panel even though they had the same shear force value. WHC of INT and EXT did not result significantly different between each other only in LS samples, in agreement to the more uniform heating and smaller cooking value difference between the surface and the centre observed in this cooking method evidenced in *Section B1* results.

### *4.3 $^{1}$H NMR mobility*

Molecular characterization was carried out with multiple $^{1}$H NMR experiments to cover a large range of molecular relaxation events. $^{1}$H mobility was studied at 20 MHz, for the fastest-relaxing component with a FID experiment while the slower relaxing proton fractions were characterized in terms of $^{1}$H $T_2$ and $^{1}$H $T_1$ relaxation times distributions.

$^{1}$H FID decays of RAW and cooked samples (NS, LS and HS) of EXT and INT are shown in *Figure B2/ 3A and Figure B2/ 3B* respectively. The first, fast relaxing portion of the FID decay ($0.0073 < t < 0.1000$ ms) is indicative of the presence of a very rigid $^{1}$H population. $^{1}$H FID decay of RAW was slower than all cooked samples, both EXT and INT, as expected, indicating a higher molecular mobility due to a significantly higher water content (*Sereno, Hill, Mitchell, Scharf, & Farhat, 2007*). The water loss due to cooking significantly

affected $^1$H FID decays. $^1$H FID were sharper in all cooked samples, more relevantly in EXT, that underwent more drastic changes during cooking as compared to the INT positions. $^1$H FID decays in NS, both EXT and INT, were sharper than LS and HS, as expected, due to the lower moisture content related to the major increase of cooking time in absence of steam.

$^1$H FID decays (t < 0.1 ms) were then fitted (*Kim, & Cormillon, 2001; Choi, & Kerr, 2003, Farhat, Blanshard, & Mitchell, 2000*) to characterize FID decay slopes and verify a correlation with the samples moisture content. All FIDs exhibited a monoexponential decay [$y= a + b * \exp(-x * c^{-1})$; $R^2 > 0.96$]. The mean coefficient *(b*), descriptive of the decay slopes, was plotted (*Figure B2/ 3C*) as a function of moisture content (g water / 100 g sample) and showed a good correlation ($R^2 > 0.9$) with the moisture content by a quadratic polynomial regression ($y = -0.0005 * x^2 + 0.0610 * x + 1.5681$), suggesting that $^1$H FID decays well reflected the differences in the moisture content of the samples and were directly related to them.

The $^1$H $T_2$ distributions, obtained using an UPEN software, were analyzed for $T_2 > 2 *$ interpulse spacing (+ instrument dead time) to avoid extrapolation of $T_2$ values at times shorter than the first point measured with the CPMG experiment. $^1$H $T_2$ quasi-continuous distributions of RAW and cooked samples, EXT and INT, are shown in *Figure B2/ 4A*. Three $^1$H $T_2$ populations were found in RAW and were named starting from the shorter to the longer relaxation time A, B and C, respectively. $^1$H populations abundance and peak relaxation times are shown in *Figure B2/ 4C*. $^1$H population abundances and relaxation times are showed only for the external position (EXT) of the samples since no significant differences were found between EXT and INT samples for all the cooking processes.

$^1$H $T_2$ populations of RAW relaxed in the ~ 0.3 - 20 ms range (peak centred at $T_{2A}$ ~0.8 ms; ~3% of the total detectable protons), in the 20-80 ms range (peak centred at $T_{2B}$ ~44 ms; ~90% of the total detectable protons) and at times longer than 80 ms (peak centred at $T_{2C}$ ~100 ms; ~7% of the total detectable protons). Similar results were previously reported in pork (*Bertram et al., 2001*) and chicken meat (*Sharifudin, Nott, & Hall, 2006*). $^1$H population A was tentatively assigned to protons associated to the water-macromolecules domain, population B to protons associated to the water - myofibrillar proteins domain and population C to the protons associated to water - sarcoplasmatic proteins domain based on the findings of low resolution $^1$H NMR studies carried out on pork and chicken meat (*Bertram, Karlsson et al., 2001; Venturi, Rocculi, Cavani, Placucci, Dalla Rosa, & Cremonini, 2007*).

The $^1$H $T_2$ distributions of RAW significantly changed upon cooking: $^1$H $T_2$ distributions of cooked samples (NS, LS and HS) showed the presence of only two resolved protons

populations. The major population (B) observed in RAW was centred at ~44 ms (~90% of the total detectable protons) and moved towards shorter relaxation times (~20 ms; ~97% of the total detectable protons); the faster relaxing population (A, centred at ~0.8 ms; ~3% of the total detectable protons) remained unchanged; the slower relaxing population (C, centred at ~100 ms ) likely merged with population B for all cooked samples. $^1$H $T_2$ distributions of LS and HS samples showed a tail at longer relaxation times up to ~ 1.2 s and ~ 2.5 s for LS and HS respectively (*Figure B2/ 4B*), that was not observable in NS.

Our results on cooked meat are in agreement with some previous works on pork meat (*Micklander Peshlov, Purslow, & Engelsen, 2002, Bertram, Wu, van den Berg et al., 2006*) that studied transversal relaxation times $T_2$ of cooked meat and the changes occurring during cooking to water and protein domains. However, *Micklander et al. (2002), Bertram et al. (2005) and Bertram, Wu, van den Berg et al. (2006)* found a resolved fourth protons population with relaxation times above 1 s that was associated to free/bulk water, expelled by the meat matrix at temperatures higher than 40°C during cooking. This $^1$H population was not detected in our $^1$H $T_2$ distributions due to the fact that the cooking process was carried out in a real oven and not in the NMR tube and, hence, meat samples were also subjected water loss.

Slower relaxing protons (t >1 s) were not observed in the $^1$H $T_2$ distributions of NS. This result may suggest that those water molecules were lost during the NS cooking process and may be related to the significant lower moisture content found in NS samples. The steam cooking processes imply different heat and mass transfers, resulting in a different denaturation process that is known to involve water re-distribution among domains characterized by different mobilities and molecular changes in the structure of meat. The different denaturation may result in an altered water distribution and mobility that is reflected in the $^1$H $T_2$ distributions: in particular the tail observed in HS, that included protons relaxing at much longer relaxation times as compared to LS, may suggest that in HS some water molecules retained a higher mobility upon cooking. In fact, HS also showed lower WHC values (*Figure B2/ 2*), as compared to LS, indicating that water molecules in this sample were less tightly associated to the meat matrix.

$^1$H NMR $T_2$ relaxation profiles have been previously related to the sensory properties of pork meat, in particular to juiciness (*Bertram et al., 2005*). $T_2$ protons relaxing at times longer than 1 s, associated to the expelled water molecules, were negatively correlated to juiciness (*Bertram et al., 2005*). In agreement with this study, HS samples, where $T_2$ protons relaxing at times longer than 1 s were detected, were also perceived as the less tender in sensory analysis as compared to LS (*Section B*).

$^1H$ $T_1$ quasi-continuous distributions of RAW and cooked samples, EXT and INT, were unimodal and representative of one observable proton population (distributions not shown). The peak relaxation times, representative of the $^1H$ $T_1$ distributions for all samples, are shown in Table 1.

$^1H$ $T_1$ relaxations times of RAW were significantly higher (~ 520 ms) than in cooked samples (~ 280-330 ms), as expected, and confirmed previous results on chicken meat (*Rongrong, & Li, 2000*).

$^1H$ $T_1$ relaxation times in LS were significantly higher (~ 328 ms) than HS (~300 ms) and NS (~280 ms) respectively, in the EXT position while no significant differences were found among the INT samples.

The statistical differences observed in the EXT $^1H$ $T_1$ values were reflected in the relative moisture content values (*Figure B2/ 1*), indicating that $^1H$ $T_1$ might be related to moisture content.

$^1H$ NMR $T_1$ experiments were previously carried out on chicken meat and $^1H$ $T_1$ was associated to an "index" of muscle structure (*Rongrong et al., 2000*). It was reported that $^1H$ $T_1$ values are affected by cooking, due to water loss and muscle shrinkage, and also by the application of an external compressive load that further reduced the cellular and extracellular spaces. It has been therefore hypothesized that the differences observed in EXT among NS, LS and HS indicated a different muscle structure in the samples, that could be related to the different cooking profiles and to the different shrinkage as previously reported in *Section B*.

### *4.4 $^1H$ NMR mobility post-centrifugation*

$^1H$ NMR post-centrifugation was carried out to investigate the effect of centrifugation drip loss on cooked meat proton mobility and also a possible effect of the cooking process on retainment of water.

$^1H$ FID decays of RAW and INT cooked samples after the centrifugation are shown in *Figure B2/ 5*. $^1H$ FID decays of samples were significantly sharper than the "not centrifuged" samples, as expected, as a consequence of the extraction of the "most mobile" water from the meat matrix.

$^1H$ FID decay of $HS_{WHC}$ was slightly less sharper than $NS_{WHC}$ and $LS_{WHC}$. This result is not in agreement with the relative WHC values previously discussed. $^1H$ FID decay slope of $HS_{WHC}$ was expected to be more similar to $NS_{WHC}$ (comparable WHC values) while $^1H$ FID decay of $LS_{WHC}$ should have been slower (higher WHC). Hence other factors could have contributed to the different decays, such as a different protein denaturation. *Riva & Schiraldi (1994)* reported that the sequence and the extent of meat protein denaturation in

the cooking process is affected by the meat heating profile: in particular water release during denaturation is strictly related to the heating rate of the cooking process.

$^1H$ $T_2$ quasi-continuous distributions of relaxation times, compared to the samples before the centrifugation (no-WHC), are shown in Figure 6A. Three $^1H$ $T_2$ populations were found in $RAW_{WHC}$, as previously observed in RAW, and were therefore named starting from the shorter to the longer relaxation time A, B and C, respectively. $^1H$ populations abundance and peak relaxation times of samples after centrifugation are shown in *Figure B2/ 6B* and *6C* respectively. $^1H$ $T_2$ distributions of $RAW_{WHC}$ showed the same lineshape of RAW but population A (faster relaxing protons) abundance was significantly higher and population C (slower relaxing protons) was significantly lower than in RAW (*Figure B2/ 4C*). $^1H$ $T_2$ relaxation times $T_{2B}$ and $T_{2C}$ were significantly reduced upon centrifugation from ~44 to ~40 ms and from ~105 to ~ 70 ms respectively.

The $^1H$ $T_2$ distributions characterized by the presence of three resolved $^1H$ populations of RAW was preserved also after the centrifugation ($RAW_{WHC}$), whereas $^1H$ $T_2$ distributions of $NS_{WHC}$, $LS_{WHC}$ and $HS_{WHC}$ were strongly different from the cooked samples before centrifugation. The $^1H$ $T_2$ slower relaxing protons observed at longer relaxation times (up to ~ 2.5 s) in LS and HS were not observable in $LS_{WHC}$ and $HS_{WHC.}$ Previous studies discussed the correlation between the more mobile $T_2$ protons and the water molecules that are lost in WHC measurements (*Tornberg, Andersson, Goransson, & von Seth., 1993, Bertram, Andersen et al., 2001*). These protons, associated to extra-myofibrillar water and to sarcoplasmatic proteins (*Bertram, Karlsson, et al., 2001*) were not observable in the $^1H$ $T_2$ distributions of $RAW_{WHC}$ (population C) and cooked samples as they were removed upon centrifugation.

The $^1H$ $T_2$ distributions of samples before and after centrifugation also had different $T_{2B}$ relaxation time: $T_{2B}$ significantly decreased and the region of the distribution characterized by relaxation times longer than ~ 30 ms was not observable, possibly because water molecules associated to the myofibrillar proteins may have been partially removed and/or became less mobile. $^1H$ $T_2$ distributions of $NS_{WHC}$, $LS_{WHC}$ and $HS_{WHC}$ had the same lineshape and the relative times $^1H$ $T_{2B}$ were comparable and not dependent on the extent of meat protein denaturation (different cooking process), possibly due to a mechanic effect of the centrifugation that may have altered the samples structure.

Moreover the faster relaxing population (A), attributed to protons associated to the water-macromolecules domain, was not observed possibly because these protons relaxed at faster relaxation times and were, therefore, not detectable in the NMR experimental window considered.

$^1H$ $T_1$ quasi-continuous distributions of RAW and cooked samples after the WHC measurements were unimodal and representative of one observable proton population

(distributions not shown). The peak relaxation times, representative of the $^1H$ $T_1$ distributions, were ~ 470 ms for $RAW_{WHC}$ and ~ 200 ms for $NS_{WHC}$, $LS_{WHC}$ and $HS_{WHC}$ (comparable among each other).

$^1H$ $T_1$ relaxations times of $RAW_{WHC}$ were significantly higher than in $NS_{WHC}$, $LS_{WHC}$ and $HS_{WHC}$, as expected. The relaxation times of all samples after the centrifugation were significantly lower than the corresponding values before the centrifugation, due to the loss of water molecules that were weakly interacting with the protein matrix. $^1H$ $T_1$ values of $NS_{WHC}$, $LS_{WHC}$ and $HS_{WHC}$ were comparable, possibly because the samples structure was strongly altered by centrifugation (mechanic - altering effect) and/or due to the fact that the samples retained water molecules, tightly associated to protein, that are not detected in the $^1H$ $T_1$ experimental time frame.

**5. Conclusions**

The present study investigated the effect of dry air, low steam and high steam oven cooking (at 100°C) on water status and distribution in turkey meat samples. Different RH in cooking affected water status in turkey meat. Steam cooked samples were characterized by a higher moisture content and a higher water mobility (slower $^1H$ FID decays, higher presence of $T_2$ protons relaxing at longer times and higher $T_1$ relaxation times). In particular, low steam cooking resulted in samples with a higher moisture content, higher WHC and a lower presence of more mobile $T_2$ protons, indicating that water was more tightly retained. Water status helped to explain the instrumental quality and sensory properties (evaluated in *Section B*) of turkey meat, mainly due to the different denaturation of protein induced by the cooking process. Moreover the higher perceived tenderness was possibly related to the lower water mobility observed in low steam cooked samples.

## 6. List of Figures

***Figure B2/ 1.*** *Moisture contents of RAW and cooked meat samples (NS, LS and HS) both EXT and INT. Average moisture contents (n=4) are expressed as means±S.D.*
*Different letters above (lower case for EXT and upper case for INT) the bars indicate significant difference among the samples ($p < 0.05$); bars with an asterisk at the same cooking condition are significantly different ($p < 0.05$).*

***Figure B2/ 2.*** *WHC values of RAW and cooked meat samples (NS, LS and HS) both EXT and INT, expressed as the percentage fraction of the total water content of fresh samples Average WHC (n=6) are expressed as means±S.D.*
*Different letters above (lower case for EXT and upper case for INT) the bars indicate significant difference among the samples ($p < 0.05$); bars with an asterisk at the same cooking condition are significantly different ($p < 0.05$).*

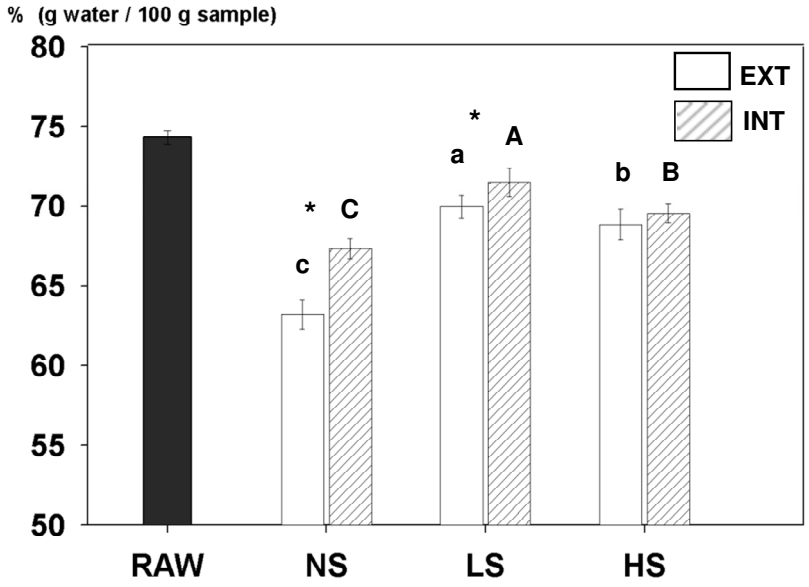
***Figure B2/ 3.*** *$^1H$ FID decays (0.08–0.10 ms range) of RAW and cooked meat samples: EXT samples (A) and INT samples (B). "b" values from FID curve monoexponential fitting (C).*

***Figure B2/ 4.*** *Characteristics $^1H$ $T_2$ quasi continuous distributions of relaxation times for RAW and cooked meat samples (NS, LS and HS) both EXT and INT (A); $^1H$ $T_2$ distributions at relaxation times in the 20 ms –7000 ms time range (B); protons abundance and peak relaxation times (C).*

***Figure B2/ 5.*** *$^1H$ FID decays (0.08–0.10 ms range) of RAW and cooked samples (INT) after centrifugation.*

***Figure B2/ 6.*** *Characteristics $^1H$ $T_2$ quasi continuous distributions of relaxation times for RAW and cooked samples (INT) (A), protons abundance (B), and peak relaxation times (C) after centrifugation.*

***Figure B2/ 1.*** *Moisture contents of RAW and cooked meat samples (NS, LS and HS) both EXT and INT. Average moisture contents (n=4) are expressed as means±S.D. Different letters above (lower case for EXT and upper case for INT) the bars indicate significant difference among the samples ($p < 0.05$); bars with an asterisk at the same cooking condition are significantly different ($p < 0.05$).*



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*Different letters above (lower case for EXT and upper case for INT) the bars indicate significant difference among the samples ($p < 0.05$); bars with an asterisk at the same cooking condition are significantly different ($p < 0.05$).*

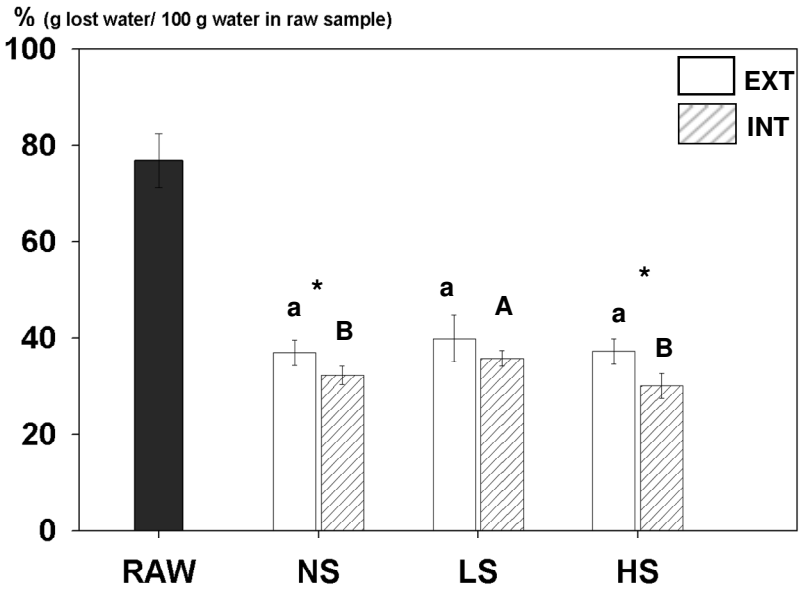


***Figure B2/ 3.*** *$^{1}$H FID decays (0.08–0.10 ms range) of RAW and cooked meat samples: EXT samples (A) and INT samples (B). "b" values from FID curve monoexponential fitting (C).*

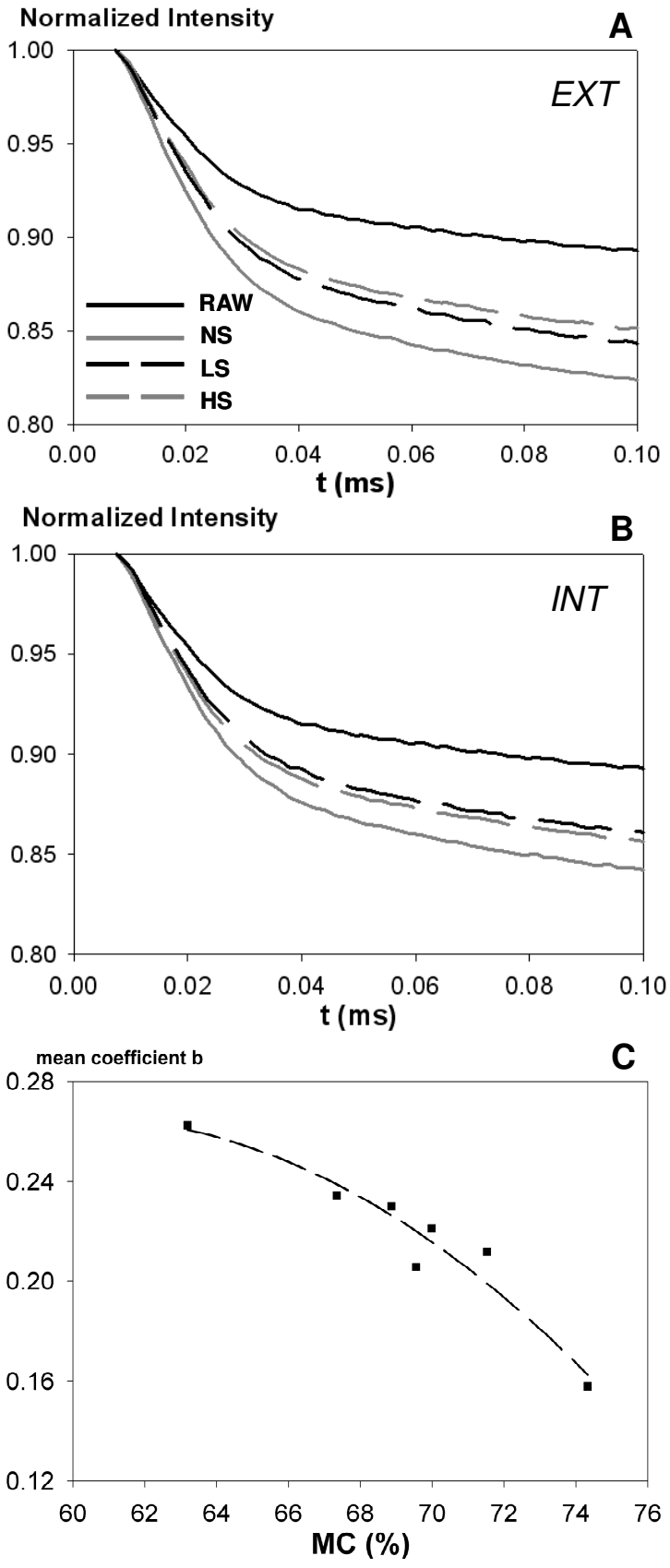


***Figure B2/ 4.*** *Characteristics $^{1}H$ $T_2$ quasi continuous distributions of relaxation times for RAW and cooked meat samples (NS, LS and HS) both EXT and INT (A); $^{1}H$ $T_2$ distributions at relaxation times in the 20 ms –7000 ms time range (B); protons abundance and peak relaxation times (C).*

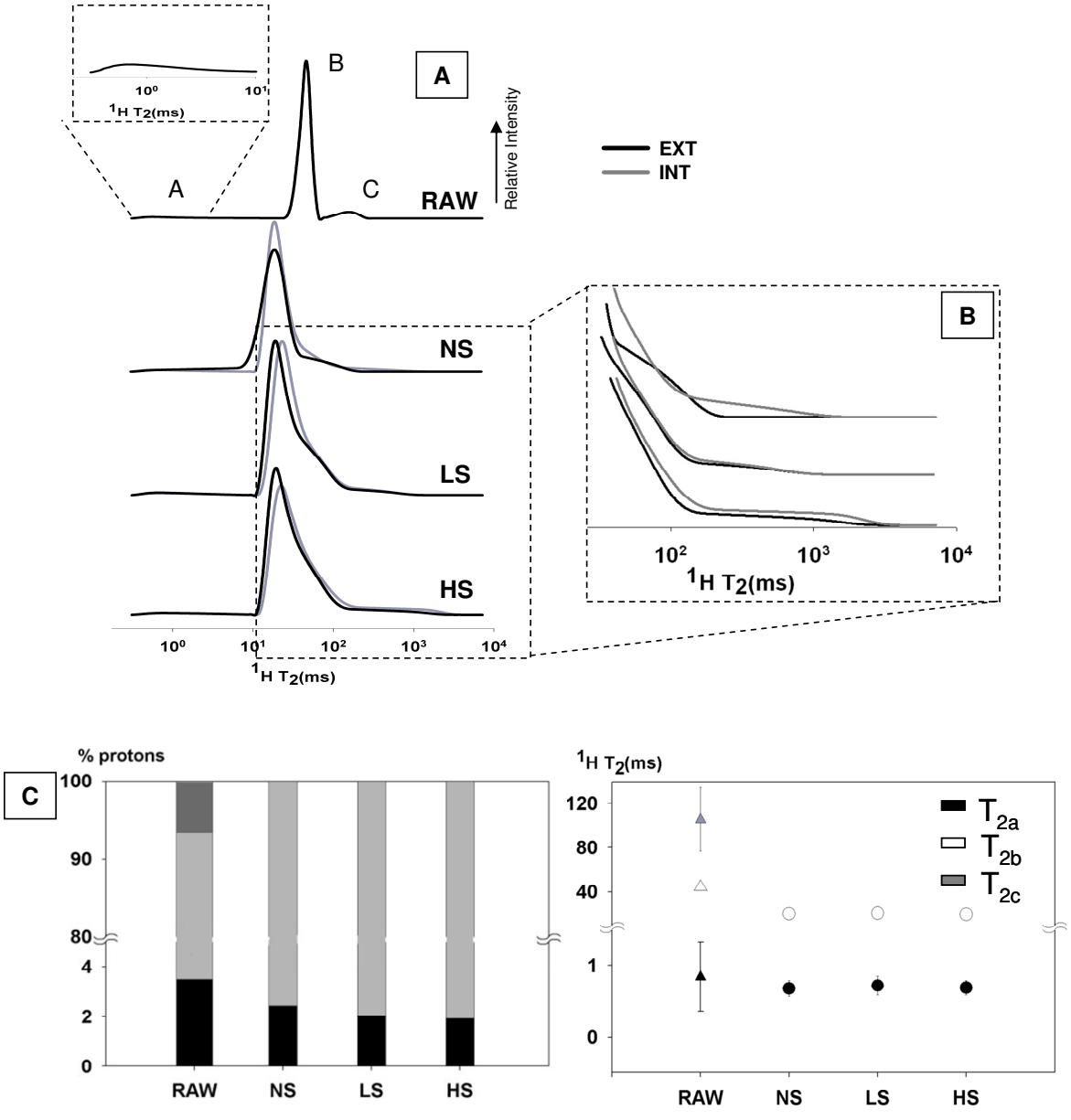


***Figure B2/ 5.*** *$^{1}$H FID decays (0.08–0.10 ms range) of RAW and cooked samples (INT) after centrifugation.*

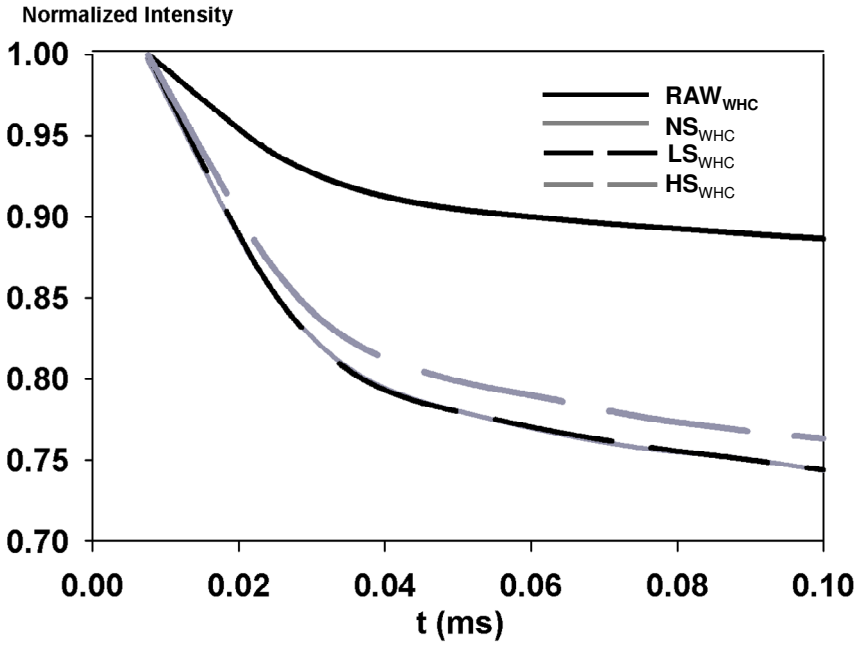
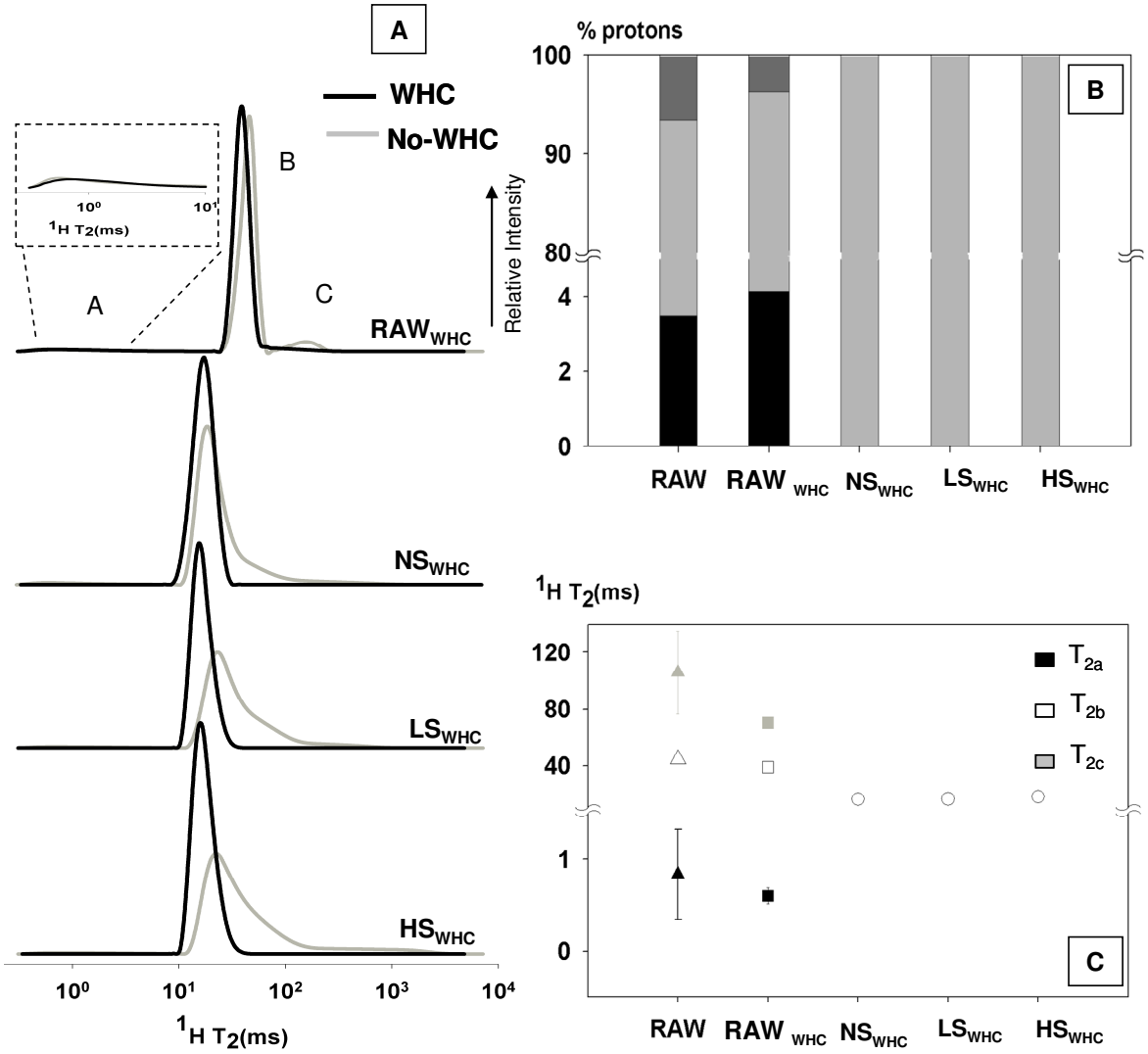


***Figure B2/ 6.*** *Characteristics $^{1}H$ $T_2$ quasi continuous distributions of relaxation times for RAW and cooked samples (INT) (A), protons abundance (B), and peak relaxation times (C) after centrifugation.*



## 7. List of Tables

***Table B2/ 1.*** *$^{1}H$ $T_1$ peak relaxation times of RAW and cooked samples (NS, LS and HS) both EXT and INT. Average $^{1}H$ $T_1$ relaxation times values are expressed as means ± S.D. a, b, c: $p<0.05$, bars with an asterisk at the same cooking condition are significantly different ($p < 0.05$).*

***Table B2/ 1.*** *$^{1}H$ $T_1$ peak relaxation times of RAW and cooked samples (NS, LS and HS) both EXT and INT. Average $^{1}H$ $T_1$ relaxation times values are expressed as means±S.D. a, b, c: p<0.05, bars with an asterisk at the same cooking condition are significantly different (p < 0.05).*

| Treatment | $^{1}H$ $T_1$ (peak time) (ms) | |
|---|---|---|
| | EXT | INT |
| NS | 280.17 ± 12.20$^{c}$ | 316.71 ± 17.37$^{a*}$ |
| LS | 328.66 ± 20.79$^{a}$ | 330.97 ± 14.62$^{a}$ |
| HS | 300.94 ± 11.35$^{b}$ | 328.28 ± 10.88$^{a*}$ |

Means with the same letter are not significantly different (ANOVA, p<0.05)
*Significant difference with independent t-test (p < 0.05) between LS and HS samples in the same position

# Section C

## STEAM OVEN COOKING AT LOW TEMPERATURES OF TURKEY MEAT: DETERMINATION OF THE MINIMUM RELATIVE HUMIDITY VALUE TO OBTAIN THE BEST MEAT QUALITY WITH THE HIGHEST WATER SAVING.

*B. Mora*

### 1. Introduction

At low temperatures the cooking of turkey meat at relative humidities below the saturation condition resulted in cooked products with better characteristics (higher cooking yield, greater perceived tenderness, etc.) than those obtained at the saturation condition, as reported in the results of *sections A and B1.* Moreover the cooking of meat with low steam quantity led to a potential water saving.

In our experimental trials the presence of low steam quantity had a positive effect on cooking of turkey meat when a temperature gradient between the surface and the center of the product existed. Cooking treatments finished when meat samples reached 74°C at their thermal centre, that is the recommended safety temperature for turkey meat (*United States Department of Agriculture, 2006*). The temperature of the surface of meat should be always higher than this value in order to allow a rapid heating by conduction through the product and then short cooking times.

When particular thermo-hygrometric conditions are applied the surface temperature value reached by the product can be close to the target temperature of the end of cooking, as observed at RH=24% at 100°C (*section A*). In this particular condition the application of steam resulted in an increase of cooking time and in a worsening of the physical characteristics of the product compared to the meat cooked without steam (low cooking yield, lower tenderness, etc.).

The surface temperature of meat is related to the thermo-hygrometric conditions of the air: in fact the surface of steam cooked meat tends to behave as a wet bulb, as in the dehydration process, and the surface temperature tends to the value of wet bulb temperature (*section A*).

Psychrometry is a simple and inexpensive method to measure the relative amounts of air and water vapour in a humid air stream. The state of a given air-water mixture is commonly described with the wet bulb temperature and the dry bulb temperature. Properties such as relative humidity can be evaluated using the dry bulb and the wet bulb

temperatures from the psychrometric chart and calculated with the *Assmann psychrometer or hygrometer* formula that describes the relationship among relative humidity, dry bulb temperature and wet bulb temperature as already explained in the *Introduction section.*

In steam cooking the final surface temperature of the product tends to the wet bulb temperature: the setting of the final temperature to be reached at the surface of the product allows to calculate the relative humidity that should be applied using the psychrometric formula.

A final surface temperature of meat of 76 °C was chosen and considered adequate to reach a temperature gradient of 2°C from the central target temperature. It gave the advantage to reach a temperature high enough to obtain a short cooking time by the application of steam and to maximize the positive characteristics of the cooked meat products and water saving, as previously reported.

## 2. Aim of the Work

The aim of this study was to determine which was the minimum relative humidity value that allowed to obtain a positive effect on meat quality, cooking performances (cooking time reduction, higher cooking yield, etc.) and the higher water saving at low cooking temperatures (80-150°C), by applying the psychrometric method in order to reach. the set minimum surface temperature

## 3. Materials and Methods

### *3.1 Relation between Wet Bulb Temperature and Relative Humidity: comparison between the theoretic psychrometric results and experimental data.*

The experimental data of the cooking conditions performed in the previous sections that led to a positive effect of the steam application were considered. They were compared with the theoretic psychrometric results for wet bulb temperature and relative humidity (RH). At 100°C the steam conditions were 35%, 43%, 62% and 88% RH, and at 110°C 24%, 43%, 62% RH.

The experimental cooking trials procedure applied was already explained in the previous section *Set up of the experimental trials.*

Dry and wet bulb temperatures inside the oven and the temperatures of the surface and of the geometric centre of each sample were recorded with wire thermocouples (type K, Ni/Al–Ni/Cr*)* as described by *Chiavaro, Rinaldi, Vittadini& Barbanti (2009).*

The theoretic wet bulb temperatures were calculated with the *Assmann psychrometer or hygrometer* formula as reported by *Vega-Mercado, Góngora-Nieto and Barbosa-Cánovas*

*(2001),* setting the dry bulb temperatures (oven's temperatures) and the RH values of the treatments, as already showed in the *Introduction section*.
The calculated wet bulb temperature data were compared to the experimental data of the wet bulb temperature and to the surface temperature of the product.

### *3.2 Determination of the minimum relative humidity value to obtain the best meat quality at different cooking temperatures and water saving evaluation.*

The minimum RH values in the dry bulb temperatures range 80-150°C were calculated setting a final surface temperature of the product (wet bulb) at 76°C.
The dry bulb temperatures and the corresponding calculated minimum RH values were then fitted with a power equation by means of an Excel® spreadsheet.
The difference between the relative humidity value of saturation at different temperatures and the minimum relative humidity value that allowed to obtain a positive effect of steam was calculated. This difference was considered as an indicator of the potential water saving in the low steam treatment and it was expressed both in terms of relative humidity and absolute humidity ($x$, $kg_{water}$ / $kg_{dry\ air}$).

## 4. Results and Discussion

### *4.1 Relation between Wet Bulb Temperature and Relative Humidity: comparison between the theoretic psychrometric results and experimental data.*

The theoretic psychrometric results of the wet bulb temperature resulted very similar to the experimental data of the final wet bulb temperature and the final surface temperature of the samples for each cooking treatment (*Figure C/ 1*).
The calculated wet bulb temperatures resulted closer to the final surface temperatures of the product (-2,5±1,9°C) than the final wet bulb temperatures using the wet cloth (-5,7±1,4°C). Hence, in our trials, the final surface temperatures of the product showed a behaviour more similar to the theoretic wet bulb temperature than the wet cloth temperature.
The calculated wet bulb temperature resulted always lower than the experimental data of the final wet bulb temperature and of the final surface temperature of the product. Hence, it was concluded that the theoretic model underestimated the real wet bulb temperature data both for the final wet bulb temperature and the final surface temperature of the sample.
The final surface temperature of a product cooked with steam and with a short cooking time could be predicted by knowing the thermo-hygrometric properties of the air (T/RH).

***4.2 Determination of the minimum relative humidity value to obtain the best meat quality at different cooking temperatures and water saving evaluation.***

The psychrometric formula allowed to calculate the minimum RH value to be applied in order to have a temperature of 76°C (wet bulb) at the product's surface in the 80-150°C dry bulb temperatures range.

The minimum RH values that determined a positive effect of steam were reported in *Figure C/ 2* as function of the dry bulb temperatures in comparison with the saturation RH values (calculated as reported in the *Introduction section*.

The relation between the minimum RH values and the dry bulb temperatures at the wet bulb temperature of 76°C could be well described by the following simple power equation:

$$RH=9*10^{8}*T_{db}^{-3,6816} \quad (R^2 = 0,999).$$

Hence, after the choice of a selected the cooking temperature ($T_{db}$), it is possible to predict which is the minimum RH to apply in order to have the better turkey meat quality characteristics and the higher water saving.

In the 80-150°C dry bulb temperatures range the minimum RH values obtained resulted well below the saturation conditions.

The gap between the minimum RH value and the saturation RH depends on the several dry bulb temperatures. The higher the difference between the minimum RH and the saturation RH at the different temperatures, the greater the water savings can be obtained. The potential water saving expressed both in terms of relative humidity and absolute humidity ($x$, $kg_{water}$ / $kg_{dry\ air}$) was calculated as the difference between the minimum RH and the saturation RH.

In *Figure C/ 3* the difference between the minimum RH values and the saturation ones (potential water saving) at low cooking temperatures (different dry bulb temperatures) were reported.

The highest potential water saving (0,93 $kg_{water}/kg_{dry\ air}$). could be obtained at 100°C. Also at 90, 110 and 120°C a consistent water saving (higher than 0,2 $kg_{water}$ / $kg_{dry\ air}$) could be reached.

**5. Conclusions**

The final surface temperatures of the product in steam oven cooking resulted well estimated by the wet bulb temperatures values calculated by the psychrometric method.

Hence, with the selected cooking temperature to use ($T_{db}$) it is possible to determine which is the minimum RH value to apply in order to have a positive effect of the application of steam on turkey breast meat cooking. The positive effects of the application

of low steam on cooking were shortest cooking times, highest cooking yields, greater perceived tenderness and a potential water saving.
The highest improvement in terms of potential water saving could be obtained at 100°C, but also the application of low steam quantities at 90, 110 and 120°C leads to interesting results.

However it is noteworthy to mention that these interesting results are referred to the set cooking conditions, with the limitation of the product geometry (parallelepipeds of 3x3x6 cm). Further studies will be necessary to evaluate the behaviour on cooking of turkey meat pieces with higher dimensions and different shapes.

## 6. List of Figures

***Figure C/ 1.*** *Comparison between the calculated wet bulb temperature data (theoretic psychrometric results), the experimental data of the wet bulb temperature and the surface temperature of the product.*

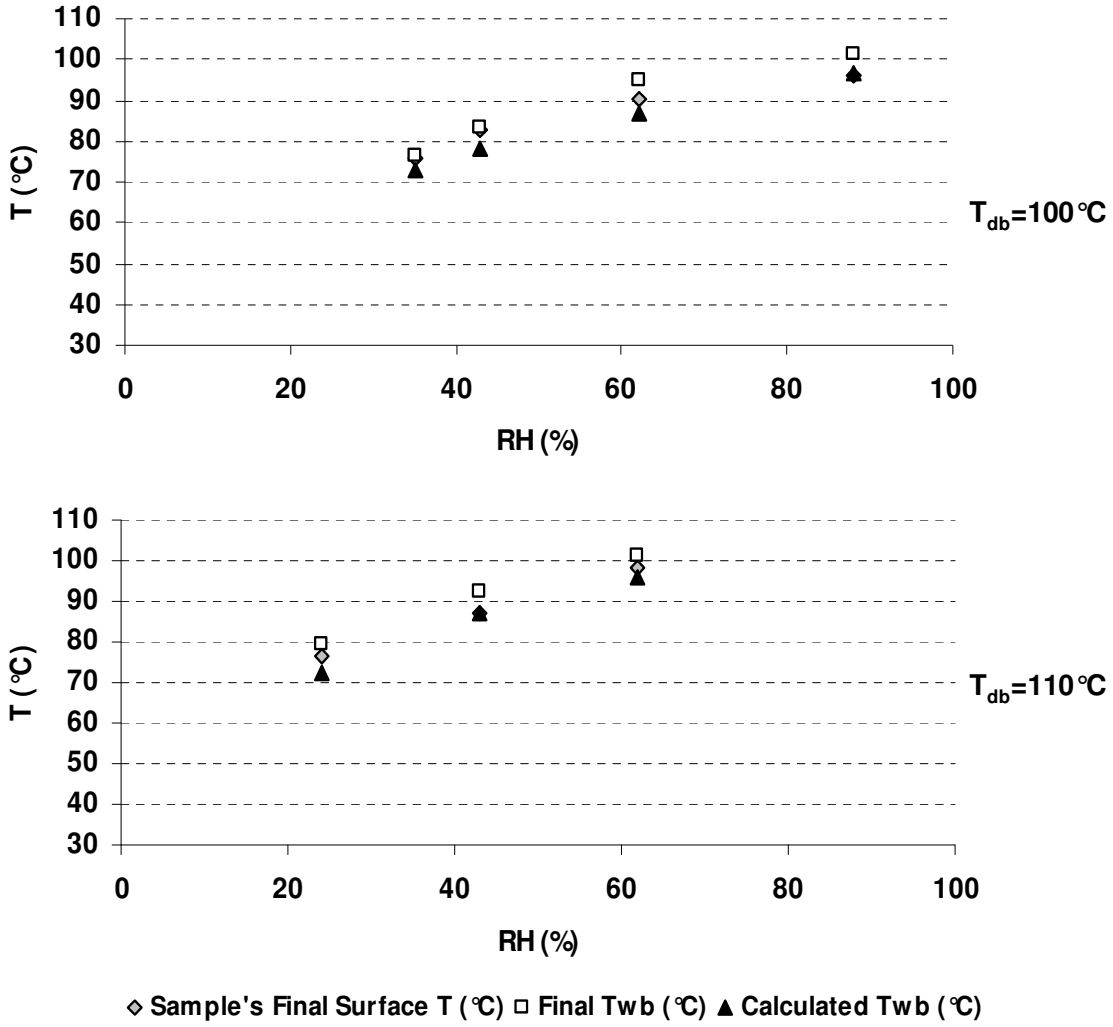


***Figure C/ 2.*** *The minimum RH values that allowed to obtain a positive effect of steam and the saturation RH values as a function of the dry bulb temperatures.*

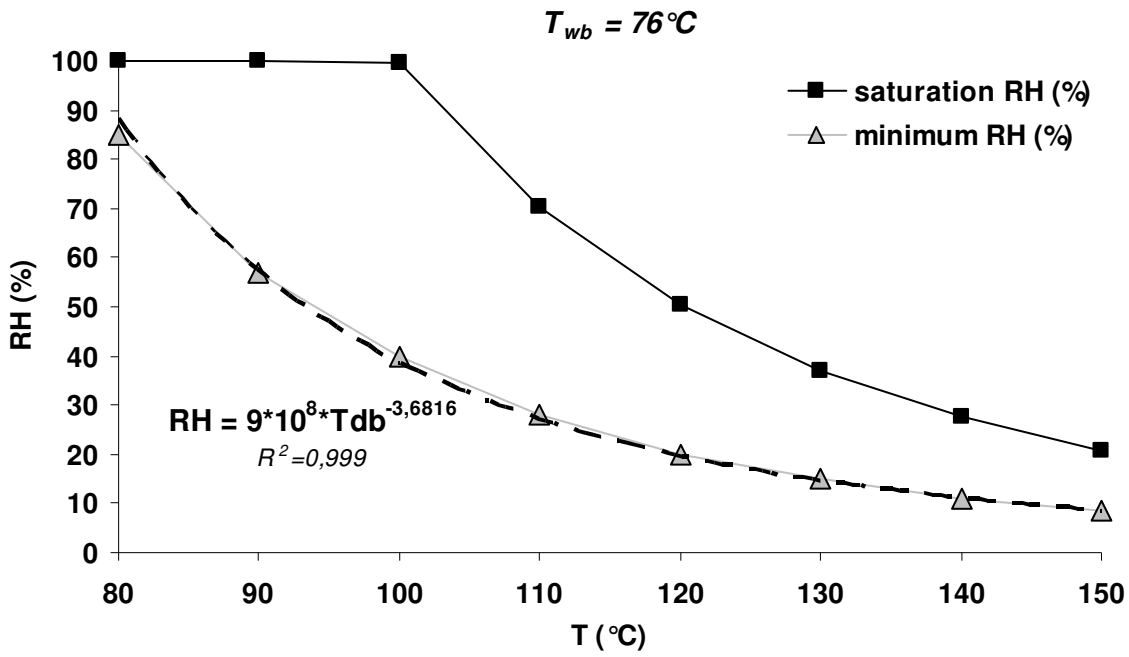
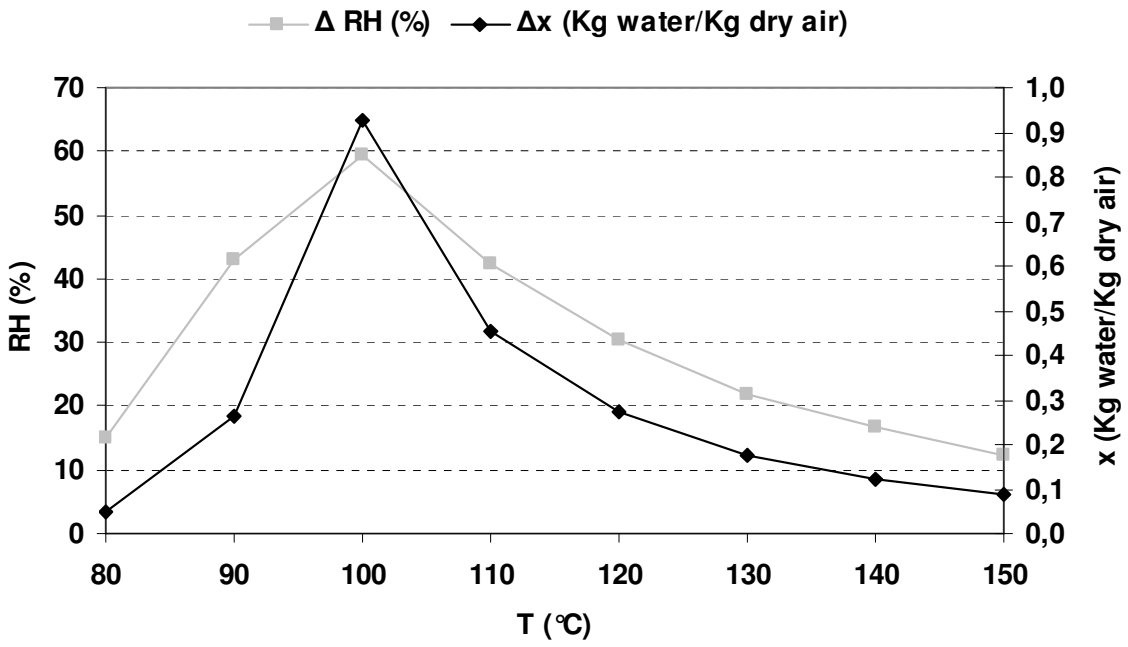


***Figure C/ 3.*** *Potential water saving due to low RH in steam cooking at low temperatures (different dry bulb temperatures): difference between minimum RH values and saturation RH both in terms of relative humidity (%) and absolute humidity (x, $kg_{water}$ / $kg_{dry\ air}$).*



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# Vita

Beatrice Mora

January 3, 1981 …….. Born in San Secondo P.se, Parma (Italy).

***Studies***

2000 – 2005 ……... Degree in Food Science and Technology, University of Parma, Parma, Italy.

2008 - 2010 …….. Ph.D. in Food Science Technology. Department of Industrial Engineering, University of Parma, Parma, Italy.

## Publications list

- Mora, B., Barbanti, D., Betta, G., Bozzoli, F. Oven cooking of turkey meat at different relative humidities. *Italian Journal of Food Science*. Submitted Sept. 2010.

- Mora, B., Curti, E., Vittadini, E., Barbanti, D. Effect of different air/steam convection cooking methods on turkey breast meat. Part 1. Instrumental quality and sensory properties. *Meat Science.* Submitted Sept. 2010.

- Curti, E., Mora, B., Barbanti, D., Vittadini, E. Effect of different air/steam convection cooking methods on turkey breast meat. Part 2. Water status. *Meat Science.* Submitted Sept. 2010.

*- Barbanti, D., Betta, G., Mora, B., Piva, M., Rinaldi, M. An experimental study on some physical properties of industrial ice creams under non-steady thermal conditions. Poster Programme: Poster n.P0322, Section 13 Food Processing, New Technologies & Process*

Optimisation. IUFoST 2010, 15th World Congress of Food Science and Technology (22-26/08/2010 Cape Town, South Africa).

- Mora, B. Low temperature cooking of meat in a steam convection- oven: physical-chemical modifications. Proceedings of the 14th Workshop on the developments in the Italian PhD Research of Food Science Technology and Biotechnology tenuto ad Oristano 16-18 September, 2009. Votazione di A "ottimo livello" e il riconoscimento di n=3 CFU da parte della Commissione presieduta dal presidente coordinatore della commissione Prof G.A. Farris.

- Mora, B., Barbanti, D., Tornielli, G.B., Ferrarini, R. (2008). Controllo e innovazione nel processo di appassimento delle uve. *Vignevini*, 10 (35), 58-62.

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- Mora, B. Low temperature cooking of meat in a steam convection- oven: physical-chemical modifications, Proceedings of the 13th Workshop on the developments in the Italian PhD Research of Food Science Technology and Biotechnology, Alba (CN) 10-12 September, 2008. Votazione di B "buon livello" e il riconoscimento di n=2 CFU da parte della Commissione presieduta dal presidente coordinatore della commissione Prof Vincenzo Gerbi.

- Tornielli G.B., Nicolis E., Mora B., Barbanti D., Ferrarini R. L'appassimento in fruttaio come tecnica per il potenziamento dell'identità dei vini Recioto e Amarone della Valpolicella. Atti del convegno: XXXI Congresso mondiale della Vigna e del Vino - OIV - 15-20 Giugno 2008- , Verona, Italia -Poster- supporto multimediale.

- Barbanti, D., Mora, B., Ferrarini, R., Tornielli G.B., Cipriani, M. (2008) Effect of various thermo-hygrometric conditions on the withering kinetics of grapes used for the production of ''Amarone" and ''Recioto" wines. *Journal of Food Engineering*, 85, 350–358.

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