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Effect of comminution temperature on the quality and shelf life of buffalo meat nuggets

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Abstract

Buffalo meat nuggets were prepared after equilibrating the ingredients to temperatures of 4, 10, 25 and 37 °C. Following comminution for 6 min, the temperatures of the batters were 16.3, 19.3, 27.4 and 34.8 °C and their pH and emulsion stability ranged from 6.18 to 6.29 and 88.76 to 95.33%, respectively. Increasing temperature of comminution led to increased cooking losses and TBARS values. However, even at 37 °C, complete emulsion breakdown did not occur as the cooking losses were still only about 12%. Texture profile analysis revealed an inverse relationship between chopping temperature and shear force. Sensory evaluation indicated that, at least up to comminution temperatures of 27.4 °C, the nuggets were acceptable. The aerobic mesophilic bacterial counts were higher for the nuggets made from batters with higher temperatures but, even at the 21st day of storage, the counts were well below the levels likely to cause spoilage in meat products. Results suggested that comminuted buffalo meat products can be manufactured in conditions where refrigeration is not available, by a preservation system (mostly chemical) to decrease microbial and chemical spoilage and also by devising an efficient marketing system for their early distribution (preferably 14 days).

Keywords: Buffalo meat; Nuggets; Comminution temperature; Quality; Shelf life

1. Introduction

Buffalo meat production in India contributes to about 53% of world meat production, about 85% of total meat being exported from India. The meat is primarily produced from spent animals when their productive life is at an end. Such meat is profitably utilized by comminuting, for the production of a variety of buffalo meat products, such as patties (Pati, Anjaneyulu, & Kondaiah, 1992), burgers (Modi, Mahendrakar, Narasimha Rao, & Sachindra, 2003), loaves (Suresh, Mendiratta, & Kondaiah, 2004), sausages (Sachindra, Sakhare, Yashoda, & Narasimha Rao, 2005) and nuggets (Thomas, Anjaneyulu, & Kondaiah, 2006). Several studies have been carried out on the effect of gross composition, ingredient quality and processing variables on a whole range of comminuted meat products. One of the most studied variables has been the temperature at which comminution take place. The reported results, however, are not consistent. Helmer and Saffle (1963) studied the effects of chopping temperatures on emulsion stability and reported that breakdown occurred in emulsions chopped at 16 °C or higher. However, no breakdown occurred in emulsions chopped at 32 °C, cooled to 4 °C with dry ice and rechopped at 16 °C. Swift, Lockett, and Fryer (1961) reported that the amount of fat emulsified decreased with an increase in final chopping temperature. The range of temperature was 18-48 °C with maximum emulsification occurring at 18 °C. Results of most of the earlier works supported the contention that optimal stability was achieved at a final comminution temperature of 16 °C (Colmenero, Carrascosa, Barreto, Fernadez, & Carballo, 1996; Hensley & Hand, 1995; Jones & Mandigo, 1982; Townsend, Ackerman, Witnauer, Palm, & Swift, 1971; Webb, Rao, Howell, Barbour,

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& Monrob, 1975). Sutton, Hand, and Newkirk (1995) found that, as end-point chopping temperature increased, batter stability and shear force decreased. However, Brown and Toledo (1975) reported that fat and water binding in meat batter was stable up to 23–24 °C. Brown and Ledward (1987) studied the quality of sausages prepared after equilibrating the ingredients to temperatures in the range 2–37 °C and reported that increasing temperature of comminution led to increased cooking losses and softening in texture but, even at the highest temperatures, complete emulsion breakdown did not occur. Also, even excessive chopping temperatures (30 °C) failed to effect emulsion stability in model chicken breast muscle emulsions (Perchonok & Regenstein, 1986). Obviously, the dependence of the emulsion stability on the comminution temperature is complex and will depend on many interrelated factors, including the type of fat, severity of comminution, fat: protein: water ratio, degree of protein denaturation, fat and water binding capacities of the ingredients and the ratio of myofibrillar to collagenous proteins in the mix (Brown & Ledward, 1987). Nevertheless, all available information indicates that high comminution temperatures are deleterious to the stability of the batter, which would suggest that such products cannot be made in tropical climates without the aid of refrigeration.

The objectives of the present investigation were (1) to study, in buffalo meat nuggets, the effect of comminution temperature on quality and shelf life and (2) to elucidate the feasibility of processing such products without reliable refrigeration facilities in tropical countries.

2. Materials and methods

2.1. Buffalo meat and fat

About 7 kg of deboned meat chunks, 1–1.5 kg in size, from the round portion and 1 kg of fat, were obtained from adult female buffalo carcasses within 5 h of their being slaughtered by the traditional halal method from a local meat market. They were packed in LDPE bags and conditioned at 4 °C for 24 h. The separable fat and connective tissues were removed and lean meat was cut into cubes of about 3 cm. The lean meat and fat were minced in a Seydelmann meat grinder (Model WD 114, Germany), using 8 mm plates. The fat was further minced through a 3 mm plate to enable proper dispersion in the emulsion. Minced lean and fat were divided into 1.5 kg and 0.25 kg lots, respectively, packed in LDPE bags, blast frozen at −18 °C and stored at this temperature. When required, they were thawed at 4 °C for 12 h.

2.2. Preparation of meat emulsion

Two kilogram batches were made, namely, 1400 g lean, 200 g fat, 200 g ice/water, 34 g salt, 6 g sodium tri polyphosphate (STPP), 60 g condiments mix (onion and garlic, 3:1), 30 g spice mix (prepared as per the formulation developed in the laboratory), 70 g refined wheat flour (binder) and 0.3 g sodium nitrite. All ingredients, including the thawed meat and fat, were stored at the designated temperatures for 12 h. The temperatures used were 4, 10, 25 and 37 °C.

The minced meat was placed in the bowl of a Seydelmann food cutter (Model K20 Ras, Germany) and salt, sodium nitrite and STPP were added and chopped exactly for 1.5 min and then water and condiments were slowly added during a further 1.5 min of chopping. In the case of the lowest temperature (4 °C), the water was added as ice flakes. The fat, which had been finely minced, was dispersed throughout the batter during a further 2 min of chopping. Finally, the binder, (refined wheat flour) and spice mix were added and the batter was chopped for a further 1 min. The temperature of the batter was recorded at all stages. For the batches made from the ingredients stored at 4 and 10 °C, the bowl was pre-cooled in ice and chilled water, respectively while, for those stored at 25 and 37 °C, the bowl was pre-warmed in water at 50 °C. The room temperatures on the days of processing varied from 24–27 °C.

2.3. Processing of buffalo meat nuggets

Meat emulsion (600 g) was placed in stainless steel moulds (17 × 11 × 4.5 cm), packed compactly and covered. The moulds were then clipped and tied and the meat blocks were cooked in a steam oven without pressure for 40 min. The internal temperature of cooked blocks was 85 °C as measured using a probe type thermometer (Oakton, China). The meat blocks were cooled to room temperature and cut into slices of 15 mm thickness, using a meat slicer (Electrolux, Model H 300, Italy). The slices were manually cut into nuggets (~15 $mm^{3)}$. The nuggets were aerobically packed in cast polypropylene bags, using a Roschermatic packaging machine (Model A-NG 91173, Germany). The samples were kept at 4 °C and examined at intervals of seven days up to 21 days. The experiment was thrice replicated.

2.4. Analytical procedures

pH was determined using a digital pH meter (Elico, Model LI 127, India). The weight of each block was recorded before and after cooking and the cooking loss was calculated (cooking loss = weight of raw blocks − weight of cooked blocks/weight of raw blocks × 100) and expressed as a percentage. The procedure of Kondaiah, Anjaneyulu, Rao, Sharma, and Joshi (1985) was followed to measure the emulsion stability. About twenty five grammes of meat emulsion were placed in a LDPE bag and heated in a thermostatically controlled water bath at 80 °C for 20 min. The stability was calculated from weight loss during cooking and expressed as percentage of the initial weight. Moisture, fat and protein contents of the nuggets were determined by standard procedures (AOAC,

1995). The procedure of Witte, Krouze, and Bailey (1970) was followed to estimate the TBARS number as mg of malonaldehyde per kg of sample. The water activity (a_w) of the nuggets was measured by a $Pa_{w\ kit}$ water activity meter (Decagon, Devices, USA).

2.5. Lovibond Tintometer colour units

The colours of buffalo meat nuggets were compared using a Lovibond Tintometer (Model E, UK). Samples, from three different places, of nuggets were taken in the sample holder and secured against the viewing aperture. The sample colour was matched by adjusting red (a) and yellow (b) units, while keeping the blue units fixed at 1.0. The corresponding colour units were recorded. The hue and chroma values were determined by using the formulae, $(\tan^{-1})^{b/a}$ and $(a^2 + b^2)^{1/2}$, respectively, where, a = red units, b = yellow units (Froehlich, Gullet, & Usborne, 1983).

2.6. Texture profile analysis

Texture profile analysis (TPA) of nuggets was conducted by the procedure described earlier (Bourne, 1978) using a Stable Microsystems Texturometer (Stable Microsystems Ltd. Surrey, England, UK) model TA-XT_2 texture analyzer attached to a software, texture expert. Chilled samples were tempered to bring to room temperature (27 °C). Uniform- sized pieces (1.5 cm^3) were used as the test samples. They were placed on a platform in a fixture and compressed to 50% of their original height at a cross head speed of 50 mm/s through a two cycle sequence, using a 25 kg load cell. The parameters determined were: hardness (N) : maximum force/energy required to compress the sample; cohesiveness : extent to which sample could be deformed prior to rupture ($A2/A1$, $A1$ being the maximum force required for the first compression and $A2$ being the maximum force required for the second compression); springiness (mm) : height that sample recovers during the time that elapses between end of the first bite and start of second bite or the distance sample recovered after the first compression, i.e., ability of sample to recover its original height after the deforming force was removed; gumminess (N) : force required for complete disintegration of semisolid meat samples for swallowing (hardness × cohesiveness); chewiness (N mm): work required to masticate the samples for swallowing (springiness × gumminess).

The texturometer was also used to measure shear force values using a Warner–Bratzler blade. Uniform-sized samples (1 cm^3) were radially sheared with a V-shaped blade attached to plunger at 50 mm/min crosshead speed. Three measurements were taken from each sample and averaged for statistical analysis.

2.7. Microbiological evaluation

Mesophilic, psychrotrophic and coliform bacterial counts of the samples were determined by standard methods (APHA, 1984). Preparation of samples and serial dilutions were done near the flame in a horizontal laminar flow apparatus (model: YSI-188, Yarco Sales Pvt. Ltd., New Delhi) which was pre-sterilized by ultraviolet irradiation observing all possible aseptic conditions. Ready-made media from Hi-media Laboratories Pvt. Ltd., Mumbai, were used for the enumeration of microbes. The plates for mesophilic counts were incubated at 37 °C for 48 h and plates showing 30–300 colonies were counted. The plates for psychrotrophic counts were incubated at 4 °C for 10–14 days and colonies were counted. Coliform count was detected by using Violet Red Bile Agar (VRBA) and the plates were incubated at 37 °C for 48 h. The number of red–purple colonies, with about 0.5 mm diameter, surrounded by a zone of precipitated bile, was counted. Colonies judged to be borderline cases were also counted. The average number of colonies for each species was expressed as $\log_{10}$ cfu/g sample.

2.8. Sensory evaluation

The nuggets were shallow pan-fried in refined mustard oil until golden brown and served warm to a seven member experienced panel of scientists and post-graduate students in the discipline of Livestock Products Technology to determine their sensory characteristics. The sensory attributes, namely appearance and colour, flavour, juiciness, texture and overall acceptability, were evaluated using an 8-point descriptive scale (Keeton, 1983) where 8 = extremely desirable as a sensory attribute and 1 = extremely undesirable. Sensory evaluation of stored nuggets was conducted to determine the keeping quality.

2.9. Statistical analysis

The experiment was replicated three times and the data generated for quality characteristics and a storage study up to 21 days were evaluated statistically (Snedecor & Cochran, 1994) by analysis of variance (ANOVA) at the institute's computer centre. Critical difference and Duncan's multiple Range Tests were used for comparing the means to elucidate the effect of comminution temperature on various parameters, namely, pH, emulsion stability, instrumental colour scores, texture profiles, TBARS number, microbiological changes and sensory attributes. The smallest difference ($D_{5\%}$) for two means to be significantly different ($P < 0.05$) is reported.

3. Results

3.1. Characteristics of buffalo meat batters made at different comminution temperatures

The thermal history of the four batters is shown in Table 1, where it is seen that final temperatures ranged from 16.3 to 34.8 °C. The batters are identified in this paper by these temperatures. The pH of the batters, immediately after

Table 1
Temperature profile during comminution of batters

Time (min)	Operation	Temperature (°C)				SEM
	During storage	4	10	25	37	
0	Prior to comminution	4.3	10.5	24.4	36.7	0.200
1.5	Prior to adding water	14.1[a]	16.7	24.9	36.1	0.197
3	Prior to adding fat	15.4	17.3	25.6	34.4	0.173
5	Prior to adding binder	16.2	19.1	27.2	34.7	0.200
6	On completion	16.3	19.3	27.4	34.8	0.185

[a] Water added as ice, $n = 3$.

Table 2
pH and emulsion stability of batters following comminution

Final temperature (°C)	pH	Emulsion stability (%)
16.3	6.29 ± 0.01^{a}	95.33 ± 0.08^{a}
19.3	6.27 ± 0.01^{a}	94.84 ± 0.10^{a}
27.4	6.24 ± 0.03^{a}	92.70 ± 0.42^{b}
34.8	6.18 ± 0.05^{b}	88.76 ± 0.11^{c}

$n = 9$. Means ± SE values bearing same superscript in a column do not differ significantly ($P < 0.05$).

comminution, varied from 6.18 to 6.29 (Table 2), but only the batter with the highest temperature (34.8 °C) differed significantly ($P < 0.05$) from the rest. The emulsion stability of the batters varied from 88.76 to 95.33, and the batters with higher temperatures (27.4 and 34.8 °C) differed significantly ($P < 0.05$) from those made at lower temperatures (16.3 and 19.3 °C). Moreover, the emulsion stability of batter prepared at the highest temperature was significantly ($P < 0.05$) lower than that prepared at 25 °C. Jones and Mandigo (1982) observed a similar dependence of temperature of comminution on emulsion stability of a standard frankfurter formulation. Similarly, Perchonok and Regenstein (1986) also reported no differences in emulsion stability between 0 and 30 °C comminution temperatures for chicken emulsions. However, Brown and Toledo (1975) reported that emulsion stability of beef emulsions remained satisfactory up to 24 °C and, thereafter, they observed a steep decline in this parameter.

3.2. Physic-chemical characteristics of buffalo meat nuggets processed from batters with different temperatures

The physicochemical characteristics of buffalo meat nuggets processed from four batters with different temperatures are shown in Table 3. Cooking loss increased with increasing comminution temperature and was higher ($P < 0.05$) for the 27.4 °C chopping temperature treatment than for 16.3 or 19.3 °C treatments, while the 34.8 °C treatment displayed a higher loss ($P < 0.01$) than all other treatments. However, it is noteworthy that, even at the highest temperature, the cooking loss was below 12%. Proximate composition results revealed a significant ($P < 0.05$) reduction in moisture content for the 27.4 and 34.8 °C temperature treatments. The nuggets processed from batter at 34.8 °C had significantly ($P < 0.05$) lower pH and shear force values than all other treatments and, the 27.4 °C temperature treatment displayed a significant ($P < 0.05$) reduction in these parameters from the 16.3 and 19.3 °C treatments. Brown and Ledward (1987) observed a similar dependence of temperature of comminution on shear force values of English sausages. Water activity did not show any significant difference ($P > 0.05$) among the four treatments. Lovibond Tintometer colour analysis revealed that, redness (*a*-values) decreased significantly ($P < 0.05$) with increase of comminution temperatures; however, a significant reduction was absent for the 19.3 °C treatment (compared to 16.3 °C). Nuggets made from batter with highest temperature were less red (lower *a*-values) and more yellow (higher *b*-values) than were those of the other three treatments. Several researchers observed similar dependence of comminution temperature on colour scores of meat products from different species (Boles, Mikkelsen, & Swan, 1998; Brown & Ledward, 1987; Palombo & Wijngaards, 1990; Perchonok & Regenstein, 1986). Texture profile analysis results (Table 4) revealed that the buffalo meat nuggets prepared from batters with higher temperatures (27.4 and 34.8 °C) differed significantly ($P < 0.05$) for most of the parameters compared to those processed from batters with lower temperatures. The 34.8 °C treatment nuggets had sig-

Table 3
Physicochemical characteristics of buffalo meat nuggets processed from batters with different temperatures

Parameter	Final temperature (°C)			
	16.3	19.3	27.4	34.8
Cooking loss (%)[#]	5.34 ± 0.11^{a}	5.61 ± 0.08^{a}	8.52 ± 0.10^{b}	11.54 ± 0.06^{c}
pH	6.46 ± 0.01^{a}	6.45 ± 0.01^{a}	6.40 ± 0.01^{b}	6.35 ± 0.01^{c}
Moisture (%)	67.24 ± 0.04^{a}	67.15 ± 0.03^{a}	66.31 ± 0.03^{b}	65.01 ± 0.02^{c}
Protein (%)	16.9 ± 0.02^{c}	16.9 ± 0.02^{c}	17.6 ± 0.03^{b}	18.7 ± 0.02^{a}
Fat (%)	11.35 ± 0.14	11.34 ± 0.10	11.21 ± 0.11	10.97 ± 0.10
Shear force (kg/cm^3)	0.33 ± 0.02^{a}	0.20 ± 0.02^{b}	0.15 ± 0.01^{c}	0.10 ± 0.02^{d}
Water activity	0.95 ± 0.01	0.95 ± 0.01	0.94 ± 0.01	0.94 ± 0.01
Instrumental colour scores				
a (redness)	9.35 ± 0.05^{a}	8.62 ± 0.05^{a}	7.14 ± 0.01^{b}	5.83 ± 0.07^{c}
b (yellowness)	5.24 ± 0.02^{b}	5.56 ± 0.01^{b}	6.42 ± 0.10^{a}	6.86 ± 0.06^{a}
Hue	29.25 ± 0.04^{c}	32.62 ± 0.10^{c}	41.22 ± 0.08^{b}	47.06 ± 0.14^{a}
Chroma	10.72 ± 0.10	10.61 ± 0.10	9.60 ± 0.09	9.00 ± 0.16

$n = 9$, n for # = 3. Means ± SE values bearing same superscript in a row do not differ significantly ($P < 0.05$).

Table 4
Texture profiles of buffalo meat nuggets processed from batters with different temperatures

Parameter	Final temperature (°C)			
	16.3	19.3	27.4	34.8
Hardness (N)	29.46 ± 0.58^{a}	24.26 ± 0.74^{b}	19.10 ± 0.52^{c}	18.85 ± 0.65^{c}
Adhesiveness (N s)	-0.075 ± 0.02	-0.069 ± 0.01	-0.011 ± 0.02	-0.024 ± 0.01
Springiness (mm)	0.867 ± 0.05^{a}	0.861 ± 0.04^{a}	0.839 ± 0.02^{ab}	0.810 ± 0.04^{b}
Cohesiveness (ratio)	0.456 ± 0.02^{a}	0.453 ± 0.01^{a}	0.435 ± 0.02^{ab}	0.409 ± 0.05^{b}
Gumminess (N)	13.42 ± 1.25^{a}	9.92 ± 1.12^{b}	8.31 ± 1.22^{b}	8.32 ± 1.54^{b}
Chewiness (N mm)	11.56 ± 1.43^{a}	8.60 ± 1.28^{b}	7.13 ± 1.30^{bc}	6.97 ± 1.27^{c}

$n = 9$. Means ± SE values bearing same superscript in a row do not differ significantly ($P < 0.05$).

nificantly lower ($P < 0.01$) hardness and chewiness than had those from all other treatments except the 27.4 °C treatment.

3.3. Keeping quality of buffalo meat nuggets processed from batters with different temperatures at refrigeration temperature (4 °C)

Even though a significant ($P < 0.05$) difference was absent among the four treatments for TBARS values during the first week of storage (Fig. 1), the 34.8 °C temperature treatment had significantly higher ($P < 0.01$) values than had all other treatments during the subsequent storage periods. In addition, the 27.4 °C treatment displayed significantly higher ($P < 0.05$) TBARS values than the 16.3 and 19.3 °C treatments. Off-flavours developed on the 21st day of storage for nuggets prepared from batter with the highest temperature. The pronounced increase of TBARS values of buffalo meat products, with the advancement of storage period is widely described in the literature (Anjaneyulu, Sharma, & Kondaiah, 1989; Sahoo & Anjaneyulu, 1997; Thomas et al., 2006).

Results of sensory evaluation (Table 5) revealed that the nuggets processed from batters with higher temperatures (27.4 and 34.8 °C) had significantly ($P < 0.05$) lower scores for most of the sensory attributes than had those processed from batters with lower temperatures (16.3 and 19.3 °C). Moreover, the reduction in sensory attributes with the advancement of storage period was greater in the nuggets processed from batter with the highest comminution temperature (34.8 °C). Colour, flavour and texture were the major sensory attributes influenced by the comminution temperature. The 34.8 °C comminution temperature treatment had significantly ($P < 0.05$) lower scores for juiciness and texture than had all other treatments, while the scores for colour and flavour were slightly lower than that of the 27.4 °C treatment. The overall acceptability scores were significantly ($P < 0.05$) lower for the 34.8 °C treatment than for all other treatments. But, it is noteworthy that, even though there was a significant difference between the 27.4 °C treatment and 16.3 and 19.3 °C treatments for overall acceptability, the scores for all these three treatments were in the range of 'extremely palatable' to 'very palatable'. Similarly, with the advancement of storage period, the colour and texture of the 27.4 °C treatment were comparable to those of the 16.3 and 19.3 °C treatments. The present findings corroborate Brown and Ledward (1987) who observed a significant reduction in various sensory attributes of English sausages made from batters with different comminution temperatures, after nine weeks of storage at −20 °C.

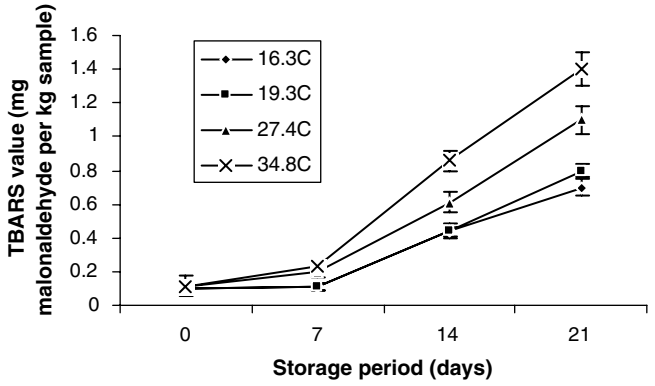

Fig. 1. TBARS values of buffalo meat nuggets processed from batters with different temperatures.

Aerobic mesophilic counts enumerated were significantly ($P < 0.05$) higher for the 34.8 °C treatment than for all other treatments (Table 6). Also, the 27.4 °C treatment had significantly higher ($P < 0.05$) aerobic mesophilic counts than had the 16.3 and 19.3 °C treatments. Significant increases ($P < 0.05$) in these counts were also observed with the advancement of storage period for all the four treatments. Increases of mesophilic bacterial counts were also observed in ground buffalo meat (Sahoo & Anjaneyulu, 1997) and in buffalo meat nuggets (Thomas et al., 2006) as the refrigerated storage advanced. Although, (detected only occasionally during the storage period), the lower temperature treatments (16.3 and 19.3 °C) gave higher psychrotrophic counts, higher temperature treatments (27.4 and 34.8 °C) gave higher coliform counts.

4. Discussion

The decreased emulsion stability observed with increase in comminution temperature in the present investigation is a direct consequence of partial and total emulsion break-

Table 5
Sensory attributes[a] of buffalo meat nuggets processed from batters with different temperatures

Parameter	Storage period (days)				
	0	7	14	21	Treatment mean ± SE
Colour and appearance					
16.3 °C	7.23 ± 0.04	7.08 ± 0.02	7.10 ± 0.02	6.91 ± 0.04	7.08 ± 0.03^{A}
19.3 °C	7.11 ± 0.02	7.12 ± 0.05	7.12 ± 0.02	6.86 ± 0.10	7.05 ± 0.05^{A}
27.4 °C	7.19 ± 0.02	7.10 ± 0.04	6.97 ± 0.10	6.50 ± 0.10	6.94 ± 0.07^{B}
34.8 °C	7.17 ± 0.06	7.10 ± 0.10	6.89 ± 0.10	6.35 ± 0.10	6.88 ± 0.09^{B}
Days mean ± SE	7.18 ± 0.04^{a}	7.10 ± 0.06^{a}	7.02 ± 0.08^{a}	6.66 ± 0.09^{b}	–
Flavour					
16.3 °C	7.27 ± 0.09	7.27 ± 0.09	7.02 ± 0.10	6.90 ± 0.06	7.12 ± 0.09^{A}
19.3 °C	7.27 ± 0.04	7.30 ± 0.06	7.02 ± 0.05	6.91 ± 0.10	7.13 ± 0.08^{A}
27.4 °C	7.24 ± 0.08	7.20 ± 0.10	6.87 ± 0.10	6.56 ± 0.12	6.97 ± 0.10^{B}
34.8 °C	7.15 ± 0.12	7.06 ± 0.05	6.81 ± 0.10	6.53 ± 0.08	6.89 ± 0.10^{B}
Days mean ± SE	7.23 ± 0.08^{a}	7.21 ± 0.07^{a}	6.93 ± 0.09^{b}	6.73 ± 0.09^{c}	–
Juiciness					
16.3 °C	7.47 ± 0.04	7.49 ± 0.02	7.28 ± 0.06	7.09 ± 0.05	7.33 ± 0.04^{A}
19.3 °C	7.45 ± 0.06	7.41 ± 0.05	7.28 ± 0.04	7.00 ± 0.01	7.29 ± 0.04^{A}
27.4 °C	7.31 ± 0.10	7.30 ± 0.10	7.10 ± 0.06	6.74 ± 0.06	7.11 ± 0.08^{B}
34.8 °C	7.24 ± 0.10	7.19 ± 0.07	7.06 ± 0.07	6.63 ± 0.12	7.03 ± 0.09^{C}
Days mean ± SE	7.37 ± 0.08^{a}	7.35 ± 0.07^{a}	7.18 ± 0.06^{b}	6.87 ± 0.07^{c}	–
Texture					
16.3 °C	7.53 ± 0.09	7.46 ± 0.12	7.29 ± 0.12	7.18 ± 0.14	7.37 ± 0.12^{A}
19.3 °C	7.46 ± 0.11	7.45 ± 0.11	7.23 ± 0.10	7.10 ± 0.11	7.37 ± 0.11^{A}
27.4 °C	7.20 ± 0.11	7.17 ± 0.08	6.94 ± 0.10	6.91 ± 0.10	7.31 ± 0.10^{A}
34.8 °C	7.03 ± 0.08	7.01 ± 0.08	6.67 ± 0.12	6.63 ± 0.12	6.84 ± 0.11^{B}
Days mean ± SE	7.31 ± 0.09^{a}	7.27 ± 0.10^{a}	7.13 ± 0.11^{b}	6.96 ± 0.12^{c}	–
Overall acceptability					
16.3 °C	7.51 ± 0.06	7.51 ± 0.06	7.33 ± 0.10	7.13 ± 0.09	7.37 ± 0.09^{A}
19.3 °C	7.52 ± 0.04	7.47 ± 0.07	7.27 ± 0.07	7.02 ± 0.05	7.32 ± 0.06^{A}
27.4 °C	7.35 ± 0.07	7.34 ± 0.07	6.93 ± 0.10	6.79 ± 0.10	7.10 ± 0.09^{B}
34.8 °C	7.24 ± 0.08	7.20 ± 0.10	6.71 ± 0.10	6.53 ± 0.06	6.92 ± 0.08^{C}
Days mean ± SE	7.41 ± 0.06^{a}	7.38 ± 0.08^{a}	7.06 ± 0.09^{b}	6.87 ± 0.07^{c}	–

$n = 21$. Means ± SE values bearing same superscript do not differ significantly ($P < 0.05$).
[a] Based on 8 point descriptive scale.

down at high comminution temperatures and is well documented in the literature (Brown & Ledward, 1987; Hammer, Haack, & Stoyanov, 2006; Jones & Mandigo, 1982; Lee & Min, 2004). Available literature also suggests that it is not necessarily the chopping temperature, as such, that dictates the stability achieved but rather the manner in which it is attained (Brown & Ledward, 1987; Tan, Aminah, Zhang, & Abdul, 2006; Teye, Wood, Whittington, Stewart, & Sheard, 2006). In the present study, lipid was added, where appropriate, in the melted or partially melted form, whereas, in most of the previous studies, chilled fat was used. It was observed that fat, added at elevated temperatures, improved stability, enabling batters to be made at temperatures above 30 °C (Brown & Ledward, 1987; Curt, Allais, Perrot, Leblanc, & Trystram, 2004; Webb et al., 1975). Moreover, a fixed but minimal comminution time was used in the present investigation (6 min), while most of the earlier workers have utilized prolonged chopping times to achieve elevated temperatures. This extended chopping might be expected to aid protein denaturation and fat coalescence, two factors that will lead to loss of stability (Brown & Ledward, 1987; Curt, Francon, & Trystram, 2004).

As discussed earlier, cooking loss, which is synonymous with emulsion stability, is an important parameter for assessing the quality of meat products. Virtually all reported works suggest that, as found in this study, breakdown of emulsion occurs with increasing comminution temperature, so that increasing cooking losses are found. However, most other workers have reported a far greater sensitivity to temperature than that found in the present study. For example, Townsend et al. (1971) reported cooking losses of 11.1% and 40.7% for samples chopped to 18.9 °C and 29.5 °C, respectively, whereas in this study, even at 34.8 °C, only 11.54% loss was seen. This might be due to the use of, a constant, minimal comminution time in the present study, compared to the use of prolonged chopping time in the previous studies to achieve the elevated temperatures.

The decrease in redness observed in this study was probably due to an increased rate of metmyoglobin formation at the higher temperatures and it would indicate that, dur-

Table 6
Microbiological characteristics (log_{10} cfu/g) of buffalo meat nuggets processed from batters with different temperatures

Parameter	Storage period (days)				
	0	7	14	21	Treatment mean ± SE
Aerobic mesophilic count					
16.3 °C	2.78 ± 0.02	3.32 ± 0.01	3.75 ± 0.05	3.96 ± 0.05	3.45 ± 0.03^{C}
19.3 °C	2.95 ± 0.03	3.40 ± 0.03	3.91 ± 0.07	4.11 ± 0.06	3.59 ± 0.05^{C}
27.4 °C	3.38 ± 0.06	3.81 ± 0.06	4.04 ± 0.05	4.34 ± 0.06	3.89 ± 0.06^{B}
34.8 °C	3.73 ± 0.05	4.02 ± 0.02	4.25 ± 0.02	4.46 ± 0.06	4.12 ± 0.04^{A}
Days mean ± SE	3.21 ± 0.04^{d}	3.64 ± 0.03^{c}	3.99 ± 0.05^{b}	4.22 ± 0.06^{a}	–
Psychrotrophic count					
16.3 °C	ND	1.95 ± 0.10	2.25 ± 0.10	2.47 ± 0.10	–
19.3 °C	ND	1.90 ± 0.09	2.28 ± 0.10	2.41 ± 0.10	–
27.4 °C	ND	ND	1.47 ± 0.14	1.90 ± 0.14	–
34.8 °C	ND	ND	ND	1.69 ± 0.08	–
Days mean ± SE	–	–	–	2.12 ± 0.10	
Coliform count					
16.3 °C	ND	ND	1.30 ± 0.16	1.30 ± 0.10	–
19.3 °C	ND	ND	1.47 ± 0.10	ND	–
27.4 °C	1.60 ± 1.10	ND	1.47 ± 0.10	1.47 ± 0.15	–
34.8 °C	1.69 ± 1.10	1.30 ± 1.26	1.47 ± 0.10	1.90 ± 0.15	1.59 ± 1.02
Days mean ± SE	–	–	1.43 ± 0.12	–	

$n = 6$. Means ± SE values bearing same superscript do not differ significantly ($P < 0.05$). ND = Not Detected.

ing the holding period of 12 h, reactions take place in one or more ingredients to produce products which, on comminution and subsequent heating, undergo non-enzymatic browning reactions (Brown & Ledward, 1987). These reactions will be encouraged at higher comminution temperatures and the lower water content of the high temperature samples might have complemented these reactions. The shear force values observed in this study were in agreement with the finding of texture profile analysis and texture scores in the sensory evaluation. The lower resistance to shear observed with increase of comminution temperature, might be due to decreased binding, as a result of higher protein denaturation, associated with increase in temperature of comminution. The addition of fat in the melted or partially melted form might also contribute to this effect.

Subjective assessment of nuggets confirmed the objective findings with regard to both colour and texture. Those prepared at higher comminution temperatures were less liked by the panelists. The major problems associated with nuggets prepared from batters with higher temperature were low texture and off-flavour development with the advancement of the storage period. The reason for the former has already been discussed. The off-flavour observed might be due to an increase of fat oxidation, as indicated by higher TBARS values, and the higher comminution temperature presumably contributed to this effect. This could have also been due to increased bacterial growth, taking place during holding of the ingredients for 12 h at higher temperatures. A positive correlation between microbial load and TBARS values was reported in ground buffalo meat (Sahoo & Anjaneyulu, 1997). Tarladgis, Watts, Younthan, and Dugan (1960) observed that the minimum threshold value or acceptable limit of TBARS value of cooked meat products during storage was 0.50–1.0 mg and, in this study, the off-flavour was perceived above 0.8 mg by the panelists.

The absence of psychrotrophic bacteria in the nuggets during the initial periods of storage might be attributed to a retardation of the log phase as a result of reduced metabolic rate due to a sudden change in the physical environment (Thomas et al., 2006). It may also be due to thorough cooking of the nuggets during processing. However, it is noteworthy that, throughout the storage period, the counts for mesophilic, psychrotrophic and coliforms, for all the four treatments, were well below the levels, namely log_{10} 7 cfu/g, log_{10} 4 cfu/g and log_{10} 3 cfu/g, respectively (Jay, 1996) that could cause microbiological spoilage of the meat products.

5. Conclusions

It is readily apparent that, the buffalo meat nuggets processed from batters with different temperatures differ quite markedly, as evidenced by their emulsion stability, cooking loss and texture profiles. The differences among the four treatments for TBARS values, sensory attributes and microbiological parameters indicated that the shelf life of buffalo meat nuggets is also influenced by the comminution temperature of the batter. Objective and subjective assessment revealed that, at least up to comminution temperatures of 27.4 °C, the nuggets were acceptable. Thus, the present findings suggest that, in tropical countries such as India, comminuted buffalo meat products could be processed, without much affecting the quality and shelf life, even in the absence of refrigeration facilities, except in peak summer months (April to August)

where the room temperature reaches about 35–40 °C, by a preservation system (mostly chemical) to inhibit/reduce microbial and chemical spoilage and also by devising an efficient marketing system for their early distribution (preferably less than 14 days).

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