Food Cooking by Microwave-Excited Plasmoid in Air Atmosphere

Eli Jerby*, Yehuda Meir, Rafael Jaffe, and Iris Jerby

Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, Israel
*E-mail: jerby@eng.tau.ac.il

This paper presents a cooking technique by a microwave-excited plasmoid ("fireball") in air atmosphere. The stable plasmoid is generated by localized microwaves from a solid or liquid substrate (e.g. salty water). Preliminary experiments yield relatively rapid cooking of meet chunks within such plasmoids. Their flavour and taste could be affected to some extent by the origin substrate content. A major concern stems, however, from the hazardous effect of nanoparticles generated by the plasmoid, and by their possible toxicity in contact with the food items. Thus, another approach is considered, in which the plasmoid serves as a means to convert microwave energy to heat, whereas the latter is provided indirectly by heat conduction to the food items. This technique can be combined with direct microwave heating, as a hybrid microwave-plasmoid cooking within the same chamber. Preliminary experimental schemes and results are presented and discussed.

Keywords: Microwave ovens, plasma cooking, food browning, food safety

INTRODUCTION

Microwave ovens, extensively used for food cooking and thermal processing, are well known for their quick, low-cost, easy-to-use, and safe heating of food [1]. Microwave cooking is preferred over conventional heating also because of its lesser effect on the original taste, and for various health-oriented reasons, such as, for instance, the larger phenolic and antioxidant content in microwave heating compared to boiling of vegetables [2]. Another example is the smaller losses in B-vitamin and minerals in microwave cooking of chickpeas compared to other cooking techniques [3].

A major issue in microwave heating is the non-uniform heating pattern and hotspot formation. The outer surface of the food item is typically heated less than the internal parts, also due to the cooler surrounding air [1]. This drawback is alleviated to some extent by hybrids with other heating techniques, combining for instance either streaming of hot air, susceptors, conventional heating, or infra-red lamps, in order to elevate the heating rate of the food's outer surface [1].

Plasma is used for fast sterilization in a non-toxic etching process which provides dry and low temperature conditions [4, 5]. In particular, disinfection of solid food items is enabled by a plasma technology [6]. Food processing by plasma is yet a premature field, which introduces advantages and disadvantages that still need to be studied [7]. The utilization of microwave-excited gaseous plasma for rapid cooking, presented in [8-10], also adds colour and texture to the food. Plasma can be generated more easily by localized microwaves also from solid and liquid substrates in forms of fire-columns and fireballs in air atmosphere [11]. However, these plasmoids may contain nano-particles [12] which might be harmful for the food quality and even make it inedible [13-15].

In this preliminary study we explore techniques for fast cooking of food items by microwave-excited fireballs and fire-columns. This paper presents experimental setups and preliminary results, and discusses the feasibility, limitations and potentials of these plasmoids for cooking of food.

MATERIALS AND METHODS

Conceptual schemes of two experimental cooking techniques are depicted in Figs. 1a, b. The substrate preferred in both cases, as the origin for the microwave-excited plasmoids [11], is salty water. A movable electrode (not shown) or a water jet may assist the initial ignition of the plasma. Vapours and plasma are ejected from the hotspot created, and form either a stable plasmoid buoyant near the cavity ceiling or a fire-column, as shown in Fig. 1a and Fig. 1b, respectively. A skewer with chunks of food items (chicken breast in our tests) is inserted through the plasma in order to cook the chunk. However, in the scheme shown in Fig. 1a the cooked food is exposed also to direct irradiation by microwaves (hence considered as a hybrid cooking mode). The fire-column shown in Fig. 1b may protrude from the microwave cavity hence enabling the cooking process in a microwave-free region outside the cavity. This separation between the plasma and the (optional) microwave cooking stages may improve the controllability of the process (e.g. for browning) and yet enable a combined plasma-microwave cooking in the proper exposure in each stage.

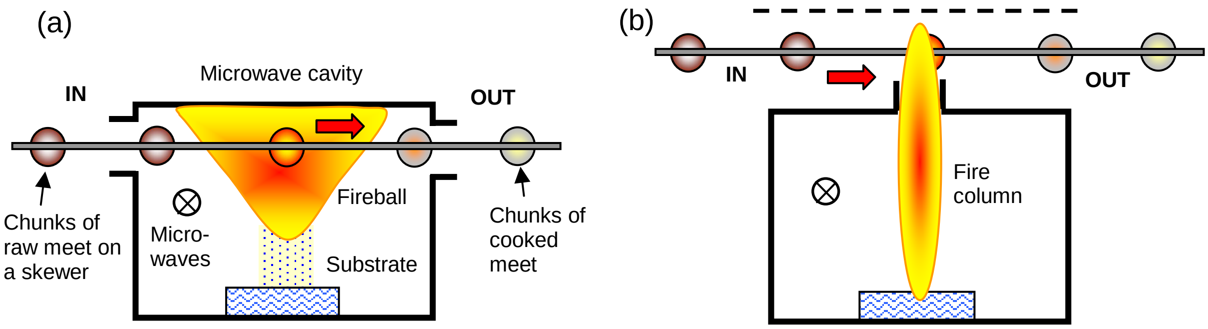

Figure 1. Conceptual schemes of cooking meet chunks by microwave-excited plasmoids: (a) Hybrid cooking by both a fireball (excited from salty water) and microwaves, within the microwave cavity. (b) Sole plasma cooking by a fire-column protruding outside the microwave cavity.

The microwave cavity is fed by a 2.45-GHz, 0.8-kW magnetron via an impedance-matching tuner, as in [11]. The openings in the cavity walls are designed to cutoff microwave leaks, and yet to enable insertion of the skewered chunks and viewing of the cooking process. For the sole-plasma scheme shown in Fig. 1b, a hole made in the cavity ceiling enables the fire-column to protrude outside the cavity and into the cooking chamber above, designed as a waveguide under cutoff at 2.45-GHz frequency. Figures 2a and b show the same experimental setup operating in fireball and fire-column modes, respectively, whereas in the latter mostly the plasma is extended into the cooking chamber. The food items tested in this preliminary experiment are mostly chicken-breast chunks, 3.5-g each. In the scheme shown in Figs. 1b, 2b, the moving skewer is passing 20 mm above the opening between the microwave cavity and the cooking chamber in order to minimize the direct effect of the evanescent microwaves on the plasma cooking process.

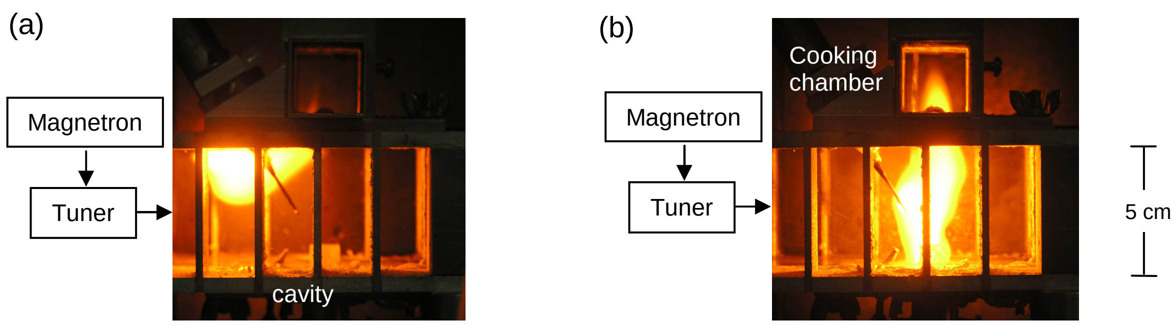

Figure 2. The microwave cavity and cooking chamber combined in the fireball mode (a) and separated in the fire-column mode (b).

RESULTS AND DISCUSSION

The preliminary feasibility tests presented in this section were performed in the conditions presented above. Figure 3 shows for instance a typical progress obtained using the cooking chamber (Fig. 2b). The results are shown for comparison with and without the plasma, at the same microwave power. In both cases, neither of the samples was cooked through after 15 s, though a slight scorching and a beginning of cooking in the outer layer is evidenced with the plasma. Cooking for 20 s yielded raw without the plasma, and small amount of scorching with it. After 30 s both samples were cooked through, but the plasma cooking created some browning and slight burning on the outer surface. After

45 s, the plasma cooked sample was dried at its interior and scorched at its outside. A more uniform plasma effect on the surface is achieved by rotating the skewer while inserted into the plasma.

	15 s	22 s	30 s	45 s
Without plasma				
With plasma				

Figure 3. Samples exposed for different time periods in the setup shown in Figs. 1b, 2b with and without plasma. The plasma scorching effect on the outer surface, in addition to the cooking through, is noticed.

In general, the plasma cooking (while isolated from the microwaves) yields a significant cooking of the outer layer with some degree of scorching, while the inside of the sample remains raw. In a proper balance with a microwave cooking, the entire sample is cooked through with an additional browning effect on the surface and a slight burning flavor, similar to barbequed meet.

In addition to common tests applied to cooking techniques, in aspects of quality, efficiency and safety, in this case also the potential toxicity of nanoparticles generated within the plasma [12] shall be taken into consideration. Nanoparticles in general have properties significantly different from the original material due to their larger surface-to-volume ratio. Their toxicological damage may involve generation of reactive oxygen species, protein misfolding, membrane perturbation, etc. [13, 14]. Though there is no regulation for nanoparticle safety, caution is suggested on the basis of the limited data available [15]. Other gaseous hazards such as hydroxyl, nitric oxide and cyano radicals may exist in microwave-generated plasmas in air atmosphere, but also in conventional flames [16].

In view of the safety concerns related to the direct contact between the food items and the plasma, another indirect approach to utilize these plasmoids has been considered. In this approach, illustrated in Fig. 4, the plasmoid is used as a *susceptor* which converts the microwave energy into heat. The latter is delivered to the food indirectly as a flame heating the food's metallic container. Calorimteric measurements have shown the potential of a nearly perfect efficiency in the energy conversion, from the net microwave power absorbed in the plasma to heat energy. Furthermore, a >1 efficiency can be achieved by incorporating an exothermal reaction, e.g. by adding sugar as carbohydrate additive to the plasma, hence gaining also the chemical energy catalyzed by the microwave plasma (a similar approach has demonstrated recently >20 energy gain by microwave ignition of thermite powders [17]).

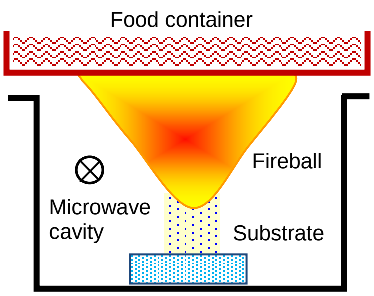

Figure 4. Indirect heating by using plasma as a susceptor to convert microwave energy to heat.

CONCLUSIONS

Preliminary experimental results demonstrate the potential of microwave-excited plasmas as means for heating and cooking of food in various schemes, including (a) direct plasma heating by inserting the food item into it, (b) hybrid cooking by microwaves and plasma combined (e.g. to gain browning and flavour effects), and (c) indirect heating by the plasma as a microwave susceptor in exothermic reaction.

Further studies are needed in order to examine aspects of safety, quality and efficiency presented by each of the approaches for a variety of foods, and to improve it further. Scale-up considerations are needed in order to define a reasonable range of applications, if any, for each of the methods discussed, either in domestic, catering, or industrial scale.

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