International Scholars Journals

African Journal of Poultry Farming ISSN 2375-0863 Vol. 9 (2), pp. 001-009, February, 2022. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Microbiological comparison of microwave and traditional thawing processes for poultry meat

Boubaker Krifi[1], Mosbah Amine[2]* and Jaafar Makram[2]

[1]High Institute of Biotechnologies, Monastir, Tunisie.

[2]Military Laboratory of Food Analysis, Tunisian Army, Tunis, Tunisia. *Corresponding author. E-mail: aminemosbah@hotmail.com. Tel: 0021622697880. Fax: 0021673465404.

Accepted 16 September, 2019

Health agencies official has been convinced of the efficiency of microwave based process mainly due to its bactericidal property and safety (non-ionizing radiation). However, many biotechnological aspects of this new method are still unknown and have raised safety concerns. This study aimed to validate the application of the thawing process of a large poultry meat block under high frequency microwave oven (2.45 Ghz within 60 s). Compared to the traditional thawing method (4°C for 48 h), we combined a visual observation and bacteriological analysis. The microwave thawing process was clearly faster than the conventional process, by at least three times. Both microwaved samples and control samples complied with the standard requirements, even after five weeks of microbial-screening of total mesophilic flora, fecal coliforms, sulfite-reducing anaerobic, *Staphylococcus aureus* and *Salmonella*. In the exposure to microwave, there was also less loss of water compared to the traditional method (2.33±0.21 l < 3.45±0.21 l). Although it showed overheating signs due to the high frequency used, it did not compromise the shelf life of the product. We validated the microbial-safety of the microwave thawing process; however, adjusting the frequency would result in better quality output and alleviate side effects in the frozen poultry.

Key words: Thawing process, poultry meat, chicken, microwave oven, quality management.

INTRODUCTION

Microwave (MW) irradiation has become increasingly popular in food processing, to brown, dry, cook and particularly in improving food quality and shelf life, despite the lack of official technical criterion (Yahmaee and Durance, 2005; FDA, 2006; *Codex Alimentarus*, 2007; Taher and Farid, 2011; Lin et al., 2014).

This technology is used mainly in household applications and recently in food industries (Ohlsson, 1989; Chaum et al., 2009, Vadivambal and Jays, 2007). In fact, its ability to interfere with biological systems is gaining popularity, particularly its heat production dynamic. In fact, MW induces heat by two reactions; the first is dipolar polarization, the cause of rotation and vibration of dipoles like free water (a_w). The second is a complementary reaction due to ionic conduction of free charges stimulated by electromagnetic field. The two reactions are triggered by the MW radiation and induce internal fractions within the foodstuff, resulting in heat production. The ionic density and moist content of a given stuff both shape the ability of the stuff to couple with MW, namely, permittivity or dielectric characteristic of the matter (Heddleson and Doors, 1994; Ang et al., 1977; Chandrasekaran et al., 2013; Venkatek and Raghavan, 2004; Komarov et al., 2005; Thostenson and Chou, 1999).

The selective MW heating effect seems to be valuable, especially in food processing and food decontamination

(Ohlsson and Bengston, 1975; Sivaramakrishnan, 2010; Tyagi and Lo, 2013). For this purpose, it has been introduced as a reliable and efficient technology, to reduce microbial hazards and produce safer products (Aranzana et al., 2013; Tinoco et al., 2014; Farkas, 1998; Thayer, 1995). Consequently, many good studies have been done on the biotechnological aspects of microwave, and have succeeded in developing promising aspects of pasteurization and even sterilization. (Holsson and Bengtsson, 1975 ; Chandrasekaran et al., 2013; Byrne et al., 2010; Dov et al., 2013, Zhang et al., 2010).

For instance, Lau and Tang (2002) have identified a fast decontamination effect in asparagus within a short time exposure; they establish recommendation on the use of MW for sensitive foodstuffs. Admittedly, MW heating process requires less thermal exposure, to reach the safety scales (Tinoco et al., 2014); therefore, it leads to better nutriments preservation (Koné et al., 2013). As a result, it has been affiliated to the so called group of “Cold pasteurization technologies.” However, the lethal effect of MW has been subjected to controversies, and seems to be more complex than expected (Wu and Yao, 2011; Hamoud-Agha et al., 2013). Put in this way, many authors have done deep investigations on MW effects. Papadopoulou et al. (1995) first reported a possibility of differences between thermal and electromagnetic effects on microorganisms. As the two effects seem to be mitigated and closely linked (Byrne et al., 2010), many trials have focused on each effect discreetly and established a major molecular modification (Nasri et al., 2013; Shames et al., 2008; Tinoco et al., 2014).

Actually and since the mid-sixties, poultry industry has been strongly supported by the authority, and has known a great improvement. Currently, poultry meat represents over 25% of the livestock sector in Tunisia and provides 53% of all meats. The production of poultry meat reached its saturation level in 2012, about 250 thousand ton with a value of 152 millions of US dollar (Tunisian Ministry of Agriculture, 2013). To balance the commercial flow, authorities regularly freeze the extra stocks, in particular, during the holy month, when demand of Tunisian customers reaches a peak and fresh meat is almost scarce.

In that connection, we have proposed to evaluate the effects of high frequency of MW on the quality of the poultry meat during the industrial thawing process. Thereby, we compared that process to the traditional thawing method without MW. And as a first published study on microwaved frozen chicken in Tunisia, we formulated general recommendations on the use of MW radiation in food processing as a contribution to the quantitative food risk assessment and HACCP plans being implemented all over the Agro-industry.

MATERIALS AND METHODS

Material for thawing

W e used a high frequency microwave oven (2.45 Ghz) "Ferrite®" with a wavelength of 12.2 cm. The oven can be loaded up to 25 kg and is provided with an electronic scale. For manipulation, we used large sterile plastic bags, designed for single use. A digital thermometer was used for food, with a measurement capacity from - 20±0.1°C to + 150±0.1°C. Its probe was a stainless steel of 12.5 cm length.

Equipment for sampling

Sampling equipment was sterile of high purity and had no influence on the microflora of the product. The sampler wore a gown, cap, mask and gloves, equipped with bags, labels and a cooler thermal insulation. Plastic bags were sterile and with an appropriate size for sampling.

Colony counting apparatus

The colony counting apparatus was equipped by a lighting system with a black background, and provided with a magnifying glass of 1.5, and an electronic counter. Incubators maintained inoculated media, boxes and bottles within a temperature range of 30 to 46°C.

Thawing chicken

Thawing in cold positive

20 kg of whole frozen chickens (18 and 20 chicken carcasses) were maintained in clean plastic yellow boxes at a maximum of -18°C. In each box, a single used plastic wrap was introduced. Then, we placed five to six chickens on the back arranged in a single level per box.

Boxes were loaded into the stock room, with temperature between 1 and 3°C, not exceeding 4°C. An empty red box was put below all boxes containing the product, without touching the ground directly. Then, the thawing processes were triggered and these lasted for 48 h.

Thawing in the microwave

We conducted the thawing in the microwave oven as it was carried out in cold storage. Once the boxes were loaded, they were placed one by one in the cavity of the microwave oven. The radiation cycle lasted for 60 s with a power of 20 KW; the energy dispatched into the foodstuff was 60 KGy.

On leaving the microwave oven, chickens were kept in a temperature between 4 to 2°C. Subsequently, the boxes were stacked one upon the other, with an empty red box below; after which they were returned to the stock room with maximum temperature equal to 4°C to complete the thawing for 15 hours.

We weighted the global load of the chicken before and after each process. The wasted water was collected in graduated bottle and evaluated at the end of the experiments; consequently, weight losses were estimated.

Sampling and sample transport

Immediately, at the end of the thawing processes, fives simples by batch and tow bath process were pulled out from the microwaved and control group, from the top and lowest boxes, weekly. We fully complied with the conditions of the sampling, randomly and aseptically, following the recommendations of the Codex Standard (*Codex Alimentarius,* 2004). We majored the temperature of each simple before we packaged, saddled, labeled and saved it in a cold

Table 1. Results of microbiological analysis obtained from the **top boxes** of chicken thawed by slow process.

Flora	Viable cell count (log_{10} CFU/g)				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
TMF	3±0.5*	2.77±0.5*	3±0.5*	2.47±0.5*	1±0.5*
FC	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*
SRA	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*
SA	<1.69±1*	<1.69±1*	<1.69±1*	<1.69±1*	<1.69±1*
Salmonella	Absent	Absent	Absent	Absent	Absent

n = 5; *Error signifiance ; TMC, total mesophilic flora ; FC, fecal coliforms; SRA, sulfite-reducing anearobic; SA, *Staphylococcus aureus*.

Table 2. Results of microbiological analysis obtained from the top boxes of chicken thawed by rapid process.

Flora	Viable cell count (log_{10} CFU/g)				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
TMF	2±0.5*	2.3±0.5*	2±0.5*	2±0.5*	1±0.5*
F C	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*
SRA	<10±0.6*	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*
S. A	< 1.69±1*	< 1.69±1*	< 1.69±1*	< 1.69±1*	< 1.69±1*
Salmonella	Absent	Absent	Absent	Absent	Absent

n = 5; *Error significance; TMC, total mesophilic flora ; FC, fecal coliforms; SRA, sulfite-reducing anearobic; SA, *Staphylococcus aureus*.

container, until the time of shipment to the laboratory (within 12 hours).

Preparation of test samples

Upon arriving at the Military Laboratory of Food Analysis, chickens were spread out in a stainless steel and 10 g of mixed portions were collected aseptically (7 g of flesh and 3 g of skin). The sample was placed in a sterile stomacher bag, in which we added 90 ml of buffered peptone water. The whole was milled using a stomacher for 2 to 3 min. The obtained homogenate was 10^{-1}; from this original solution, we conducted a series of decimal dilutions, up to 10^{-5}.

To search for *Salmonella* spp., 25 g of the skin of the chicken was suddenly taken, to which we added 225 ml of buffered peptone water. The performed essays followed the recommendations of the order of December 21th, 1979 (JORF, 1980).

Bacteriological analysis

The enumeration of Total Mesophilic Flora (TMF) was done according to the International Standard, ISO 2293 (ISO, 1976), by counting the observed microorganisms at 30°C. The enumeration of Fecal Coliforms (FC) followed the French standard, NF V08-060 (AFNOR, 2009a), in which Thermotolerant Coliforms (TC) were evaluated by counting the observed colonies at 44°C. The evaluation of *Staphylococcus aureus* (SA) was made according to ISO 6888-1 (ISO, 1999). A special interest was given to the coagulase positive staphylococci by using a specific medium (Baird-Parker solid medium) at 37°C. Sulfite-Reducing Anaerobic (SRA) culture was carried out according to the French Standard NF V08-061 (AFNOR, 2009b) at a temperature of 46°C. The detection of *Salmonella* was performed according to ISO 6579 (ISO, 2002).

Incertitude errors were evaluated for each of the bacteria separately, except for *salmonella,* where no reliable method of calculation is currently available. In fact, the error significance was estimated by computing the standard derivation of the reproducibility, according to the ISO Standard 19036 (ISO, 2006), recommended by the General Directorate of Health and Consumer (European Commission, 2006). We estimated the error rates from 0.5 to 1 log_{10} reduction.

RESULTS AND DISCUSSION

Food safety impact

In our study, we demonstrated that, bacteria are usually related to quality (TMF, FC and SRA) and thus reflecting food safety concern (SA and *Salmonella*) meet its standards and satisfactory achieve the safety requirements in both upper (Tables 1 and 2) and lowest cases (Tables 3 and 4). Indeed, for the TMF, the seeds level obtained were well below the threshold of 5 log_{10} CFU/g. Also, the results of FC were below the required threshold of 3 log_{10}, followed by 1 log_{10} CFU/g.

The count of SRA throughout five weeks was less than 1 log_{10} CFU/g, and below the value set at 1.47 log_{10} CFU/g. In the same way, the results of SA were less than 1.69 log_{10} CFU/g, and met the safety standards (< 2.69 log_{10} CFU/g); thence it clearly averted toxin formation. We also noted that all tests are free of *Salmonella* and would not harm consumer's health.

Table 3. Results of microbiological analysis obtained from the bottom most boxes of chicken thawed by slow process.

Flora	Viable cell count (Log_{10} CFU/g)				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
TMF	1±0.5*	2.69±0.5*	3±0.5*	2±0.5*	1±0.5*
Fecal coliforms	<1±0.5*	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*
SRA	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*
S. aureus	< 1.69±1*	< 1.69±1*	< 1.69±1*	< 1.69±1*	< 1.69±1*
Salmonella	Absent	Absent	Absent	Absent	Absent

n = 5; *Error significance; TMC, total mesophilic flora; FC, fecal coliforms; SRA, sulfite-reducing anearobic; SA, *Staphylococcus aureus*.

Table 4. Results of microbiological analysis obtained from the bottom most boxes of chicken thawed by rapid process.

Flora	Viable cell count (Log_{10} CFU/g)				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
TMF	1±0.5*	2±0.5*	2.3±0.5*	2±0.5*	1±0.5*
Fecal coliforms	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*	<1±0.7*
SRA	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*	<1±0.6*
S. aureus	<1.69±1*	<1.69±1*	<1.69±1*	<1.69±1*	<1.69±1*
Salmonella	Absent	Absent	Absent	Absent	Absent

n = 5; *Error significance; TMC, total mesophilic flora; FC, fecal coliforms; SRA, sulfite-reducing anearobic; SA, *Staphylococcus aureus*.

Moreover, the obtained averages of TMF under the two processes imply that the upper boxes are slightly loaded with germs than the lowest boxes. The monitored rates were 2.44 log_{10} > 1.93 log_{10} CFU/g (Tables 1 and 3) and 1.86 log_{10} > 1.66 log_{10} CFU/g (Tables 2 and 4) subsequently for slow and rapid processes. Meanwhile, we did not observe a change in the contamination distribution after exposure to MW.

In the light of the foregoing results, we can conclude that, bacteria were not fully eradicated during the MW irradiation. This matches the results of Schlissemberg et al. (2013), who did not succeed in inactivating all the aerobic mesophilic bacteria experimentally inoculated onto ground beef, after exposing to radio frequency of 1000 MHz during 7.5 min. To illustrate this point, scientists (Harisson and Carpenter., 1989) described an effective proliferation of radiotolerant and thermotolerant bacteria even after prolonged exposure to MW. They have considered *Lesteria* as the most resistant vegetative bacterium, and at present, it is being introduced as a safety indicator of food processing (Jo et al., 2007, Kamat et al., Nair, 1996, Schlisselberg et al., 2013, JORF, 2007).

These findings are corroborated by the absence in our study of significant differences of microbial load, between microwaved food and the control group. We also underscore that exposure to MW kept the same bacterial distribution between both lowest and top boxes (p-value >0.1), using analysis of variances test (ANOVA) of Biostat TGV ® software Jussieu, Paris.

In fact, the thermal destructive point within the samples was not reached; the whole temperature monitored did not exceed 4°C, which may explain the persistence of some bacteria after MW of exposure. These findings are expected, since many reports scientifically demonstrated the absence of the destructive effect of MW under a minimum required exposure. That is, we have not been able to confirm the inactivation effect of the high MW frequency at cold temperature, in spite of the high energy (60 KGy) deployed in this case.

At this particular point, our results joined the conclusions of Welt et al. (1994), which did not find any inactivation effect against the spores of *Clostridium sporogenes* at sublethal temperature, even after the use of high power (400 W). According to Lu et al. (2011), the decontamination of *Salmonella enteritica,* experimentally inoculated onto tomatoes, was 1.45 log_{10} reductions after 40 s exposure to MW field of 700 W; the maximum monitored temperature was 48°C.

Clearly, Lau and Tang (2002) had more success in inactivating *Salmonella*, within few dozen of seconds, in both Japanese pepper and coriander. The authors had achieved a destruction rate of 5 log_{10} reductions, following exposure to MW field of 950 W; they also pointed out the need to reach a lethal temperature within the sample (63°C) to observe a significant bacterial des-

truction. Correspondingly, Gentrya and Roberts (2005) consider that MW would effectively diminish *Echerichia coli* contamination in apple cider by 5 $\log_{10}$ reductions, using a continuous flow exposure system, with a power of 200 W and a temperature of 40°C.

The same conclusions were drawn in meat processing. In particular, Apostolo et al. (2005) achieved a high level of decontamination, as high as 6 $\log_{10}$ reductions, of *E. coli* in chicken, by applying a power of 800 W for 30 s; the temperature of the food was 75°C.

The same attempt was reproduced on milk, with comparable inactivation amount in both *Lesteria innocula* and *E. coli;* the reductions were 5 $\log_{10}$ and 6 $\log_{10}$ respectively. The power scale formerly used was slightly above the earlier one (1200 W during 55 s), with less heat production (65°C) (Awua et al., 2005). Besides, MW was found to control *Salmonella* in eggs 5 times faster than the conventional heating method and then provides an effective pasteurization scale (61.1°C within 2.5 min) (Dev et al., 2008; Sivaramakrishnan, 2010) .

According to Byrne et al. (2010), sterilization was also effective in meat. The authors had decreased the amount of *Bacillus cereus* spores by 1.8 $\log_{10}$ and *Clostridium perfrengins* spores by 4.1 $\log_{10}$ reductions, by applying a radiofrequency of 500 W combined to hot water (80°C).

In other studies, MW radiation had no effect on pathogen microbe in chicken meat; in fact, despite, the higher MW scale used in chicken (1138.8 W during 30 s), the survival abilities of *E. coli* and *Campylobacter jejuni* were not eroded. In that case, the temperature in the meat did not exceed 47°C (Goksoy et al., 2000), far from the safe level, namely 74°C (*Codex Alimentarus*, 1993). Our results are in agreement with the authors' observation; they further confirmed heat dependant inactivation of MW.

Similarly, Palaniappan et al. (1990) believed that the inactivation effect was only due to the ohmic heating of the radiations. Others reported deadly cellular and genetic injuries after a sublethal exposure to high MW frequencies (Nasri et al., 2013; Shamis et al., 2008; Uemura and Isode, 2002). Hong et al. (2004) and Wu and Yaho, (2011) placed emphasis on the interference of MW with critical cell compounds, as well as DNA, ARN and Cell membrane. They established the occurrence of multiple disruptions and mutations, just like Dreyfuss and Chipley (1980), who support that MW inactivation cannot be solely correlated to the thermal effect, but that many enzymatic alterations may explain the electroporation and metabolic breakdown of bacterial cell at mild temperatures.

In the following earlier mentioned results, it appears that MW irradiation did not change the contamination patterns, neither in the short run (just after the exposure) nor in the long run (five weeks after the exposure). This implies that the persistent bacteria have kept their capacity to survive and multiply, regardless the process of thawing used in chicken*, inter alia;* no deadly athermal (MW) effects were proved at our industrial level (p-value > 0.1), using analysis of variances test (ANOVA) of Biostat TGV® software.

Hence, we admit that the inactivation effect of MW is an energy dependent phenomenon, in total approval with most reports (Apostolo et al., 2004; Awua et al., 2005; Lau and Tang et al., 2002; Lu et al., 2011; Dreyfuss and Chipley, 1980; Heddleson and Doores, 1994; Harrison, 1988). In that case, to be effective, the MW energy absorbed by the foodstuff must certainly be converted to a minimum heat threshold (Goksoy et al., 2000). Otherwise, the bacteriolethal temperature would not be reached.

Last but not the least, the variable anisotropic character of the frozen food and its dynamic boundary conditions complicate even more MW behavior, and especially its impact on food quality (Ang et al., 1977; Rattanadecho, 2004).

Impact on food quality

Bengtsson and Risman (1971) and Akkari et al. (2006) studied the dielectric properties of food and water at different temperature ranges, in an attempt to understand the MW dynamics. They stated that frozen food has less permittivity compared to fresh food, and is less able to absorb and convert (MW) energy into heat. Admittedly, the dielectric property is meanly correlated with moist content, in as much as free water (a_w) has a high permittivity and improves the energy absorption of a given stuff (Chandrasekaran et al., 2013; Akkari et al., 2006; Ryyniinen, 1995).

In fact, during the thawing of the ice, the dietetical property of the frozen food would go in two different ways, depending on the (a_w) amount. While the permittivity of the liquid phase is increasing along with the melting ice, conversely the permittivity of the frozen part remains low and behaves as transparent materiel to MW radiations (Chaiyo and Rattanadecho, 2011). As the tow opposite reactions are going on, further heat runaway is induced, with substantial thermal variation within the matter (Yang and Gunasekaran, 2004; Venkatesh and Raghavan, 2004, Chaiyo and Rattanadech, 2011). The final result is an incomplete thawing with loss of water (Ryymine, 1995; Komarov et al. 2005, Taher and Farid, 2001).

In our study, we also met the same drawbacks of partly thawing reaction with water losses, but we have succeeded in alleviating it, by putting the meat at rest at 4°C until the establishment of the thermal equalization between the two phases of the foodstuff.

With time, water losses following the traditional thawing method were more compared to the MW thawing process (3.45±0.21 l > 2.33 ±0.21 l). Likewise, Taher and Farid (2001) have mathematically validated those observations by simulating the MW dynamic in frozen meat. We also

estimate that, water losses have influenced the final weight of the meat blocks, which were 17.5 ±0.15 Kg at the end of the MW thawing process and 16.37±0.15 Kg at the end of the traditional thawing method, with corresponding weight reduction of 12.5 and 18.15%, respectively. The results were statistically significant ($p < 0.05$) using t-student of Biostat TGV ® software.

The observations of Schlisselberg et al. (2013) meet our finding and support the occurrence of weight loss. Indeed, the authors found 17% of weigh loss in fresh ground beef after exposure to radio frequency for longer period (7.5 min).

Actually, after the use of the MW radiation, the thermal balance was reached faster, by at least three times, than in the conventional process; in fact the thawing lasted for15 hours during the MW processing; whereas the traditional one took 48 h. Undoubtedly, our observations met the conclusion of most specialists in this field (Tinoco et al., 2014; Schlisselberg et al., 2013; Dev et al., 2008), which confirmed the fast MW processing of foodstuff, and the less thermal load requirement of MW heating (Koné et al., 2013; Lau and Tang, 2002).

In our experiment, we provided a first index of the microbiological safety and rapidity of MW in thawing poultry meat, under the specific condition of the thermal equalization period. Although, we have observed uneven cooking signs within the samples. In fact, the external aspect and the color uniformity of the chicken are important elements for consumers' acceptance. These criteria were depreciated by the appearance of red spots (more than two spots per chicken) located especially on the thighs. Actually, Goskoy et al. (2000) and Apostolou et al. (2004) explained that overheating marks (or hotspot effects) are a common drawback of the MW usage. They also asserted that the high frequencies of the MW diminish the wave penetration within the foodstuff and increase the hotspot distribution, especially, around the edges of the chicken. Also, Hmou-Agha et al., (2013) showed the uneven distribution of the hotspot, and their concentration in the asymmetric shapes, with uneven cooking signs (Chandrasekaran et al., 2013; Harrison et Carpenter, 1989). These conclusions are same with our results especially, due to the high frequency we used in our experiment (2.45 GHz).

We also found that this anomaly has no effect on the shelf life of the product; the chickens complied with safety standards, even throughout five weeks of cold storage; likewise the demonstrations of Goskoy et al. (2000). Further, Abu-Gyamfi et al. (2008) found an appropriate agreement between quality preservation and microbial control in ready-to-eat chicken, by applying an optimum radiation of 3 KGy; as a consequence, the shelf life of the product was extended to at least 14 days. Also Uemura et al. (2010) improved the quality of soybean derived food; tofu, made from flash-radiated soybean milk had the best breaking strength.

Almost all authors are convinced that MW process enhances food quality preservation and taste retention (Cocci, 2008). Adedeji et al. (2009) added that microwave at 6.7 w/g power density decreases significantly the oil uptake in chicken nuggets during deep-fat frying, and then improves its nutritional value. In concordance with the observations of Arocas et al. (2011), who confirmed the protective effects of MW on the retro-gradation of starch during the thawing of ready to eat sauces, similarly Hill, (1994) & Bedoui et al. (2011), and (Fiore et al., 2013) provided evidences of the preservation of food texture and vitamins content after exposure to MW. Meanwhile, the energy consumed and heat exposure were less than that in conventional cooking method by at least 30 p.100 (Wang et al, 2012, Schlisselberg et al., 2013).

Conversely, Ozkoc et al. (2009) refuted these results and mentioned fast bread staling after exposure to MW. This is similar to the findings of Lu et al, (2011), who reported a structural damage in tomatoes after 50 s of exposure to MW. Also, Liu et al. (2002) described an increasing redness after meat irradiation, due to modifications of myoglobin. These results were supported by Wu and Yao, (2011); Harrison et al. Carpenter (1989), who observed an increase of food microbial load after exposure to MW.

Many factors would explain this discrepancy over the authenticity of MW effects. Basically, the difficulty with MW processing is the large number of factors that rule the heat transfer behavior, which is inherent in food characteristics (thickness, size, shape, and permittivity) and not MW field proprieties (frequency, power, strength, wave length, and exposure period) (Harisson et Carpenter, 1989; Yang and Gusasekara., 2004; Lu et al., 2011; Vadivambal and Jayas, 2007). This may have influenced the results of this study.

In fact, previous reports agreed over the conditional and random reproducibility of microwaves effects (Goksoy et al., 2000; Law and Tang, 2002). Obviously, frequency use is admitted to have a leading role in MW efficacy and its penetration capacity within the food; it better averts hotspot effects (Goksoy et al., 2000; Venkatesh and Raghavan, 2004; Cherbanski et al., 2013). That is, pulsed MW heating with frequency sweeper has clearly proved its reliability in controlling bacterial conta-mination and averts uneven thermal distribution within the sample (Huang and Sites, 2007; Hung et al., 2006; Yang and Gunasekaran., 2004; Gentry et al., 2005; Kone et al., 2013; Vadivabal et al., 2010; Brow et al., 1999).

Also, Lau and Tang (2002) and Fiore et al. (2013) used a low microwave frequency to improve thermal distribution within food. Burfoot et al. (1988) too achieved the same performance using a frequency of 896 MHz, and effectively pasteurized ready to eat meat, whereas higher frequency (2450 MHz) induced less uniform thermal distribution.

Komarov et al. (2005) formulated the same assumption on frequency impact in thermal uniformity and proposed the use a frequency fare under the level that we have

already used, to enhance the ionic conduction and penetration of MW within foodstuff.

For the same purpose, Taher and Farid, (2001) suggested the use of a cyclic (MW) exposure, every 20 s, to avoid overheating effects in frozen food

Also, recent studies have confirmed the synergistic effect of combined strategies in controlling food hazard (Maktabi et al., 2011; Law and Tang, 2002, Adu-Gyamfi et al., 2008); in fact, water assisted (MW) heating, thawing or drying, which are currently being integrated in MW devices have increased the thermal sensitivity of bacteria (Byrne, 2010) and improved thermal uniformity within food (Miranda et al., 2012; Brody et al., 2012; Schlisselberg et al., 2013).

Thawing using air impingement technology has accelerated the thawing process, over four times faster than the conventional method, without increasing the temperature to a level, where microbial growth becomes a concern (Brent et al., 2006).

Conclusion and Recommendations

Microwave is already admitted to control food contamination and reduce nutriments destruction also. We have shown that microwaved food complies with the microbiological safety objectives and provides an appropriate level of security for the consumers. It is also a faster method to process food especially during crisis and food shortages, especially in Tunisia, where the freezing and thawing of the strategic stocks occur daily.

Although the validation of microbial safety of microwaved food is proved, it did not systematically imply the chemical stability of the processed stuff. In fact, a number of critical issues remain unresolved, which magnify the quality concerns and emphasize the need to use innovative technologies.

In future prospects, more studies are required to scrutinize the MW electrical property and adjust it to food characteristics

It is well established, that frozen food has poor permittivity and is deeply influenced by the temperature and frequency being used (Chaiyo and Rattanadech, 2011; Venkatesh and Raghavan, 2004; Ohlsson, 1989). For that reason, we suggest using a frequency sweeper for the thawing process, and to start with low frequencies and then increase it along with the progress of the melting point.

We also recommend considering the heating effect as the only effective element in bacterial inactivation, especially at industrial level to avoid any safety abuse that may imperil consumer's health.

At the legislative level, it is also necessary to enforce the current legislation and standardize the use of microwave, in order to establish accurate and repro-ducible technological performances and then better suit food safety and quality.

ACKNOWLEDGEMENT

We gratefully acknowledge the Tunisian Defence Ministry for its invaluable support to this study.

REFERENCES

Adedeji AA, Ngadi MO, Raghvan GSV (2009). Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. J. Food Eng. 91:146-153.

Adu-Gyamfi A, Kketsia-Tabiri J, Apea Bah F (2008). Radiosensitivities of bacterial isolates on minced chiken and poached chicken meal and their elimination following irradiation and chilled storage. Radiat. Phys. Chem. 77:174-178.

AFNOR (2009a). NF V08-61 :Microbilogie des aliments-Dénombrement en anaérobiose des bacteries sulfuto-reducteuces par comptage des colonies à 46°C. International organisation for standardization. Geneva. Switzeland.

AFNOR (2009b). NF V08-060 : Microbilogie des aliments-Dénombrement des coliformes thermotolérants par comptage des colonies obtenues à 44°C. International organisation for standardization. Geneva. Switzeland.

Akkari E, Chevallier S, Boillereaux L (2006). Observation-based monitoring of thermal runaway in microwaves food defrosting. J. Process Contr. 6:993-1001.

Ang TK, Ford DJ, Pei CT (1977). Microwave Freeze-Drying of food : A theoritical Investigation. Int. J. Heat Mass Transfer. 20:517-526.

Anonymous (2013). Balance Economique Agricole pour l'année 2013, Compte redue annuel. Ministre de l'agriculture et des ressources hydrauliques.

Apostolo I, Papadopouloua C, Levidiotoua S, Ioannides k (2005). The effect of short-time microwave exposures on *Escherichia coli* O157:H7 inoculated onto chicken meat portions and whole chickens. Int. J. Food Microbiol. 101:105–110.

Aranzana LG, Santamaría P , López R , Garijo P , Gutiérrez AR , Cerdán TG, Alfaro IL (2013). Microwave technology as a new tool to improve microbiological control of oak barrels: A preliminary study. Food Contr. 30:536-539.

Arocas A, Sanz T, Hernando MI, Fiszman SM (2011). Comparing microwave- and water bath-thawed starch-based sauces : Infrared thermography, rheology and microstructure. Food Hydrocolloids 25:1554-1562.

Awua GB, Ramaswamy HS, Economides A, Mallikarjunan K (2005). Inactivation of *Escherichia coli* K-12 and *Listeria innocua* in milk using radio frequency (RF) heating. Innovative Food Sci. Emerg. Technol. 6:396-402.

Bedoui ID, Abdellaoui H, Alexa R, Jocolot P, Druon C, Tessier FJ, Laguerre JC (2011). Optimization of microwave cooking of courgette in terms of nutriment preservation and energy consumption. Procedia Food Sci. 1:805-813.

Bengtsson NE, Risman PO (1971). Dielectric properties of food at 3 GHz as determined by a cavity perturbation technique.II. Measurment on food materiels. J. Microwave Power. 6:107-123.

Brent A, Anderson R, Singh P (2006). Modling the thawing of frozen foods using air impingement technology. Int. J. Refri. 29:294-304.

Brows JR (1999). Variable frequency microwaves heating on food. J. Microwave Power. 34(4):227-38.

Burfoot D, Griffin WJ, James SJ (1988). Microwave Pasteurisation of Prepared Meals. J. Food Eng. 8:145-156.

Byrne B, Lyng JG, Dunne G, Bolton JD (2010). Radio frequency heating of comminuted meats – Considerations in relation to microbial challenge studies. Food Contr. 21:125-131.

Chaiyo K, Rattanadech P (2001). Numerical analysis of microwave melting of ice-saturated porous medium filled in rectangular waveguide with resonator using a combined transfinite interpolation and PDE methods. Int. J. Heat Mass Transfer. 54:2043-2055.

Chandrasekaran S, Ramanathan S, Basak S (2013). Microwave food processing-A review. Food Res. Int. 52:243-261.

Cha-um, W, Rattanadecho P, Pakdee W (2009). Experimental and

numerical analysis of microwave heating of water and oil using a rectangular wave guide: Influence of sample sizes, positions, and microwave power. Food Bioprocess Technol. 3:813-825.

Cherbanski R, Rudniak L (2013). Modelling of microwave heating of water in a monomode applicator e Influence of operating conditions. Int. J. Therm. Sci. 1-16 in press.

Cocci E, Sacchetti G, Vallicelli M, Angioloni A, Dalla Rosa M (2008). Spaghetti cooking by microwave oven: Cooking kinetics and product quality. J. Food Eng. 85:537-546.

Codex Alimentarus (1993). Code d'usages en matiere d'hygiene pour les aliments precuisines et cuisines en restauration collective. CAC/RCP.39-1993. FAO, Rome

Codex Alimentarus (1997). Principles for the establishment and application of microbiological criteria for foods. CAC/GL.21–1997. FAO, Rome.

Codex Alimentarus (2007). Directives generales sur l'echantillonnage. CAC/GL.50-2007. FAO, Rome.

Codex Alimentarus (2007).Codex general standard for quick frozen fish fillets. Codex Stan. 190-1995. FAO, Rome.

Dev SRS, Rghavan GSV, Gariepy Y (2008). Dielectric properties of egg components and microwave heating for in-shell pasteurisation of egg. J. Food Eng. 86:207-214.

Dov B. Schlisselberg, Kler E, Kalily E, Kisluk G, Karniel O, Yaron S (2013). Inactivation of foodborne pathogens in ground beef by cooking with highly controlled radio frequency energy. Int. J. Food Microbiol. 160: 219–226.

Dreyfuss MS, Chipley JR (1980). Comparison of effects of sublethal microwave radiation and conventional heating on the metabolic activity of *Staphylococcus aureus*. Appl. Environ. Microbiol. 39(1):13-16.

Dreyfuss MS, Chipley JR (1980). Comparison of Effects of Sublethal Microwave Radiation and Conventional Heating on the Metabolic Activity of Staphylococcus aureus. Appl. Environ. Microbiol. 39:13-16.

European Commission (2006). Document d orientations relatif à l échantillonnage et l'analyse microbioLogiques des denrées alimentaires dans le cadre des contrôles officiels effectues en application du règlement (CE) n° 882/2004. Brussels. Belgium.

Farkas J (1998). Irradiation as a method for decontaminating food a review. Int. J. Food Microbiol. 44:189-204.

FDA (2006). Kinetics of Microbial inactivation for alternative Food Processing Technologies: Microwave and Radio Frequency Processing. www.fda.gov/food/foodScienceResearch/safetyPracticesforfoodprocess.

Fiore A, Di Monaco A, Cavella S, Visconti A, Karneili O, Bernhardt S, Fogliano V (2013). Chemical profile and sensory properties of different foods cooked by a new radiofrequency oven. Food Chem. 139:515–520.

Gentrya ST, Roberts JS (2005). Design and evaluation of a continuous flow microwave pasteurization system for apple cider. Food Sci. Technol. 38:227–238.

Goksoy EO, James C, Corry JEL (2000). The effect of short-time microwave exposures on inoculated pathogens on chicken and the shelf-life of uninoculated chicken meat. J. Food Eng. 45:153-160.

Hamoud-Agha MM, Curet S, Simonin H, Boillereaux L (2013). Microwave inactivation of Echericjia coli K12 CIP 54.117 in a gel medium: Experimental and numerical strudy. J. Food Eng. 116:315-323.

Harrison MA, Carpenter SL (1989). Survival of *Listeria monocytogenes*in cooked poultry.Food Microbiol. 6:153-l57.

Heddleson RA, Doores S (1994). Factors affecting microwave heating of foods and microwave induced destruction of food borne pathogens. A review. J. Food Protect. 57(11):1025-1037.

Hill MA (1994). Vitamine retention in microwave cooking and cook-chill foods. Food Chem. 49:131-136.

Hong SM, Park JK, Lee YO (2004). Mechanisms of microwave irradiation involved in the destruction of fecal coliforms from biosolids. Water Res. 38:1615–1625.

Huang L, Sites J (2007). Automatic control of a microwave heating process for in-package pasteurization of beef frankfurters. J. Food Eng. 80:226-233.

ISO (1979). ISO 2293 : Meat and meat products- Aerobic count at 30 degrees. International organisation for standardization. Geneva. Switzeland.

ISO (1999). ISO 6888-1 : Microbilogie- Directives générales pour le dénombrement de *Staphylococcus aureus*-Méthode de comptage des colonies. International organisation for standardization. Geneva. Switzeland.

ISO (2002). ISO 6579 : Microbilogie des aliments –Méthode horizontale pour la recherche des *Salmonella* spp. International organisation for standardization. Geneva. Switzeland.

ISO (2006). ISO 19036 : Microbilogie des denrees alimentaires et des aliments pour animeaux- Guide pour l estimation de l incertitue des mesures pour les determinations quantitatives. ISO/TC 34/SC 9. International organisation for standardization. Geneva. Switzeland.

Jo C, Kim HJ, Kim DH, Lee WK, Ham JS, Byun MW (2007). Radiation sensitivity pathogens in ice cream. Food Cont. 18:859-865.

Journal Officiel de la République Française (1980). Arrête du 21 décembre 1979 relatif aux critères microbiologiques auxquels doivent satisfaire certaines denrées animales ou d'origine animale. J.O.R.F du 19 Janvier. p. 784-789.

Journal Officiel de la République Française (2007). Règlement (CE) N°1441/2007 de la commission du 5 décembre 2007. Concernant les critères microbiologiques applicables aux denrées alimentaires. J.O.R.F. du 7 décembre.12. L 322.

Journal officiel de la République Tunisienne (1992). Loi n° 92-117 du 7 décembre relative à la protection du consommateur. J.O.R.T, 83 : p.1571-1574.

Kamat AS, Nair PM (1996). Identification of Listeria innocua as a Biological Indicator for Inactivation of L.monocutogenes by some Meat Processing Treatments. Food Sci.Technol. 29:714-720.

Komarov V, Wang S, Tang J (2005). Permittivity and measurement, in: V. Komarov, S. Wang, J. Tang (Eds.). *Encyclopedia* of RF and Microwave Engineering, Wiley-interscience, New York. pp. 3694-3711.

Kone KY, Druon C, Gnimpieba EZ, Delmotte M, Duquenoy A, Laguerre JC (2013). Power density control in microwave assisted air drying to improve quality of food. J. Food Eng. 119:750-757.

Lau MH, Tang J (2002). Pasteurization of pickled asparagus using 915 MHz microwaves. J. Food Eng. 51:283-290.

Lin YC, Hsu KH, Lin JF (2014). Rapid palm-biodiesel production assisted by a microwave system and sodium methoxide catalyst. Fuel. 115:306-311.

Liu Y, Fan X, Chen YR, Thayer DW (2003). Changes in structure and color charachteristics of irradiated chicken breasts as a fuction of dosage and storage time. Meat Sci. 63:301-307.

Lu Y, Turley A, Dong X, Wu C (2011). Reduction of *Salmonella enterica* on grape tomatoes using microwave heating. Int. J. Food Microbiol. 145:349-352.

Maktabi S, Watson I, Parton R (2011). Synergistic effect of UV, laser and microwave radiation or conventional heating on *E. coli* and on some spoilage and pathogenic bacteria. Innovative Food Sci. Emerg. Technol. 12:129-134.

Miranda BDLV , López S, Malo AL, Morales MES (2012). Inactivation of *Salmonella Typhimurium* in fresh vegetables using water-assisted microwave heating. Food Contr. 26:19-22.

Nasri K, Daghfous D, Landoulsi A (2013). Effects of microwave (2.45 GHz) irradiation on some biological characters of *Salmonella typhimurium*. C. R. BioLogies. 336:194-202.

Ohlsson T (1989). Dielectrical properties and Microwave processing, in: RP. Singh, AG. Medina (Eds.). Food Properties and computer aiding engineering of Food Processing System. NATO Adv. Sci. Inst. Ser., Ser. 168. pp.73-92.

Ohlsson T, Bengtsson NE (1975).dielectric Food Data for Microwave Sterilization Processing. J. Microwave Power. 10:93-108.

Ozkoc SO, Sumnu G, Sahin S, Turabi E (2009). Investigation of physicochemical properties of breads baked in micrpwave and infrared-microwave combination ovens during storage. Eur. Food Res. Technol. 288:883-893.

Palaniappan S, Sastry SK, Richter ER (1990). Effects of electricity on microorganisms. J. Food Process Preserv. 14:393-414.

Papadopoulou C, Demetriou D, Panagiou A, Levidiotou S, Gessouli H, Ioannides K, Antoniades G (1995). Survival of Enterobacteria in liquid cultures during microwave radiation and conventional heating.

Microbiol. Res.150:305-309.
Rattanadecho P (2004). Theoritical and experimental investigation of microwave thawing of frozen layer using microwave oven (effects of layered configurations and layer thickness). Int. J. Heat Mass Transfer. 47:937-945.
Ryyniinen S (1995). Electromagnetic properties of food materials: a review of a basic principles. J. Food Eng. 26:409-429.
Schlisselberg DB, Kler E, Kalily E, Kisluk G, Karniel O, Yaron S (2013). Inactivation of foodborne pathogens in groud beef by cooking with highly controlled radio frequency energy. Int. J. Food Microbiol. 160:219-226.
Shamis Y, Taube A, Croft R, Crawford RJ, Ivanova EP (2012). Influence of 18 GHz Microwave Radiation on the Enzymatic of *Escherichia Coli* laxtate Dehydrogenase and Cytochrome c Oxidase. J. Phys. Sci. Appl. 2(6):143-151.
Sivaramakrishnan SR (2010). Microwave Pasteurization of Shell Eggs. PhD dissertation, University of McGill, USA.
Taher BJ, Farid MM (2001). Cyclic microwave thawing of frozen meat: experimental and theoretical investigation. Chim. Eng. Process 40:379-389.
Thayer DW (1995). Use of Irradiation to kill Enteric Pathogens on Meat and poultry. J. Food Safety 15:181-192.
Thostenson ET, Chou TW (1999). Microwave processing: fundamentals and applications. Composites: Part A. 30:1055-1071.
Tinoco MB, Navarrete NM, Rodrigo D (2014). Impact of temperature on lethality of kiwifruit puree pasteurization by thermal and microwave processing. Food Contr. 35:22-25.
Tyagi VK, Lo SL (2013). Microwave irradiation: A sustainable way for sludge treatment and resource recovery. Renew. Sustain. Energy Rev. 18:288-305.
Uemura K, Isobe S (2002). Developing a new apparatus for inactivating *Echerichia coli* in saline water with high electrical field AC. J. Food Eng. 53:203-207.
Uemura K, Takahashi C, Kobayashi I (2010). Inactivation of *Bacillus subtilis* spores in soybean milk by radio-frequency flash heating. J. Food Eng. 100:622–626.
Vadivambal R, Jayas DS (2007). Changes in quality of microwave-treated agricultural products- A review. Bioprocess Biosyst. Eng. 98:1-16.
Venkatesh MS, Raghavan GSV (2004). An Overview of Microwave Processing and Dielectric Properties of Agri-food Materials a papier review. Bios. Eng.88:1-18.
Wang Y, Zhang M, Mujumdar AS, Mothibe KJ, Azam SMR (2012). Effect of microwave freeze drying of stem lettuce cubes in a circular conduit drying chamber. J. Food Eng. 113:177-186.
Welt BA, Tong CH, Rossen JL, Lund DB (1994). Effect of microwave Radiation on Inactivation of Clostridium sporogenes (PA 3679) Spores. App. Envi. Microbiol. 60:482-488.
Wu Y, Yao M (2011). Effects of microwave irradiation on concentration, diversity and gene mutation of culturable airborne microorganisms of inhalable sizes in different environments. J. Aerosol Sci. 42:800–810.
Yahmaee P, Durance TD (2005). Destruction and injury of Escherichia coli during microwave under vacuum. J. Appl. Microbiol. 98:498-506.
Yang HW, Gunasekaran S (2004). Comparison of temperature distribution in model food cylinders based on Maxwell's equations and Lambert's law during pulsed microwave heating. J. Food Engineering. 64:445-453.
Zhang Q, Brian D, Welch J, Park H, Wu CY, Sigmund W (2010). Microwave assisted nanofibrous air filtration for disinfection of bioaerosols. technical note. J. Aerosol Sci. 41:880-888.