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Evaluation of physical, rheological, microbial and organoleptic properties of meat powder produced by Refractance-Window drying

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ABSTRACT

Meat spoils very rapidly and its microbial load exceeds the permitted limit very soon even if it is kept in a refrigerator. The main goal of this study was to dry meat by a Refractance-Window drier successfully, for the first time, and evaluate its compositional, physical, rheological behavior, microbiological and organoleptic properties. Meat powder produced by RW drying had good physical properties including maximum absolute density of 0.81g cm^{-3}, porosity of 0.67, rehydration ratio of 2.8, L^* value of 64 and minimum a^*/b^* value of 0.57. Herschel-Bulkley and Bingham models could predict rheological indices of meat powder solutions with high R^2 rates of 0.955-0.995. Sensory evaluation indicated that although meat powder obtained from 3mm slices was more favourable for panelists, the consistency of 2mm meat powders was more agreeable, which could be attributed to better functional properties of more dried samples. *100°C&2mm* treatment could decrease aerobic bacterial count from 6.1 to 3.7 log CFU/g and *Enterobacteriaceae* population from 3.1 log CFU/g to nil successfully. In summary, our comparison indicated that meat powder produced by Refractance-Window drying technique can lead to better dried products than dried meats having been prepared with other novel techniques recently.

KEYWORDS: bacterial population, meat powder, overall acceptance, Refractance-Window drying

Introduction

Proteins accelerate chemical reactions in our body, maintain and strengthen its structure, serve as its chemical messengers, fight against its infection and distribute oxygen throughout it. Animal proteins are usually considered complete proteins because they contain all of the essential amino acids our bodies need. Nevertheless, meat spoils very rapidly and its microbial load exceeds permitted limits very soon even if it is kept in refrigerators; besides, microbial growth adversely affects organoleptic properties of the food product during meat storage.[1,2] Drying process is an effective way to preserve quality and increase shelf life of food products during long-term storage.

Also, it brings about several other benefits including major weight or volume reduction, and as a result, dwindling costs of packaging, storage and transportation of the product.

Common hot air drying has disadvantages including long drying duration, reducing organoleptic and nutritional qualities of food products, and case hardening.[3,4] Application of high temperatures (120–170°C) during drum drying diminishes nutritional quality of food products; although this equipment could be coupled by a vacuum chamber, it might come at the cost of high capital investment. Osmotic drying is not applicable to all kinds of products and could affect sensory evaluation of the samples.[5] Industrial application of microwave drying is restricted and it needs complicated controlling equipment. So, there was a need to develop an alternative rather fast processing method that could guarantee quality retention and maximize financial productivity during drying process.

Refractance-Window (RW) technology is a drying system in which water is circulated at atmospheric pressure to convey heat to the product and dry it; in this approach, wet product, especially fruits and vegetables, is applied on the surface of an infrared-transparent conveyer belt passed above heated circulating water; in fact, circulation of hot water is maintained to ensure uniform temperature profile in the product.[6,7] The infrared-transparent surface could be a Mylar membrane or even a Pyrex glass since as surveyed by Florence et al.[8] this kind of glass can reflect, scatter and absorb parts of near-infrared energy. Nonetheless, recent researches have shown infrared energy might not play a major role in this kind of drying for food samples at all. In detail, Zotarelli et al.[9] investigating into effect of process variables including water temperature, product thickness and radiant source on drying characteristics of mango pulp by RW approach, revealed that radiative heat transfer contributes to less than 5% of total amount of energy delivery to food during the process. Anyhow, contrary to several hours required for other conventional drying systems such as freeze drying, this system usually takes from less than 5min to 200min to complete drying treatment, depending on the product itself, available equipment, and required quality or process duration.[10] Milder temperatures applied, less capital investment and energy resources required, and desirable sensory properties of the final product are other advantages of this drying type.

Regardless of the possibility of applying RW drying approach for meat, there are a couple of recent researches dealt with extending the shelf life of meat and meat products either by application of novel methods or by combination of well-known approaches. Cantalejo et al.[11] studied combined effects of ozone and freeze-drying on the shelf life of broiler chicken meat. They concluded that ozone treatment affected sensory evaluation of the final product adversely; besides, length of drying procedure (ozone treatment and freeze drying) and its cost make application of this method unreasonable to some extent. Baslar et al.[12] introduced ultrasonic vacuum drying technique as a novel process for treatment of beef meats. However, they did not succeed to shorten the drying time to a rapid and effective duration and total drying times of between 5 to 16hours were required to dry beef meat completely. Babic et al.[13] studied the effects of freeze-drying process parameters on broiler chicken breast meat. However, they spent around 20hours as the total drying time; so, this procedure could be very time consuming, energy demanding, and not cost-effective.

So, the probability of applying RW drying apparatus for successful drying of meat products, as a new solution for the problem, made it necessary to survey the history of applying RW technique on food products. Hernández-Santos et al.[14] compared the effects of different drying techniques (RW and convective), temperatures (74 and 94°C) and samples thickness (0.2 and 0.4 cm) on drying time as well as quality of carrot slices. They reported that RW (at 94°C) could dwindle drying time by approximately 45% compared with convective drying method (at the same temperature). Besides, RW dried carrot samples had higher total polyphenols and antioxidant activities than convective dried ones at each temperature or thickness. Castoldi et al.[15] surveyed impacts of different drying conditions including diverse water temperatures (between 65 and 95°C with 10°C increments) and pulp thickness (2 and 3mm) of RW method on drying rates and characteristics of tomato powder. The drying process of tomato powder completed after only 17min; meanwhile, high solubility rates of 87-95% and short dispersion times of 4-9s were achieved for tomato powder produced through this method. In another research, Caparino et al.[16] compared drying rates and microstructural changes in mango powder dried by RW or freeze drying methods. They observed that dwindling water content of mango solids from 6.52kg water/kg mango solids to below 0.05kg water/kg mango solids was completed in about 3min while freeze drying lasted nearly 31 h. They also reported the lack of significant differences in glass transition temperatures of RW-dried and freeze-dried mango powder solids at all water activities, except for $a_w = 0.86$. Finally, and more relevantly, Aghaei[17] compared the effects of different drying methods i.e. traditional, RW with Mylar membrane, RW with Pyrex surface, and oven, and various temperatures of 25, 60, 70 and 80°C on physical, nutritional and organoleptic properties of saffron. They concluded that RW with Pyrex surface and 80°C could result in better picrocrocin, safranal, crocin maintenance than other drying approaches and temperatures.

So, after regarding the literature review represented above, there were a couple of questions which could be responded by carrying out the current research, including which drying temperatures and product thickness are better to be deployed in RW method, how the diverse characteristics including physical, rheological, microbial and organoleptic properties of dried meat powders will be after RW processing, whether the characteristics of meat powder obtained by RW drying are superior than other food powders or dried meats obtained by other drying techniques.

Materials and Methods

RW drying

A laboratory-scale RW dryer was used for drying of meat slices. The main components of the dryer included a 5.5 L stainless-steel thermostatic water bath (Memmert, Gernany), and a heating unit. The temperature of hot water was continuously monitored using pre-calibrated type T thermocouple sensors. The temperatures applied on the meat slices (2 and 3mm) were 80-100°C. During drying, thermal energy from hot water was transmitted through the surface to meat slices by conduction and radiation, used to remove moisture from the product. According to our pretests, it was indicated that 120 and 150min, at temperatures of 100 and 80°C respectively, were enough to reach desired moisture ratio of below 0.10in our dried samples. Then, dried meat pieces were ground by an electric coffee/spice grinder (Bialetti, Italy) till fine powder was obtained. Milled meat powder was sieved using a 1.0mm sieve. Finally, the milled powder was weighed and stored in a dark air-tight glass container before further analysis.

Compositional analysis

Determination of moisture, ash, protein, fat, and total volatile nitrogen (TVN) of meat samples and final powders was performed according to AOAC.[18]

Physical properties of meat powders

The bulk density (ρ_b), absolute density (ρ_{abs}), porosity (ε), Hausner ratio (HR), and Hygroscopicity were measured according to the methods of Akhavan Mahdavi et al.[19]

To determine Water Solubility Index (WSI), 2g of powder was added to distilled water (50mL) at 40°C and agitated in a glass beaker with a magnetic stirrer for 20min to allow for complete dispersion. The mixture was left resting for 15min and centrifuged (3-18K, Sigma) at 17,640×g for 20min at 30°C to separate the phases involved.[19] The supernatant was collected in a beaker, heated with a heater (HPM 6 Basic, IKA Labortechnik) at 100°C for 10-20min to evaporate most of its redundant water, and transferred to a pre-dried and weighed Erlenmeyer flask. Then, the Erlenmeyer flask was dried in an oven at 105°C for 1.5h, cooled in a desiccator (to avoid condensation affecting the results) and weighed. The powder solubility was calculated as[20]:

$$\mathrm{WSI} = \frac{100\left(\mathrm{W}_3 - \mathrm{W}_2\right)}{\mathrm{W}_1}$$

where W_1, W_2 and W_3 are sample weight, weight of flask, and weight of flask + dried powder, respectively.

Rehydration Ratio (RR) of samples was measured according to the methods of Davoodi et al.[21] Color parameters of meat and meat powder samples were analyzed using image processing method.[20] The pictures were analyzed by Image J software (version 1.42e, Wayne Rasband, National Institutes of Health, USA) and RBG parameters of the samples were converted to L^*, a^* and b^* values (CIELAB scale); Additionally, the ratios of a^* to b^* values were calculated to evaluate color quality of the samples.[22]

The measurement of water activity was performed with a thermostatic fully automatic computer-controlled device (Novasina LabMaster Standard Water Activity Instrument, Switzerland) where 2g of samples filled its low volume cells at 25°C.

Determination of the viscosity of meat powder solutions

First, the solution of 1% (w/w) of meat powders in distilled water was prepared. Then, the solution (16mL) was placed within the annulus of a concentric cylinder viscometer (Brookfield, model RVDV- II + pro, USA) having its spindle No.S02; the solution was poured into the measuring cup and the bob was immersed in the sample. All experiments were conducted at the temperature of 29°C, using a thermostatic circulating water bath (Model ULA- 40Y, Brookfield, Inc., USA). The shear rate was varied between 12.2 and 245s^{-1}. Different models of Bingham, Power law, Casson, and Herschel-Bulkley were used to model rheological behaviors of meat powder solutions.

Microbial analysis

For aerobic bacterial count, 10g of each sample was weighed and mixed with 90mL peptone water. The mixture was then shaken thoroughly for 2-3min, and allowed to settle for about 15min . From the first dilution (10^{-1}), serial dilutions were made up to 10^{-5} and 0.1mL of each dilution was inoculated onto sterile plate count agar (PCA) using the surface plating technique. The plates were incubated in an inverted position at 37˚C for 48hours, and plates with $30 < X > 300$ colonies were counted. The results were expressed as the log of colony-forming units per g (log CFU/g) of homogenized sample. For the determination of yeasts and molds, the above-mentioned method was followed except that the cultural medium was solidified potato dextrose agar and plates were incubated at 25˚C for 3-5 days. For determination of *Enterobacteriaceae*, the method was similar to the aforementioned method except that the diluent was cultured on 10-12mL of Mac-Conkey agar, then, after solidification, over layered with another 5-10mL of Mac-Conkey Agar and the plates were incubated at 37˚C for 48hours .[23]

Sensory evaluation

Barley soups containing raw meat or meat powder were subjected to sensory evaluation by 12 trained panelists. Assessed organoleptic attributes included color, aroma, consistency, taste and overall acceptance.

Statistical analysis

Mean comparison and the analyses of variance (ANOVA) were carried out using Statistical Analysis System (SAS) package, version 9.1 (SAS Institute, Inc., Cary, NC) and Duncan's multiple range tests at probability level of 0.05. All data were reported as mean ± standard error of two replicates unless the results were incongruent in which cases (e.g. RR of treatment 80°C&3mm) more than two replications was carried out. Optimization procedure and depiction of Figures were carried out by Excel software.

Results and Discussion

Composition of meat powders

As obvious in **Table 1**, moisture contents of 10% or lower was achieved by drying of meat slices (1.5-3mm) for 2-2.5h at *80 or 100°C* in RW drying. As predicted, moisture content of the meat powders obtained from 2mm slice thickness was less than its counterparts of 3mm thickness. Oil content of meat powder (measured by Soxhlet method) was 15.5 ± 2.3%. However, fat content of raw shank meat of local calves is dependent on its type: 3% in low-fat calf meat which we consumed in our experiments, 5% in medium-fat calf meat and 8% in high-fat calf meat.

As expected and clear in **Table 1**, the protein content of meat increased substantially and critically after drying: from 23 to 75%. This considerable raise shows this product could be used suitably for protein-rich diets. The increased ratio in protein rate was approximately 3.26 times from before to after drying, hinting that converting meat to meat powder would bring high value added and profit margin for industrial producers interested in supplying this product. The protein rates of different treatments were not different significantly. The rate of TVN increased principally: from 17.1 ± 1.0 to 60.1 ± 2.0%. However, the point is that the ratio of TVN to total protein remained nearly constant from before to after drying procedure; this proportion was 0.74 before drying, which reached around 0.81 after drying.

Density and porosity

While bulk density values of meat powders were varied from 0.27 to 0.39g cm^{-3}, absolute density values were in the range of 0.76-0.81g cm^{-3} (**Table 2**). The samples with lower final moistures had higher bulk densities since these samples, milled very well and converted to particles with lower sizes, could be packed much more effectively and the air among particles could be depleted appropriately, so their bulk volumes were lower and bulk densities higher. Samples dried at higher temperatures and lower thickness had higher bulk densities.

Hausner Ratio (HR)

The results of Hausner ratios for different treatments were represented in **Table 2**; in fact, except the treatment of *100°C&2mm* the result of which was similar to those powders with medium or rather difficult flowing properties, meat powders of other treatments had very difficult flowing properties and the use of external effective forces e.g. extruders or other carriers should be regarded if they (meat powders) are going to be used in production lines of the food industry (e.g. in formulations of cakes or cutlets).

Hygroscopicity

As can be seen in **Figure 1**, the major changes in hygroscopicity of meat powders happened in the first decade of the experiment when (fourth day) the absorption/desorption of moisture reached to its peak rate. Samples produced from both treatments of *80°C&2mm*, and *100°C&2mm* absorbed the moisture from the environment, the rates of which were 8.45 and 5.81g /100g . However, samples of other treatments (*80°C&3mm, 100°C&3mm*) lost their moisture, with their peak rates being -13 and -8.75g /100g, respectively. So, the absorption rate of moisture by meat powders prepared by RW method is low even in the environments with high relative humidity, which could be desirable for the application of meat powders in production lines of different food products since there will be no restriction regarding their moisture absorption from surrounding environments.

WSI

Water solubility indices of different meat powders were in the narrow range of 11.13-12.68%. The results indicated that higher temperatures caused less WSI. This could be explained by more protein denaturation, stable covalent linkage formation, and/or Maillard reaction during drying at elevated temperatures.[24] There is another theory too: during gradual heating, gelation of meat proteins occurs, which involves unfolding and consequent interlinking of muscle proteins and forming a strong three-dimensional network able to trap and stabilize water in itself; however, exposure to high temperatures might cause this gel to shrink severely and lead to a very tough texture.[25]

RR

RR of meat powders were in the range of 2.2-2.8. Again, lower temperature and thinner slices could result in better properties of the dried product. Regarding the temperature effect, the latter issue could be due to two reasons: first, high temperatures can bring about irreversible cellular collapse, deeply shrunken capillaries and diminished hydrophilic properties;[26] second reason is possibly extensive protein denaturation and probable hydrogen connections of macromolecules. [26] The similar pattern was reported by Seremet et al.[27] and Babic et al.[13] Generally, RR of meat powders obtained by RW drying in this research was much better than RR of other dried meat products e.g. 1.08-1.17 for pork meat dried at various combined cooking times, cooking pressures and drying temperatures,[28] 0.7-0.8 for chicken meat dried at different combined ozone and freeze drying conditions,[11] 0.6-0.9 for chicken meat dried by different combined conditions of superheated-steam drying and heat pump or hot air drying,[29] or 0.4-0.6 for freeze dried chicken breast meat[11] but lower than RR of some other dried food produces e.g. 4.48 for pulsed vacuum dried red pepper.[30]

Color

Drying of meat improved its transparency and color values significantly (**Table 3**). In the current research, the samples dried less satisfactory (*80°C&3mm*, *100°C&3mm* with higher moisture contents) had undesirable color parameters and their redness and a^*/b^* values were higher than other treatments. The main reason is that color compounds (myoglobin) of initial fresh meats remained more and, as a result, the redness of those survived pigments appeared in the less dried samples, increasing a^*/b^* value.

At higher temperatures, L^* values of meat powders were lower and a^*/b^* values higher, implying that more browning occurred. This event could be due to enzymatic and, more importantly, nonenzymatic reactions, considering that nonenzymatic browning reaction occurs at temperatures of 80-90°C and its intensity increases at higher temperatures. Higher thickness, which required longer treatment of the meat slices, caused worse color values, which is according to the results obtained by Paengkanya et al.[31]

Water activity

Water activity of dried meat powder was 0.298 ± 0.001. Although even lower water activities might be achieved for other dried food products (e.g. 0.12 for mango powder as revealed by Capartino et al.[32]),

this water activity is very desirable in food products since in the range of 0.2-0.4, not only is bacterial or yeast & molds growth stopped but also the rates of lipid oxidation, Maillard reactions, enzymatic activity and hydrolysis reactions become very low while in lower or higher water activities, those reactions might surge; as an example, lipid oxidation reaches to its peaks at water activities of 0-0.1 and 0.5-0.7. In the case of storage of meat powder obtained by RW drying, as it is clear from the results of water activity, the possibility of growth at such low water activities (around 0.3) is not provided for microorganisms.

Rheological properties

There are three different phases in the shear stress-shear rate curves of meat powder solutions (**Figure 2**): an initial minor ascending phase, a subsequent descending phase and finally, the most important one, a major ascending section. When looking at the viscosity-shear rate curve of meat powder solutions (**Figure 3**), two major phases are distinguishable: in the first phase continuing until the shear rate of around 100s $^{-1}$, viscosity reduces very steeply; but, in the second phase, viscosity raises gradually until the final point. As obvious in the curve of viscosity-shear rate, the rheological behavior of solutions is shear thickening, in its major (second) phase, as the n index of the solution is above 1 (**Table 4**) too.

Regarding **Figure 3**, the increase in suspension viscosity at high shear rates could occur due to secondary flows, grain-inertia effects (i.e. momentum transfer due to collisions between particles with fluctuating velocities) or transition to turbulence.[33] As an example, one explanation could be that connections and interactions among particles (especially proteins of meat powder which constitute the major part of the product) with each other or with aqueous environment were weak initially and, as a result, small hydrodynamic forces were able to break the agglomerations, but gradually, due to the break of particles to smaller ones at high shear rates, these connections increased and strengthened, resulting in higher viscosities and product resistances.[34]

As it could be observed in **Figure 3**, (two) solutions of *100°C* dried samples showed very similar rheological behaviors regarding their viscosities at different shear rates. So, it seems that temperature could be a determining index in the viscosity behavior of meat powder solutions. When comparing apparent viscosities (in **Figure 3**) at shear rates of 20-50s $^{-1}$, since shear rates of 1-100s $^{-1}$ are usually used for assessing sensory evaluation and mouth feel of food products, it could be seen that higher temperatures led to higher viscosities; the latter fact may be attributed to denaturation of protein structures or protein unfolding and interactions at higher temperatures, leading to a larger hydrodynamic radius of the particles and increased viscosity.[35] In other words, exposure of amino acid side chains during drying might result in a raise in electrostatic and hydrophobic intermolecular interactions.[36]

Among the various models applied to fit the rheological data of RW drying, Bingham and Herschel-Bulkley models fitted the data better than power law and Casson models (**Table 4**).

Microbial analysis

Drying caused microbial population of raw meat to decrease significantly; furthermore, drying of meat slices with thickness of *2mm* at *100°C* decreased this population more effectively than other treatments as you can see in **Table 5**. The most important point of **Table 5** is about yeast and molds population. As **Table 5** indicates, despite that sanitary issues were regarded during the meat processing since *Enterobacteriaceae* population which is a useful indicator of hygiene and post-processing contamination for heat processed foods was zero in processed products, mold an yeast population in the meat powder were higher than that in the raw meat; the reason is that in this project, it was impossible for us to control the processing environments completely and, more importantly, sterilize all equipment used during the process (mechanical slicer of meat, glass used in the RW drying apparatus, electrical grinder, environment during transfer of raw or processed meat/meat powder or other materials, …). However, there are novel methods to meet hygienic standards during industrial processing of food products e.g. cleaning in place (CIP) of surfaces and equipment. Another research suggestion, for further development of this subject, is to consider production of meat powder by RW technology where the processing section of the equipment is enclosed in a hygienic room and to compare the results of that kind of processing with the results of this research; in fact, in the modified way, controlling the air flow around the food samples, to avoid contamination of meat samples which are very susceptible to microbial contamination, is provided. Indeed, this option is possible in both batch and continuous RW processing of meat samples. Anyway, the rate of decrease in bacterial and fungi population in this research is reasonable when other similar studies, e.g. Cantalejo et al.[11] or Nagwekar et al.,[37] are considered.

Sensory evaluation

Soups containing meat powders produced from meat slices with 3mm thickness, having more moisture content, were more desirable than soups having *2mm* samples, especially in their taste (**Figure 4**). The reason is probably that these treatments were less affected by the drying procedure and, consequently, the initial texture, properties and taste of fresh meat were remained more effectively than other treatments. Another point of our sensory evaluation is that the only organoleptic property which did not follow the above-mentioned order was “consistency” in case of which meat powders prepared from *2mm* slice thickness had priority for the panelists. The reason could be that when proteins are affected by drying processes more deeply (e.g. in *2mm* samples), their structures are denaturated and their functional properties are improved due to the exposure of internal structures of proteins to the environment.

Optimization results

In the last step, to see the desirability of each treatment, we gave the importance (weight) to each response (physical, rheological, microbial and sensory evaluation) in Excel software (**Table 6**) and scored four treatments from 1 to 4 for each response, with 4 given to the best treatment and 1 to the worst; finally, we multiplied the average score of each treatment by 25 to report it in terms of percent. Bulk density was preferred to be maximized since it enabled its more effective storage (less volume per weight). However, maximizing bulk density might come at the expense of lower porosity and, as a result, solubility if absolute density did not raise in the similar ratio; so, porosity was intended to be maximized to consider the ratio of bulk to absolute density in our optimization procedure. The results indicated the order of overall desirability for treatments: *100°C&2mm* (76%), *80°C&2mm* (66%), *80°C&3mm* (58%), and *100°C&3mm* (49%). The main reason of this selection by the software was the high importance of microbial hazards for us as high temperature and, more importantly, thinner meat slices could minimize microbial contamination; on the other hand, treatment *100°C&3mm*, resulting in the highest aerobic bacterial count and moisture content, rated the lowest overall desirability: even below 50%.

Conclusion

While it is difficult to store raw meat for a long time, or consume it under different harsh conditions, meat powder could be produced by RW drying technique easily with low capital cost but effectively. Prepared meat powder by this technique could be very attractive for those people inclined in consuming pure protein products, e.g. professional sportsmen or children at puberty ages. Meat powder produced by RW drying had good physical properties, compared with meat products dried by other drying techniques, including maximum absolute density of 0.81g cm^{-3}, porosity of 0.67, rehydration ratio of 2.8, $L*$ value of 64 and minimum $a*/b*$ value of 0.57, low microbial population, as low as 3.72 log CFU/g of aerobic bacterial count, and zero population of *Enterobacteriaceae*, and desirable organoleptic properties, as high overall acceptance as 54-58 (out of 60). As far as rheological properties of meat powders are concerned, it was found that higher temperatures (*100°C* compared with *80°C*) resulted in higher viscosities at shear rates of 20-50s^{-1}, due to protein unfolding and interactions at higher temperatures, leading to a larger hydrodynamic radius of the particles. Meat powder could be incorporated into formulation of other food products e.g. cake, cutlet, dissolved into hot aqueous solutions e.g. soup, or consumed in other diverse ways. In comparison with other available drying techniques of meat products, RW drying method results in better characteristics of the final powder. The only important notice is that since this protein-rich powder is a very desirable medium for the growth or germination of microorganisms including *Staphylococcus* or yeast & molds, special and advance sanitary considerations are needed. Due to the latter point, applying high temperatures (*100°C*) on thin meat slices (*2mm*) is suggested for drying purpose.

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Table 1. Water and protein content of meat powders obtained through different treatments of meat slices by Refractance-Windows drying technique.

Treatment	Water Content (% w.b.)	Protein content (% w.b.)
Raw meat	76.009 ± 1.08^{a}	23.060 ± 1.09^{b}
80°C, 2 mm	8.211 ± 0.13^{c}	74.255 ± 0.22^{a}
80°C, 3 mm	10.110 ± 0.16^{c}	75.510 ± 1.63^{a}
100°C, 2 mm	9.971 ± 0.01^{c}	74.445 ± 0.83^{a}
100°C, 3 mm	16.465 ± 2.00^{b}	75.995 ± 0.32^{a}

Table 2. Physical properties of meat powders obtained through different treatments of meat slices by Refractance-Windows drying technique.

Physical property Treatment	Bulk density (g cm^{-3})	Absolute density (g cm^{-3})	Porosity	Hausner ratio	Water solubility index (%)	Rehydration ratio
80°C, 2 mm	0.374 ± 0.01^{ab}	0.787 ± 0.00^{ab}	0.525 ± 0.01^{bc}	1.397 ± 0.20^{b}	12.685 ± 0.43^{a}	2.830 ± 0.04^{a}
80°C, 3 mm	0.268 ± 0.01^{c}	0.808 ± 0.03^{a}	0.668 ± 0.02^{a}	1.924 ± 0.03^{a}	11.126 ± 0.39^{c}	2.320 ± 0.03^{b}
100°C, 2 mm	0.386 ± 0.00^{a}	0.756 ± 0.01^{b}	0.489 ± 0.01^{c}	1.285 ± 0.10^{b}	12.112 ± 0.13^{ab}	2.404 ± 0.05^{b}
100°C, 3 mm	0.339 ± 0.03^{b}	0.788 ± 0.01^{ab}	0.569 ± 0.03^{b}	1.429 ± 0.06^{b}	11.412 ± 0.25^{bc}	2.222 ± 0.17^{b}

Table 3. Color values of meat powders obtained through different treatments of meat slices by Refractance-Windows drying technique.

Treatment Color value	80°C, 2 mm	80°C, 3 mm	100°C, 2 mm	100°C, 3 mm	Raw meat
*L** value	58.873 ± 0.22	64.146 ± 0.48	60.709 ± 0.16	53.312 ± 1.20	30.422 ± 1.20
*a** value	12.993 ± 0.41	14.506 ± 0.65	13.579 ± 0.64	18.039 ± 0.41	41.461 ± 2.02
*b** value	22.952 ± 0.35	24.638 ± 0.31	23.615 ± 0.55	21.793 ± 0.43	11.201 ± 2.41
*a**/*b** value	0.566	0.589	0.575	0.828	3.701

Table 4. Rheological indices of meat powder (solutions) produced through different treatments of meat slices by Refractance-Windows drying technique.

Model	Bingham		Power law		Casson		Herschel-Bulkely	
Treatment	R^2	Equation	R^2	Equation	R^2	Equation	R^2	Equation
80°C,2 mm	0.958	$\tau = 0.002\gamma - 0.06$	0.933	$\tau = 0.001\gamma^{1.14}$	0.948	$\tau^{0.5} = 0.05\gamma^{0.5} - 0.010^{0.5}$	0.923	$\tau = (1.4E - 11)\gamma^{4.46} + 0.106$
80°C,3 mm	0.964	$\tau = 0.002\gamma - 0.05$	0.953	$\tau = 0.001\gamma^{1.12}$	0.960	$\tau^{0.5} = 0.05\gamma^{0.5} - 0.007^{0.5}$	0.971	$\tau = (8.0E - 09)\gamma^{3.26} + 0.107$
100°C, 2 mm	0.951	$\tau = 0.002\gamma - 0.04$	0.936	$\tau = 0.001\gamma^{1.06}$	0.945	$\tau^{0.5} = 0.04\gamma^{0.5} - 0.003^{0.5}$	0.995	$\tau = (7.2E - 09)\gamma^{3.24} + 0.129$
100°C, 3 mm	0.955	$\tau = 0.002\gamma - 0.05$	0.937	$\tau = 0.001\gamma^{1.07}$	0.948	$\tau^{0.5} = 0.05\gamma^{0.5} - 0.004^{0.5}$	0.939	$\tau = (7.5E - 12)\gamma^{4.55} + 0.131$

Table 5. Microbial properties of meat powders obtained through different treatments of meat slices by Refractance-Windows drying technique.

Microorganism Treatment	Aerobic bacterial count (log CFU/g)	Yeast & molds (log CFU/g)	*Enterobacteriaceae* (log CFU/g)
80°C, 2 mm	4.518 ± 0.04^{b}	4.238 ± 0.09^{ab}	No growth
80°C, 3 mm	4.454 ± 0.03^{b}	4.522 ± 0.06^{a}	No growth
100°C, 2 mm	3.724 ± 0.03^{c}	4.115 ± 0.16^{b}	No growth
100°C, 3 mm	6.115 ± 0.16^{a}	4.544 ± 0.03^{a}	No growth
Raw meat	6.094 ± 0.07^{a}	3.718 ± 0.13^{c}	3.146 ± 0.12

Table 6. Optimization table of physical, rheological, microbial and sensory evaluation for meat powder produced by Refractance-window drying method of meat slices.

Response	Lower limit	Upper limit	Unit	Goal	Importance
Moisture content	8.221	16.465	%	minimize	3
Bulk density	0.268	0.386	g cm^{-3}	maximize	1
Porosity	0.489	0.668	–	maximize	1
Hausner ratio	1.285	1.924	–	minimize	1
Water solubility index	11.126	12.685	%	maximize	2
Rehydration ratio	2.222	2.83	–	maximize	2
L*	53.312	64.146	–	maximize	2
a*/b*	0.566	0.828	–	minimize	2
Viscosity	1.75	3.49	mPa s	maximize	2
Aerobic bacteria count	3.72	6.115	Log CFU/g	minimize	6
Yeast and molds	4.12	4.522	Log CFU/g	minimize	6
Sensory evaluation[1]	44.25	49.50	–	maximize	4
Overall acceptance	44	58	–	maximize	4

[1] The average score of four organoleptic properties: aroma, color, consistency, taste.

Figure 1. Hygroscopicity of meat powders obtained by Refractance-Window drying of meat slices (2 or 3mm) at 80 or 100°C.

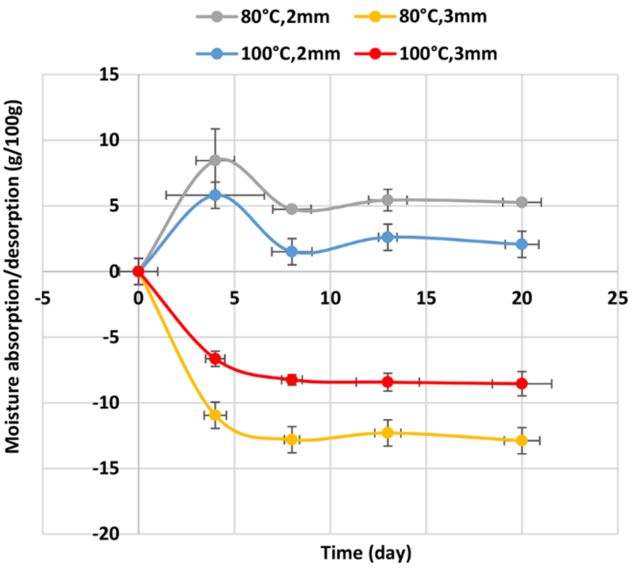

Figure 2. Shear stress vs. shear rate of meat powder (solutions) obtained by different drying treatments (80 and 100°C) of meat slices (2 and 3 mm).

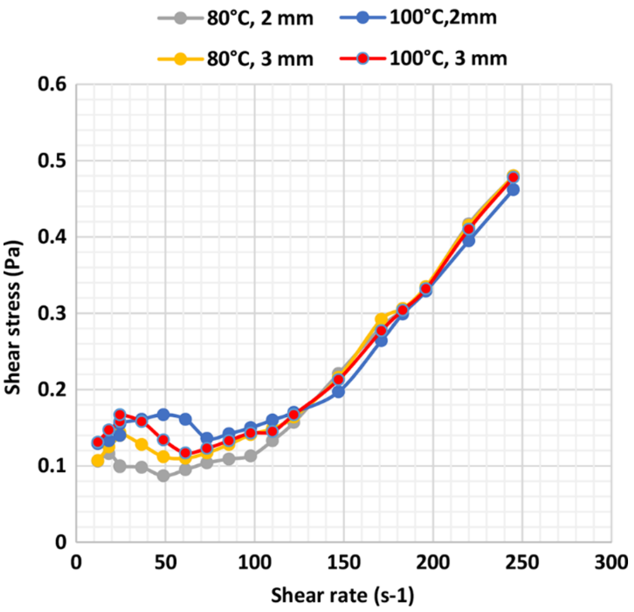

Figure 3. Viscosities of meat powder (solutions) obtained by different drying treatments (80 and 100°C) of meat slices (2 and 3 mm).

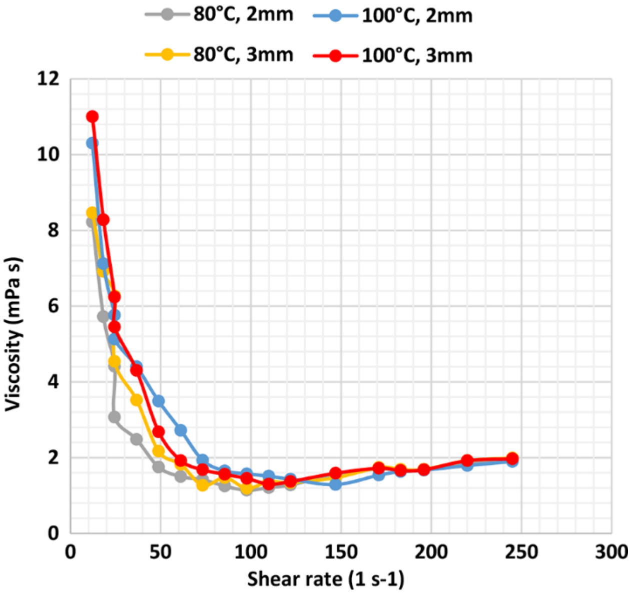

Figure 4. Sensory evaluation of meat powders (solutions) obtained by different drying treatments (80 and 100°C) of meat slices (2 and 3 mm).