

Assessing the Baking Characteristics of Mozzarella and Pizza Cheeses

Bhargav M. Rajani^{1,*}, Atanu H. Jana², Satish C. Parmar³

Abstract

Mozzarella/Pizza cheese is considered an important specialty cheese since it can be consumed directly or as an ingredient in other food products. It exhibits functional properties inclusive of baking properties such as Shred ability, meltability, fat leakage, stretchability, browning, etc. during their end use application in food. Assessing such properties of cheese is of significance since the cheese users at the restaurants and even the varied connoisseurs of cheese have 'whims and wishes' that the cheese should perform in a specific manner during their utility. The modification in the cheese making processes and the development of novelty cheese demands accurate functionality tests and the cheese-makers are required to correlate such data with their end use application. In this Review, the assessment of baking properties of Mozzarella and/or Pizza cheese using recommended procedures have been illustrated as a ready reckoner for the cheese makers.

Keywords: Functionality, Shred ability, meltability, fat leakage, stretchability, browning

INTRODUCTION

More than 900 varieties of cheeses are documented in literature [1]; cheeses are classified based on their form, manufacturing protocol, chemical composition and ripening protocol [2]. The Indian cheese market was expected to grow at a compound annual growth rate (CAGR) of ~18.0% during the period 2015–2020 [3].

Mozzarella cheese has another variant named Pizza cheese [4]. Such cheese is soft, unripened stretched curd variety of cheese of Pasta-filata family, originating from Battipaglia region of Italy [5]. Mozzarella cheese has witnessed a substantial growth globally over the years owing to its popularity and suitability as a pizza topping [6]. Mozzarella cheese has prized property viz. stretchability, which makes it highly suitable as a pizza topping [7, 8] as well as in prepared foods such as cheese burgers, sandwiches, pasta dishes, sauces, etc. [9]. The pizza market in India is worth over ₹1500 crores and

*Author for Correspondence

Bhargav M. Rajani

¹M. Tech Scholar, Department of Dairy Technology, SMC College of Dairy Science, Anand, Gujarat, India

²Professor & Head, Department of Dairy Processing & Operations, SMC College of Dairy Science, Anand, Gujarat, India

³Assistant Professor, Department of Dairy Chemistry, SMC College of Dairy Science, Anand, Gujarat, India

Received Date: December 23, 2020

Accepted Date: December 28, 2020

Published Date: April 15, 2021

Citation: Bhargav M. Rajani, Atanu H. Jana, Satish C. Parmar. Assessing the Baking Characteristics of Mozzarella and Pizza Cheeses. Research & Reviews: Journal of Dairy Science & Technology. 2021; 10(1): 22–43p.

has been growing at an annual growth rate of 26.0% since past 5 years [10]. As an ingredient in pizza, as well as in other applications, Pizza cheese (also referred to as low-moisture, part-skim Mozzarella cheese) exhibits functional traits such as shredding, melting, stretching and fat leakage (synonymously known as oiling-off). These and other crucial attributes of cheese result from careful control of the manufacturing parameters such as acidification rate and extent, stretching parameters, salting and the compositional aspects of the cheese product [11]. Since Pizza cheese is invariably used in prepared foods, the assessment of their functional characteristics including baking properties is of great significance.

Baking Characteristics of Mozzarella/Pizza Cheese

Based on the survey conducted at some pizza restaurants, properties such as Shred ability, meltability, stretchability, oiling off, and browning were identified as determinants of cheese quality by the respondents of the study [12]. At the pizza restaurants, it is common to use forced-air ovens to bake the cheese topping at temperatures $\geq 250^{\circ}\text{C}$ for a period ranging from 4.0–6.0 min [13]. Baked pizzas are invariably served hot ($50\text{--}70^{\circ}\text{C}$) to the consumers, depending on the cooling period and the environment (e.g., in cardboard box, room temperature). Baking conditions inevitably induce changes in the composition, appearance, structure and flow attributes of cheese product [14, 15].

Pizza cheese should ideally possess the following: (i) it should possess required stringiness and intermediate toughness; and (ii) during shredding, grinding and slicing there should be minimal matting. Pizza cheese must possess specific functional properties in both melted and unmelted states. Fresh Mozzarella is unfit for pizza application, since it melts to a tough, elastic and granular consistency with restricted stretch. Ageing of cheese for a few weeks (2–3 weeks) makes it amenable for pizza application. The melted aged cheese becomes viscous, less elastic and attains greater stretch [16].

The refrigerated storage of cheese induces some changes in the baking characteristics of product viz., improvement in the melt and stretch of product. Frozen storage (at -18°C) of Mozzarella cheese is believed by some manufacturers to adversely affect the cheese quality [8, 17, 18]. The key problems identified by the end users of Pizza cheese were poor shredding properties, excessive free oil, soupy melted cheese and blistering [12].

Changes in the functionality of cheese during storage were due to change in pH, proteolysis, protein-bound water and free oil development in the product. Prolonged storage (>4 weeks) of cheese under refrigerated condition (5°C) leads to a soft and fluid mass upon melting, dissuading it for pizza application. The extended storage period for such cheese makes the cheese shreds susceptible to clumping/balling; upon baking, the cheese has tendency to exude excess free oil and there is loss of chewiness [19]. The baking attributes of Pizza cheese in response to their end use functionality are shown in Table 1. The factors determining the baking properties of Pizza cheese are delineated in Table 2.

Table 1. Baking Properties of Cheese in Relation to Their End Use Functionality.

Descriptor Terms	Definition and Properties	Significance
Shred ability	Physical attributes such as the ease of machinability, the shape and integrity of shreds, the propensity of cheese shreds to mat with each other	- For application as pizza topping, the cheese needs to be shredded - Commercially available packaged shredded cheese offering convenience
Meltability	Tendency of the cheese to soften upon heating	Toasted sandwiches, pizza, burgers, breaded cheese sticks, cheese insets in bratwurst and burger patties. Ability to maintain a uniform softening with minimal oiling-off when used in toasted sandwiches and other heated food preparations
Viscosity/flow	Tendency of the cheese to spread and flow when completely melted	- Cooker 'drop-down' viscosity after manufacture - Optimum hot-fill ability into loaves during packaging - Restricted flow during toasting (food preparation)
Stretchability	Tendency of the heated cheese to form strings when extended	Shredded cheese on pizza, in breaded cheese sticks
Browning	Manifestation due to high temperature pizza baking as a result of Maillard browning reaction between the accumulated galactose and the peptides formed during proteolysis in cheese	- Slight browning is acceptable - Burning/blistering of cheese are considered a defect

Source: Jana and Tagalpallear (2017) [20].

Table 2. Factors Affecting the Baking Characteristics of Pizza Cheese.

Factors	Shred ability	Meltability	Fat leakage	Stretchability	Browning	Reference
Type of Milk						
Cow	-	Increase	-	Increase	-	[20]
Buffalo	-	Decrease	-	Decrease	-	
Heat treatment* (↑)	-	Decrease	-	Decrease	-	
Homogenization# (↑)	Decrease	Decrease	Decrease	Decrease	-	
Starter culture						
ST + LH	-	Increase	-	-	-	
ST + LB	-	Decrease	-	-	-	
Composition of Cheese						
Moisture (↑)	Decrease	Increase	-	Decrease	-	[21]
Fat (↑)	Decrease	Increase	Increase	-	-	
Fat (↓)	-	Decrease	Decrease	-	Increase	
Galactose	-	-	-	-	Increase	
Salt (↑)	-	Decrease	Decrease	Decrease	-	
Salt (↓)	-	Increase	Increase	Increase	-	
Cooking temperature** (↑)	-	Decrease	-	-	-	
Storage Changes						
Fresh cheese	Moderate	Moderate	-	-	-	[22]
Refrigerated storage (30 days)	Decrease	Increase	Increase	Increase	-	
HPP of milk	-	-	-	-	Decrease	
Microwave processing of milk	-	Increase	Increase	Increase	Decrease	[23]
Ultrafiltration of milk	-	Decrease	Increase	-	-	[23]

Note: * Heat Treatment, 82°C; # Homogenization, 6700 kPa; ST= *Streptococcus salivarius* subsp. *thermophilus*; LH= *Lactobacillus helveticus*; LB= *Lactobacillus delbrueckii* ssp. *bulgaricus*; Moisture=52.0%; Salt (↑), 3.0%; Salt (↓), 0.4%; **Cooking temperature, 46°C; HPP: High pressure processing at 400 MPa; Microwave processing at 900 W for 2.0 min.

Significance of Assessing the Baking Characteristics of Cheese

Assessing the baking properties of cheese is of significance to the cheese makers as well as to the consumers alike. Nowadays, packaged pre-shredded cheese is available in the market, a convenience factor for the connoisseurs of cheese. Pizza cheese is invariably shredded, cut or diced to improve its handling. Shredding offers improved functionalities owing to faster and even melting. The melt of cheese can be high/low depending on the manufacturing conditions. If melt of the cheese is desired (i.e. high), the pizza topped with cheese can be removed from the oven earlier than a cheese having poor melt quality. Contrary to this, Pizza cheese with poor melt quality has greater tendency to burning or blistering owing to the greater residence time in the oven. The extent of free oil formed may influence cheese dehydration and affect cheese browning during baking. Stretch quality is considered an important aspect in baking applications since it is a stretched variety of cheese. The length, tension and type of stretch (strings, strands or fibrous) are important quality attributes of cheese. Blistering and browning are sometimes encountered in cheese; burnt appearance is undesirable. The browning of Mozzarella cheese results from Maillard reaction owing to the elevated temperature used during baking. Blisters are trapped pockets of heated air and steam that may preferentially scorch the cheese shreds during baking. Hence, considering the above mentioned points, the assessment of the baking properties of Pizza cheese is of paramount importance for its end use applications on pizza and other dishes [20].

Methods to Assess the Baking Characteristics of Cheese

The changing habits of diet and use of newer equipment for processing of cheese products demands specific ‘tailor-made’ functionalities expected out from such product. Today’s cheese maker is in a better position to exploit the basic knowledge on cheese science in producing ‘tailor-made’ cheese product, suiting the consumer’s whims and wishes. The consumer might demand cheese having limited/high melt, high/low stretch, limited oiling off, low browning, etc. Hence, developing accurate tests to assess the functional properties of cheese and correlating such data with the varying end-use applications of cheese is the prime need for the cheese industry [20]. Some of the important baking characteristics of Pizza cheese are discussed in depth under separate headings. Table 3 shows the tests that have been recommended to assess a specific property of cheese in relation to baking.

Table 3. Tests Recommended to Assess Functional Properties of Mozzarella Cheese.

S.N.	Property Assessed	Recommended Tests
1	Shred ability	Empirical test, Image processing algorithm method
2	Meltability	Tube test and its modified version, Arnott test, Helical viscometry, Schreiber test and its modified version, Small Amplitude Oscillatory Shear analysis, Farinograph-E test, Differential Scanning Calorimetry, Rapid visco-analyzer, Rheometer test, Meltmeter, Computer vision method
3	Fat leakage	Modified Gerber method, Fat ring test, Babcock based method, Computer vision method
4	Stretchability	Fork test, 3-prong hook test/Clamp method, Hot iron test, Vertical uniaxial extension method, Utah State University Stretch test, Texture Analyzer, Ring-and-Ball method, Capillary Rheometer test, Empirical test, Stretch-strand thickness test
5	Browning	Empirical test, Chroma meter, Machine vision and image analysis (computer vision)

Pizza Baking Properties as Affected by Manufacturing Conditions and Storage

Low-fat (6.0%) Mozzarella cheese were prepared by pre-acidification of milk with citric acid to pH 6.1 and using encapsulated ropy or non-ropy exo-polysaccharide (EPS) producing *Streptococcus salivarius* subsp. *thermophilus* as starter culture. The control cheese (without EPS starter) were firmer and their meltability and stretchability were initially (up to 45th days) low. Hardness of cheeses reduced while the melt and stretch improved with progression of refrigerated storage up to 90th days. On baking, the control cheese exhibited incomplete shred fusion. Pre-acidification of cheese milk with citric acid reduced the cheese hardness and improved the cheese meltability. The cheese made using capsular and ropy-EPS were softer but had lower springiness. Superior meltability was observed in experimental cheeses at initial stage (40 days or so) of storage, which became similar to that of control cheese at 90th day of storage. From 45th day of storage, the cheeses made using EPS cultures showed an improvement in the shred fusion and meltability, and were associated with reduced surface scorching [24].

Effect of Freezing Conditions on the Meltability and Fat Leakage of Mozzarella Cheese

Low-moisture part skim (LMPS) Mozzarella cheese loaves (28.0×10.0×10.0 cm) ripened for 6 and 14 days at 4°C and stored at –20°C were studied. Two freezing speeds (i.e. slow and fast freezing from –1.1 to –6.7°C) were studied. The result of test revealed that Mozzarella cheese can be frozen without any quality loss provided the cheese was pre-aged for 14 days at 4°C [25].

The detailed description of the assessment methods used to determine the baking parameters of Mozzarella cheese is dealt herein.

SHRED ABILITY

Shred ability is a broad term which considers the physical attributes viz. facilitates machinability, the shape and propensity of shreds to remain intact, the matting behaviour of cheese shreds, and the fines production as a consequence of shredding operation [26]. In order to utilize Pizza cheese in baking application, the cheese first needs to be shredded for ease of melting in the baking oven. According to Childs *et al.*, the Mozzarella cheese shred preferences and quality were related to the length, thickness and straightness of shreds; the preferences (as per cent) were 60.0, 20.0 and 20.0 respectively [26]. A high proportion of long shreds is desirable when shredding Mozzarella cheese. Soft cheese is associated with poor shredding since it tends to stick to the blade, forms gummy balls of cheese, and have tendency to mat with each other. Conversely, firm and dry Mozzarella cheese tends to shatter easily into fines [27]. In order to maximize the shred size, Mozzarella cheese is recommended to be shredded at low (4°C) temperature; it reduces the adhesion of the cheese to the shredder blade [28]. The former shred evaluation methods were manual, either sieving to account for the small fragments or by individually measuring the shreds size [29]. The recently developed methods to assess shred ability of cheese are as detailed below.

Empirical Test

Shred ability of cheese is assessed by the presence of fines, size of the shreds, and adhesion of

cheese to the blade after shredding at specific temperatures (viz., 4, 13 or 22°C). To reduce the adhesion of the cheese to the shredder, it is desirable to minimize defects associated with matting of shreds and maximize the shred size. Mozzarella cheese is recommended to be shredded at low temperatures (4°C); they are required to be stored at low temperatures (4°C) to reduce defects associated with the matting of shreds [30]. Based on the Empirical shred test, low milk renneting pH (≤ 6.4) and longer cheese aging period (≥ 36 days) effectively decreased the fines production in case of Mozzarella cheese by 26.0% during shredding; young cheese measured ~ 8.1 mm as against 10.0 mm for aged (36 days) cheese [30].

Image Processing Algorithm Method

A robust and efficient algorithm called the 'X–Y sweep method' has been proposed for image segmentation. In this method, a visual scene is swept in X as well as Y directions and two sets of run-length codes are generated. According to the width conditions and spatial relations with the neighbor run-length codes, the latter are grouped as segments. A joint is formed by collecting the pixels that cannot be swept through in X or Y directions. The occluded shred shaped objects are recovered by merging the neighbor blocks based on the local, semi-local and global descriptions. The sorting method based on topology is harnessed to locate the best match. The 'X–Y sweep method' suits all the shred-shaped entities. The tests based on '*in situ*' cheese shreds (i.e., touching and superimposing as dispensed from its package) could be considered $\sim 95.0\%$ accurate in measuring the shred lengths. Based on the shred length distribution histogram, the uniformity of shreds can be objectively assessed. Few cheese shred quality indices, such as, (i) degree of free-flowing, and (ii) degree of matting are proposed based on X–Y sweep measurements [29].

An image analysis system is able to measure accurately the physical characteristics of the shreds and assign values that correlate well with the shred quality of cheese. The shred quality of cheese is directly related to (a) the dimension (viz., length) of the shreds that are formed, and (b) indirectly related to the number of fragments created and also related to the stickiness amongst the shreds. This method can be used to rapidly assess the commercial quality of cheese and ensure uniformity [31].

Effect of Salting Technique and Pre-Acidification on Shred ability of Cheese

The milled cheese curds were salted either by brining (20.0% NaCl solution, 20.0 min contact period) or dry salting (3.0% NaCl with contact period of 10.0 min with the curd). Dry salting of cheese led to an increase in shredding efficiency compared to brine salted cheese. The microstructure of the brine salted cheeses was more porous, whereas the dry salted cheese was quite homogeneous and had a continuous protein matrix culminating in superior shred quality in the latter cheese. The Pizza cheese was pre-acidified with lactic acid (20.0%) up to pH 6.3, using 2.5% activated yoghurt starter culture for further acidification. Pizza cheeses prepared from pH adjusted milk were associated with superior shredding property as compared to the non-adjusted pH milk cheese counterpart [32].

MELTABILITY

Cooked Mozzarella cheese should melt uniformly, so that no individual cheese shred particles are visible upon melting, post baking. Melted cheese have an array of applications, such as for pizza topping, cheese slices on hamburgers, toasted sandwiches, fillings, layers in lasagna and sauces [17]. The meltability of Mozzarella cheese depends mainly on the amount of active water (water bound by the protein matrix), which dictates its water-binding capacity. Low fat cheeses ($\leq 35.0\%$ fat on dry matter, FDM) tend to form a dry skin when heated, limiting the cheese meltability. Contrary to this, when full-fat cheeses ($\geq 35.0\%$ FDM) are heated, the fat globules tend to agglomerate into aggregates culminating in enhanced meltability [33]. Mozzarella cheese melts poorly soon after manufacture; a ripening period of 1–3 weeks is required to attain desired meltability owing to proteolytic changes during storage [34]. Some tests suitable to assess meltability of cheese are detailed herein.

Tube Test

A cheese sample of specific weight and dimension is placed in a glass tube that is horizontally

heated in an oven at specified conditions (i.e. oven temperature of 104°C; 1 h contact period). The extent of flow of cheese mass is measured to quantify the melted texture of the product [35]. A mass of 10.0 g of grated cheese is placed in a tube (32.0 mm×250.0 mm) and packed to form a plug at the bottom. The height of cheese is marked on the test tube. The test tube is covered with perforated aluminium foil for passage of gases. The test tube is kept vertically in a refrigerator at 4°C for 30.0 min and then placed horizontally in an oven maintained at 104°C for 1 h [36, 37]. Meltability was measured as the flow distance (i.e. mm) of the melted cheese [35].

Cheese with higher fat content (i.e. 54.0% fat) resulted in markedly higher (by 12.0%) meltability as compared to low fat (30.0% fat) cheese. The Pizza cheese having lower fat content or stored for longer period (6 weeks at 2°C) were associated with inferior meltability. At storage period of 6 weeks, the meltability of cheese was lowered by ~21.0% as compared to the values noted in freshly prepared Pizza cheese [35].

Modified Tube Test

The cheese samples (10.0 g), in finely grated state, was put into the glass tubes (200×20.0×3.0 mm) and sealed using a perforated rubber stopper. Vernier caliper is used to measure the length of the compressed cheese sample. The tubes containing cheese samples are placed horizontally in the oven pre-heated to 110°C and kept there for 100.0 min and later allowed to cool to 22°C. The distance to which the melted cheese traversed is recorded. The melt character of cheese is expressed in terms of the melt distance (in mm) and the meltability property (expressed in per cent) is computed as follows [38]:

Meltability (mm)=Length (final) – Length (initial)

Meltability (%) = [Length (final) – Length (initial)]/Initial length×100

Helical Viscometry

Brookfield viscometer works on the principle of rotational viscometry. Such probe measures the viscosity by sensing the torque required to rotate a spindle at constant speed while immersed in the sample fluid. The torque is proportional to the viscous drag on the immersed spindle, and thus to the viscosity of the fluid.

A melting temperature of 60°C was found apt for testing since it simulates the cheese temperature of pizza that is being retrieved from the oven [16]. A Brookfield RVTDV-2 digital viscometer coupled with a strip-chart recorder is mounted on a helipath stand and fitted with t-bar spindle. The grated cheese sample (150.0 g) of LMPS Mozzarella cheese and/or ~23.0 cm of cheese disc is held in a glass cylinder (58.0 mm diameter). A water-bath set at 60°C is used. The test measures the resistance to rotational motion as the t-bar spindle is raised through a column of melted cheese. The differences in the resistance profile correlated well with the capacity of the melted cheese to form fibrous strands and the rigidity of such strands [16].

Recorder output registered the resistance profile of the apparent viscosity in terms of a peak. The apparent viscosity profile was dependent on the shape as well as size of the specific cheese, but various cheese variants exhibited varying viscosity profiles, depending on their melting properties. Correlation was observed between the highest peak height and the capacity of the melted cheese to convert into fibrous strands as well as their rigidity. The peak height (maximal) for Mozzarella cheeses (~18.0 cm; n=46; n is number of cheese samples) differed by an average of 9.4% [16].

Rheometer

The properties of the melted cheese can be measured using a rheometer. Immediately after being melted at 90°C, the cheese samples are loaded between serrated plates (35.0 mm diameter) at a gap height of 1.2 mm. Any portion of cheese that protruded the plate surfaces was trimmed and left aside. The lower plate temperature was maintained at 90°C using a Peltier effect temperature controller. The

sample edges were covered with paraffin oil and a solvent trap was used to avoid the moisture loss. A 5.0 min resting period prior to actual measurement permitted the temperature to equilibrate and to relax the structure of the sample [39].

In another study, a rheometer was fitted with a PP50 plate system to determine the solidifying and melting temperatures for Mozzarella cheese. The gap size varied between cheese tests from 1.5 to 5.0 mm. The cheese was placed on the Peltier plate and such plate was lowered until the normal force recorded was 10.0 mN. The gap is then locked in that position. Initially an amplitude sweep is run at 1.0 Hz up to 100.0% strain at 20°C. The cheese sample (25.0 g with 10.0 ml distilled water; held for 30.0 min) is heated from 20 to 90°C at the rate of 0.5°C/min and then cooled to 20°C at the same pace. A new amplitude sweep is carried out after the temperature treatment. The storage modulus (G') as a function of temperature is measured to characterize the changes in the stiffness of cheese. The solidifying and melting temperatures of Mozzarella cheese (60.0% moisture, 19.0% fat, 18.0% protein) were noted to be 38 and 58°C respectively [40].

Schreiber Test

In Schreiber test, the diameter of the cheese discs (Figure 1) is measured in two perpendicular directions and averaged. Each cheese disc (39.5 mm diameter, 5.0 mm height) is placed in the center of a glass petri dish, covered with a lid and heated (at 100.8°C) in a convection oven for a period of 5.0 min. The petri dishes are retrieved from the oven and allowed to cool for 30.0 min. The expansion of the cheese samples is measured by taking six measurements around the circumference. The scale has six lines marked on a concentric set of circles (Figure 2). Schreiber meltability is expressed as the mean of six readings on the arbitrary scale of 0–10 units at equal angular directions (Figure 1) [7, 41]. According to Richoux *et al.*, the meltability is expressed as the per cent increase in the cheese disc diameter upon heating at 225°C for 3.0 min [42].

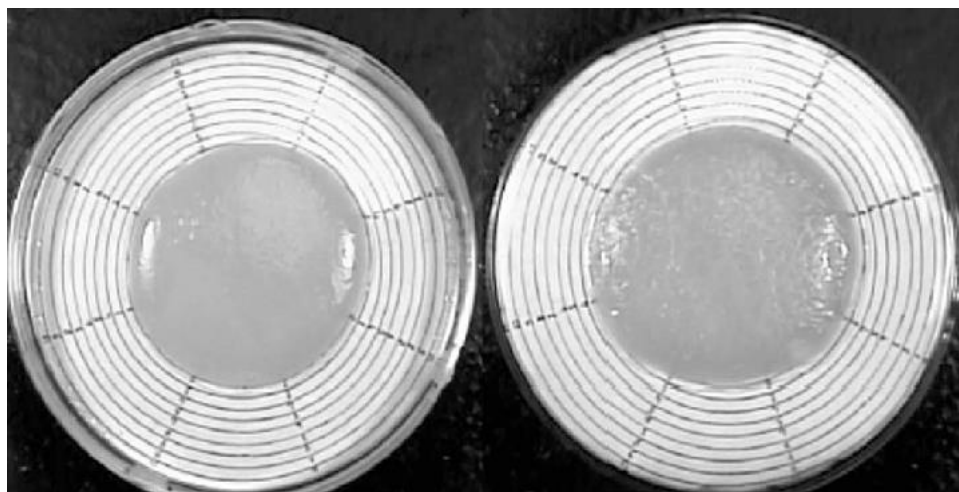


Figure 1. Schreiber Discs.

Modified Schreiber Test

The test investigates the effect of oven temperatures (i.e. 60 to 232°C; 70 and 90°C being intermediate temperatures) and three heating surfaces (viz., glass petri dish, aluminium plate (2.5 mm thick), and stainless steel (0.7 mm thick plate). The temperature of cheese (shredded form) during heating is monitored using a copper-constantan thermocouple. Two aspects viz., maximum diameter and the area of spread of the heated cheese mass are measured [43].

The area of spread and the maximum diameter tended to increase as the oven temperature was

raised from 60 to 232°C. Modified Schreiber test entails performing the method at a lower temperature (90 vs. 100.8°C) on an aluminium plate; the area of the melted cheese indicates the cheese meltability [43].

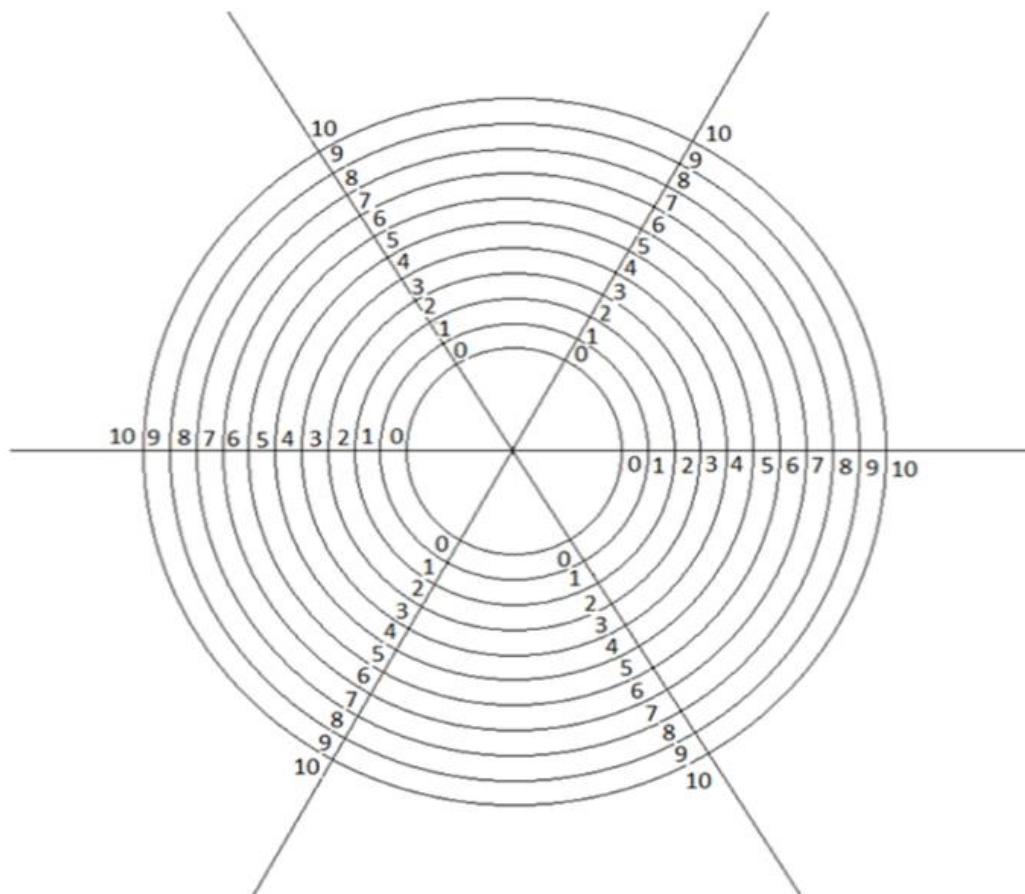


Figure 2. Schreiber Meltability Concentric Circles (Arbitrary Scale 0–10).

Small Amplitude Oscillatory Shear Analysis

The small amplitude oscillatory shear (SAOS) test is a valuable and non-destructive test which was originally employed to investigate the changes in the structure of fresh cement paste. The test entails the paste to be deformed at miniscule strain amplitude, i.e., within the linear viscoelastic region. Similar type of test has been applied for assessing the meltability of cheese samples. This method is based on temperature sweep of SAOS.

Mozzarella cheeses are sampled (40.0 mm diameter, 3.0 mm thick) in disc and serrated parallel plate (40.0 mm diameter) forms; the latter one prevented slippage. Temperature step sweeps from 10 to 90°C were performed with a temperature step of 5°C and 3.0 min holding time at each measured temperature point. Measurements are performed at a constant strain of 0.05% and a constant frequency of 0.8 Hz. The elastic modulus (G') and viscous modulus (G'') vs. temperature curves are plotted. Based on the Arrhenius plots of Mozzarella cheese samples, the values of activation energy (E_a) is calculated within the temperature range of 30 to 45°C.

In a study on 11 Mozzarella cheese samples, the meltability of product produced under varying stretching conditions (e.g. long stretch time, high stretch speed, high stretch temperature) were at par with each other. However, high fat (~28.0%) and low fat (~19.5%) cheese samples had the highest

(6.5 mm²/g) and least (3.5 mm²/g) meltability values respectively; and cheese prepared using low draining pH (5.39) had similar meltability with the ones with low calcium content (5340.0 mg/g), and vice versa (5.51 pH, 7760.0 mg Ca/g) [44].

Arnott Test

Arnott test is a later version of Schreiber meltability. Initially, the thickness of the cheese disc (17.0 mm diameter) is noted. Readings are taken at the edge of cheese disc (unheated) from four directions with about 90° in between. After subjecting the cheese disc to heating (100°C/15.0 min) in a convection oven, it is allowed to cool and the readings are taken once again. The maximum thickness along the edge of the melted spread is measured and the mean of these readings is considered as the thickness of the cheese, post heating [45].

Arnott meltability is expressed as the per cent decrease in the cheese cylinder thickness after heating:

$$M_{an} = (H_i - H_f) / H_i \times 100$$

Where, M_{an} (%) is the meltability (%); H_i and H_f = thickness (mm) of the cheese disc before and after heating respectively.

Farinograph Test

The Farinograph-E rheometer has been used especially in the baking industry as a reliable, reproducible means to know about the water absorption and kneading properties of flours. The same test has been used for measuring the meltability of cheese. Torque (resistance against farinograph paddles) and other qualitative parameters (viz., texture, fat globules, protein matrix) are measured and the graphs are plotted (torque vs. time). The changes in the torques at varying temperatures (20 to 60°C at an interval of 10°C) and at varying time intervals (5.0 to 35.0 min) are noted. The period had a marked effect on the torque. Magnitudes of torque were markedly different for cheeses having varying fat content. The interaction of time (5.0 to 35.0 min) with milk fat was found to be significant. Farinograph can be used to control the meltability of cheese [46].

Computer Vision Technique

This method analyses the influence of dimensions of cheese on its melting property using Computer Vision Technique (CVT). CVT has been used to evaluate the topping percentage and distribution of cheese on pizza for quality inspection. Blocks of LMPS Mozzarella cheese are initially kept in a deep freezer (-20°C) and then transferred to a fridge (5°C) for one day. The blocks of cheese are cut into slices (2.0, 2.5, 3.0 and 4.0 mm thick) and then shaped into square pieces (45×45 mm²); other sizes can also be taken (viz., side length 25.0, 60.0 and 70.0 mm²). Such cheese slices are wrapped with cling film, sealed into a food bag and stored at 5°C. A square slice of cheese, taken out from the fridge, is placed in a pizza pan and baked in oven (130°C, up to 10 min). During cooking, the pan is removed from the oven at periodic time intervals to capture the images of the melted cheese [47]. The CVT system includes a lens, a charged coupled device camera supported by a copy stand, an IC-PCI frame grabber, a monitor and a computer. A lighting unit to illuminate the dark room comprises of 2-dulux fluorescent lamps (each with 11 W and 5000 K colour temperature). The images are captured by the camera under appropriate brightness and contrast and saved in Red, Green and Blue light (RGB) format. Image processing and area measurement are performed using macros written in Optimas 6.51 [47].

The meltability of cheese is represented by the difference (D_t) between cheese areas at cooking time t (min) and the one noted prior to cooking.

$$D_t = A_t - A_0$$

Where, A_t = cheese area (mm²) at period 't' min; cooking A_0 = initial cheese area (mm²).

The meltability of cheese increased linearly when the side length of square cheese slices increased from 25.0 to 70.0 mm. Similar trend was also noted when the thickness of cheese slice increased from 2.0 to 4.0 mm [47].

Differential Scanning Calorimetry

The Differential Scanning Calorimetry (DSC) is a thermodynamic tool for direct assessment of the heat energy uptake taking place in a cheese sample within a regulated increase or decrease in temperature. The calorimetry is particularly applied to monitor the changes in the phase transitions of fat, melting range and elucidates the physical and textural properties of fats in bulk and final products. The combination of DSC and X-ray diffraction is used to identify the stable β -form fat crystals which leads to grainy mouth feel in the resultant product.

The Mozzarella cheese sample (20.0–25.0 mg) is placed in a volatile (readily evaporable) sample holder and heated at 5°C/min. Thermograms (i.e. heat flow vs. temperature relationship), in the range of 5 to 70°C are obtained using DSC device. The sensitivity of the instrument is set in the range 2.0–20.0 mcal/sec and the recorder chart speed at 2.0 cm/min. The thermograms reveal that the variations in the melt quality of cheeses are related to the differences at very low energy levels which tend to be lower than those of latent heat as well as below sensible heat. The factor to evaluate meltability of cheese should ideally be based on the comprehensive rheological analysis representing the values in terms of temperature and time based entities [41].

Rapid Visco Analyzer

Rapid Visco Analyzer (RVA) test is used for testing the viscous properties of several ingredients/food viz., starch, grain, dairy products, etc. Cheese discs of 15.0 g (15.0 mm height, 34.0 mm diameter) is tempered at 4°C for about 1 h and then placed in the bottom of the canister. The canister is placed into the RVA device. During the test, the temperature of cheese sample is raised from 25 to 90°C within 5.0 min, held for 3.0 min at 90°C, and then cooled to 25°C within 6.0 min. In the first 2.0 min of the test, the stirring speed is raised from static to 300 rpm; rest of the test is carried out at a constant rpm of 300. The parameters monitored such as melt time, hot viscosity, period required to cool at 5000 cP and solidification times gives fair indication of the apparent viscosity of the cheese product being assessed. RVA melt test is capable enough to measure the melting properties of cheese and furnishes further information about the melt property of process cheese spread and related products [48].

Meltmeter

University of Wisconsin (UW), Madison Meltmeter consists of three components viz., (a) a heater with thermal controller, (b) a linear variable differential transformer, and (c) a computer having facility of data acquisition. The system functions in the lubricated squeeze-flow configuration and can be used per se, being operated at a constant (i.e. 0.7 and 0.9 N) force. The melt quality of cheese product is expressed as the per cent change in the height of cheese sample (7.0×30.0 mm) after 16.0 sec at a constant force, when heated to 65°C [13, 49].

FAT LEAKAGE

Free oil is formed when the melted fat leaves the protein matrix to the surface [34]. Mozzarella cheese tends to release free oil upon melting, referred to as ‘fat leakage’. The free oil formation is of significance owing to the consumer’s concern over appealing food appearance and healthy diet. From the aesthetic view point, some free oil is regarded desirable, providing a shiny appearance; formation of pool of oil is undesirable [14]. Limited fat leakage is also considered undesirable [50].

The methods used to assess fat leakage are as follows:

Oil-Ring Test

In this test, the cheese discs are melted on filter paper under defined conditions. An oil ring is formed on the filter paper after heating. Such specific area is measured to quantify the formation of free oil [16].

Centrifugal Free Oil Test

A test for free oil in melted Mozzarella cheese utilizes standard Babcock equipment. An aliquot of 18.0 g of full-fat or LMPS Mozzarella cheese is weighed into 50.0 or 20.0% Paley-Babcock bottles. The bottles are immersed in boiling water for 4.0 min. Distilled water (20.0 ml at 57.5°C) is added and the bottles are centrifuged (1150±50 rpm) in hot (57.5°C) condition for 10.0 min. A portion of methanolic solution (methanol: distilled water, 1:1 at 21°C) is added to a calibrated level up to 40.0 ml in the bottle and then centrifuged for 2.0 min. The bottles are rocked manually for 10.0 sec, centrifuged for 2.0 min, and a repeated manual rocking is carried out for 10.0 sec and centrifuged for further 2.0 min. The bottles are finally tempered at 57.5°C water-bath for 5.0 min and the fat column measured with glymol [16].

The Free oil is expressed as (a) % in cheese, and (b) % in cheese fat, using the following formula:

Free oil (% in cheese) = Measured fat column/2

Free oil (% in cheese fat) = Measured fat column/2/[% total fat in cheese]

In one study the free oil (as % of cheese fat) for Mozzarella cheeses (n=64) ranged from 8.8 to 84.9%. Free oil increased with increasing cheese FDM content [16].

Modified Gerber Test

Cheese sample (6.0 g) is accurately weighed into a 200 mm Screw cap Pyrex tube. The tube with sample is immersed in boiling water for 4.0 min and then removed. An aliquot of 10.0 ml of acidified water (pH 2.2 adjusted using HCl) at 60°C is dispensed onto the melted sample. The sample tube is then centrifuged in a Gerber centrifuge for 5.0 min. After centrifugation, 10.0 ml of 1:1 distilled water: methanol (v/v) is added. The sample tube is then placed in a temperature controlled (60°C) water bath for 1.0 min, centrifuged for 2.0 min and once again tempered at 60°C for 1.0 min. Distinct yellow butter oil layer surfaced on the aqueous methanol mixture which is quantitatively transferred to a Gerber bottle. The aqueous methanol was also transferred to the bottle, rinsing the pipette free of butter oil residues. The Gerber bottle is stoppered, tempered at 60°C for 1.0 min, centrifuged for 2.0 min, tempered at 60°C for additional 2.0 min and then measured. The noted value is divided by 2 to give free oil (as per cent in cheese) [51].

STRETCHABILITY

The stretch property of Mozzarella cheese owes to the high content of large peptides and intact casein [17]. Under tension, Mozzarella cheese should form fibrous strands in hot condition and should elongate without breaking. The ability of Mozzarella cheese to form such fibrous strands is quantified as stretchability. Stretch quality is considered an important aspect during its end usage in baking applications. Thus, the length, tension and type of stretch (strings, feathering or fibrous) are important quality attributes of Pizza cheese. Retention of stretch quality in Mozzarella cheese during refrigerated storage is related to the extent of inactivation of the residual milk coagulant during cheese making [20].

Commonly, there are two types of methods to assess stretch behavior of cheese: objective methods and empirical methods. The empirical tests include (i) fork test, (ii) 3-pronged-hook probe tensile test, and (iii) imitative tensile stretch test. These methods are reported to have poor reproducibility, especially since the cheese samples are exposed to ambient conditions, and control over temperature or the moisture loss during the test is lacking. The objective methods, mainly derived from polymer methods, are believed to be superior methods to measure the stretch character of molten cheese. These methods include (i) piston-type capillary rheometer [52], (ii) vertical uniaxial extension apparatus [53], and (iii) ring-and-ball method [54].

Some countries have laid down the standard for 'stretch test' for cheese. In European countries, Italy and USA, the stretch behavior of cheese is evaluated through 'fork test', 'imitative tensile stretch test' and 'ring-and-ball' methods [55]. Indian standard (Food Safety and Standard Act, FSSA) has so far not included the stretch test for Mozzarella and Pizza cheeses [4]. During stretching of Mozzarella

cheese strands, neck thinning occurs simultaneously with neck propagation. Factors specifically related to the load and deformation prior to, during and after the formation of a stable neck is utilized to differentiate the stretch profiles of various stretched cheese varieties [56].

Apostolopoulos and Marshall proposed a test based on consumer's perspective in assessing the stretchability of cheese on pizza [31]. A circular plate (60.0 mm diameter) is used as a template to hold the pizza crust, and a smaller circular piece (with a vertical rod attached) is cut out, permitting the center of the template to be raised independently of the edge. A similarly sized pizza crust is portioned and placed on the template and a standard weight of cheese is strewn on top of the crust. The entire apparatus is heated in a microwave oven for 15.0 sec, sufficient to melt the cheese. Upon retrieval from the oven, the vertical rod is attached to the head of a tensile testing machine and pulled vertically (at 1500.0 mm/min speed), stretching the melted cheese strand. The extensibility of the cheese was construed as the distance of travelled until all the cheese strands broke. Mean of five replicates is reported. This method was modified by Guinee and O'Callaghan, such that the two halves of a pizza topped with cheese (loading 0.25 g/cm²) are pulled horizontally (speed of 0.033–0.100 m/s), rather than vertically [57]. Baking of pizza topped with cheese is carried out at 280°C for 4.0 min. Stretch was considered as the distance the cheese stretched until complete strand failure took place. The stretchability of cheese using this method was influenced by the load of cheese per unit area of pizza surface, and by the period of holding the pizza prior to stretching.

The description of some other tests for determining stretch behavior of cheese is dealt herein.

Hot Iron Test

This test was used in ancient times to determine the condition of the cheese curd ready for stretching. A piece of iron rod (15.0 cm long, 1.5 in diameter) is heated till red hot. Under specific condition, the curd adheres to the iron rod, and when pulled away, the curd is drawn into fine threads. The length of the threads is considered to be proportional to the acidity of the curd. For instance, the larger the stretched threads, the higher will be the acidity of Mozzarella cheese [58].

Pizza Fork Test

The test is conducted 3.0 min after retrieval of pizza topped with cheese from the oven (i.e. oven temperature 266°C, holding time 6.0 min). The stretch of cheese strands is measured as the inches travelled by the cheese clinging to the fork, until it breaks [59]. As per United States Department of Agriculture, Mozzarella cheese topped on pizza base when baked at 218.3°C (i.e. 425°F) for 12.0 min in a convection oven should stretch to a minimum of 3.0 in of unbroken string [60].

3-Prong Hook Test/Clamp Method

In an oil bath (temperature 70 or 90°C), melted cheese (21.0±0.3 g) is elongated (i.e. stretched) by a hook probe, manipulated by an Instron tensile tester. The strands of cheese are lifted from the melted cheese reservoir to a distance of 30.0 cm and the parameters recorded include the load and extension data [61]. The parameters related to stretchability viz. yield load, unstable deformation gradient and inversion point extension are noted. The yield load is obtained from the values of load and extension curve, which in turn determines the stretchability of cheese. This test has been considered to be more appropriate than the 'pizza fork test' to assess the stretch of cheese [61]. This test overcomes the drawbacks associated with other tests such as subjective stretching speeds and variations in the ambient temperature and humidity (Figure 3).

Utah State University Stretch Test

Utah State University (USU) test is being used as a standard test for evaluating stretch of Mozzarella cheese in the United States. Cheese (30.0, 50.0 g) is placed in a stainless steel cup (for 30.0 g cheese: height 5.0 cm, diameter 3.5 cm; for 50.0 g cheese: height 12.5 cm, diameter 3.5 cm)

and tempered in a water bath at specific temperature (i.e. 60, 70, 80 or 90°C) for 30.0 min. The cup is then placed in a water-jacketed holder mounted on the base of the instrument. A 3-pronged hook-shaped probe is lowered into the melted cheese and then pulled vertically until all the cheese strands break or when 30.0 cm height was reached. The distance to which the cheese strands could be lifted is defined as the stretch length [55].

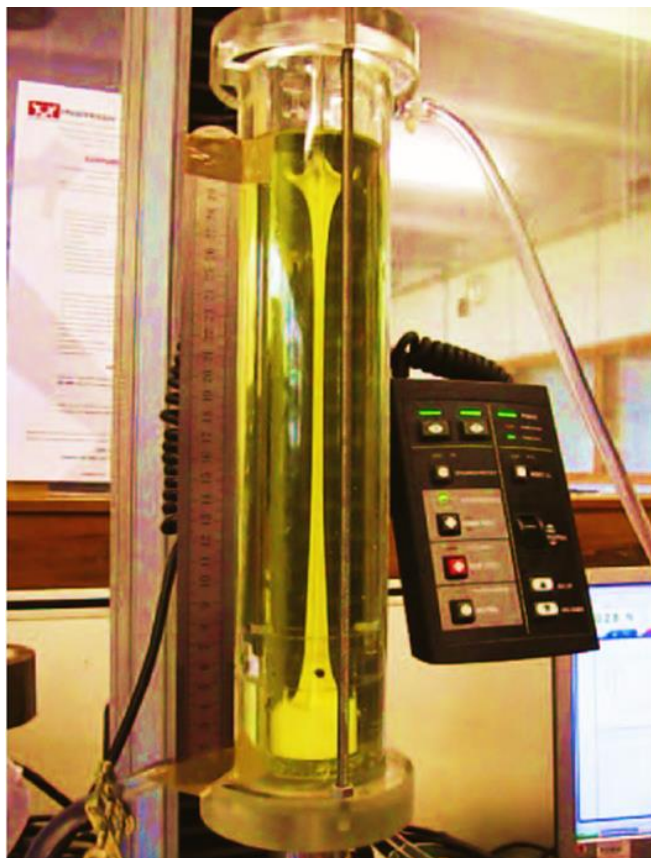


Figure 3. Three Prong Hook Apparatus.
Source: Ma et al. [61].

In one study, three non-fat (NF) cheeses and four LMPS Mozzarella cheeses were subjected to this test. The stretch length was maximum 30.0 cm for cheese NF-1,3 and LMPS-1,3 and 4 at 60°C; NF-1 and LMPS-3 at 70°C; NF-1 and LMPS-4 at 80°C; and LMPS-4 at 90°C. Evaluating the cheese for stretch quality at varying temperatures (e.g., 70°C, 90°C) provided information on predicted performance of the cheese during baking, as well as at the time of consumption. ‘USU stretch test’ provided better characterization of Pizza cheese than did the ‘Pizza fork test’. Besides stretch length, the USU stretch test also measures viscosity, elasticity and the thickness of the cheese strands [55, 59].

Ring-and-Ball Method

In this test, the cheese sample (6×6 cm² cubes) is cast in shouldered rings and heated (65°C/15 sec) at a controlled rate under the weight of a steel ball (150.0 g). The test measures the softening point of cheese; softening point is the temperature at which the cheese/bitumen discs soften and sag downward at a specific distance. This method provides control on the moisture loss and temperature during stretch by immersing the entire set-up in a mineral oil bath maintained at a temperature of 65°C [54].

Testing of Mozzarella cheese by this method has revealed that as the cheese advances towards the date of expiry, the stretch length tends to decrease. The average stretch length varied from 0.0 to

9.0 cm between the youngest and the oldest cheese samples. This method is able to discriminate between cheeses of different ages. The test is reproducible and gives reliable stretch length [54].

Vertical Uniaxial Extension Method

A vertical uniaxial extension (VUE) apparatus has been developed for determining the elongational properties of Mozzarella cheese as affected by the refrigerated storage. The specimen of cheese is initially kept in a refrigerator (60.0×7.0×6.0 mm; length × width × thickness) which is later on suspended in hot oil (60°C) for 3.0 min. The cheese undergoes melting and then stretches with help of special clamp attached to a load cell (113.0 g) under the influence of a constant force of 0.14 and 0.18 N [53].

In one study, the cheese strands did not break even after 400.0% extension when performing VUE test. Strain rate (0.001 to 1.0/sec) and sample temperature (from 25 to 50°C) both increased during the test. Transient elongational viscosity (TEV) of Mozzarella cheese decreased with increasing strain rate and the cheese sample temperature. Proteolytic changes in Mozzarella during refrigerated storage did not alter the TEV of the product. This test provided useful information on the processing operations involving extensional deformation of melted cheese or flow of the plastic cheese curd during cheese manufacture. The TEV of Mozzarella cheese decreased as the strain rate (0.001 to 1.0/sec) and the cheese temperature (from 25 to 50°C) was simultaneously raised during the test [53].

Capillary Rheometer Test

This method is used to measure shear viscosity, flow property and also stretchability of cheese. The setup consists of a piston-type capillary rheometer connected with a microprocessor for data collection and elaboration and a pick up system equipped with a force transducer (detects the strength of the melt). The Mozzarella cheese (1.5 mm diameter) was loaded in the setup. The barrel environmental chamber is set to the selected temperature (55 to 85°C) with a control accuracy of 0.5°C and the cheese is allowed to equilibrate for some time. During the test, the actual temperature of the sample is measured by means of a thermocouple located near the capillary exit and continuously recorded. The speed at which the driving wheel of the pickup system rotates is controlled by the computer. Initially the extrusion speed and the pickup speed of the thread of melted cheese are kept equal in order to avoid elongation. During the test, the pickup speed increases linearly with time at a preset rate and the cheese thread is stretched until it breaks. Test reproducibility obtained is ±15.0% [52].

Empirical Test

Prior to loading the cheese, the pizza base was cut cleanly in half and the halves were aligned in their original position to form a flush interface. Shredded cheese (4°C) was distributed evenly over the base (2.42 kg/m²) which was then placed in a thermostatically controlled electric fan oven at 280°C for 4.0 min. The melted pizza pie is then laid on a circular wooden board, already cut in two equal parts. Such specific board has dimension as well as having orientation that is similar to that of the pizza. Half portion of the pizza is fixed in a specific manner. The unfastened section of pizza pie is retrieved from the oven after 1.0 min and subsequently pulled manually until the elongated strands of the melted cheese mass connecting both the halves of the pizza base are fully broken [62].

Texture Analyzer

The texture analyzer is used to measure several textural properties of Mozzarella cheese viz., firmness, adhesive trait, tensile force, etc. Stretch test is undertaken using a Texture Analyzer utilizing a probe specifically meant for testing the stretch quality of melted cheese. The probe set comprises of a vessel, a special fork (double-sided) as well as a temperature sensor. The cheese sample (40.0 g) is cut into cubes, and then the cubes are put evenly in the vessel and covered. The fork is inserted in the vessel. The vessel with cheese and fork is then heated in a microwave oven for 60.0 sec to melt the cheese cubes sufficiently. The vessel set is kept in a retainer and the temperature probe is inserted into

the melted cheeses immediately after heating. The stretch test is carried out when the temperature of the cheese reaches 55°C with a test speed of 20.0 to 270.0 mm/s. The stretch performance of the cheese is observed visually [38].

Stretch-Strand Thickness Test

Insert 1 tine (slender pointed projecting part) of fork up to 1.0 cm into melted (60°C) cheese sample (20.0 g). The melted cheese is pulled up at a uniform rate up to 6.0 in height and then stopped. The melted cheese strand thickness is measured at 3.0 in of stretch. If the cheese strand does not reach 6.0 in height, the response is not taken [63].

The 'fork test', the 'imitative tensile stretch test', and the '3-pronged-hook probe tensile test' exposes the test cheese samples to ambient conditions during stretching and thus give poorly reproducible results [54].

BROWNING OF CHEESE

Browning of cheese during baking is mainly caused by Maillard reaction during high heat (200 to 300°C) of the oven. The browning of cheese can occur during processing (e.g. processed Pizza cheese making) [64], and during storage of Mozzarella cheese, especially in warm climates [65]. The browning of cheese is assessed either on baked pizza [66] or on cheese heated in a water bath [17]. The colour of the cheese is measured using colorimeters or spectrophotometers. Browning is then evaluated through computer vision technology [67]. Few tests to determine the extent of cheese browning during baking is dealt herein.

Empirical Test

Browning tests for Mozzarella cheese are performed using a Colorimeter. Duplicate cheese samples are cooked for up to 2.0 min at 232°C or even at 307°C; each color index (L^* , a^* , b^* values) are determined five times.

Hunter L^* , a^* , b^* is a color scale that stems from Opponent-Color Theory. This theory states that the receptors in the human eye perceives the color of any food object in the following manner: L^* scale: Light vs. dark; low (0–50) values are indicative of dark while (51–100) value is indicative of light color; a^* scale: Red vs. green; numbers with positive sign is indicative of red (0 to 120) while those numbers carrying a negative sign is indicative of green (0 to –120) color; b^* scale: Yellow vs. blue; number having positive sign (i.e. 0 to 120) is indicative of yellow, while any number having negative sign is indicative of blue (0 to –120) color [66].

In a study, LMPS Mozzarella cheeses prepared using strains of *Streptococcus* sp. KK-3 and *Lactobacillus helveticus* KK-31 (1:1, v/v) (culture releasing less quantity of galactose in the cheese curd) were compared with high browning cheese made using culture *Streptococcus* sp. KK-4 (capable of releasing higher quantum of galactose into the cheese curd). A portion of 125 g of each cheese (aged 144 days under refrigerated condition at 2°C) prepared as indicated earlier was used for pizza making and assessed for browning behaviour [66].

In one study, both brown and low browned pizzas were acceptable to the panelists. This indicated that browning of Mozzarella cheese on pizza was not a deleterious entity [66].

Computer Vision Technique

The browning property of cheese during baking conditions is tested using computer vision system [67]. A slice of cheese (3.0 mm thick) is taken out from the fridge, placed in the middle of a pizza pan (282.5 mm diameter, 12.5 mm high) and finally placed in an oven. Convection heating was used to cook the cheese slice at 70–200°C for up to 30.0 min. During cooking, the pan is removed from the

oven periodically to acquire the image [67].

The gray value (GV) of the cheese slices was obtained from the images captured. GV is a description of the level of greyness or brightness. GV is derived as the mean luminance of pixels within the framework of the cheese slice; values ranging between 0 and 255. A value of 0 corresponds to 'completely black' and a value of 255 represents 'fully white'. A browning factor, defined as the ratio of GV, before and after cooking, represented the browning property as follows:

$$BF\% = GV_0/GV_t \times 100$$

GV₀ and GV_t=GV of cheese slices prior to cooking and at cooking time t respectively [67].

The influence of baking temperature (70–200°C) and time (0.0–20.0 min) on the browning of cheese was reported to be statistically ($p < 0.05$) significant. When cooking for 2.0–4.0 min, the browning factor of Mozzarella cheese increased almost linearly with the rise in the baking temperature [67].

ASSESSMENT OF BLISTERING AND BROWNING OF CHEESE BY MACHINE VISION AND IMAGE ANALYSIS

A holistic approach has been devised based on machine vision system as well as image analysis method in order to assess the blistering and browning properties of Mozzarella cheese. Blisters are trapped pockets of heated air and steam that may be preferentially scorched during baking. Minimal blisters in cheese are tolerable. To evaluate blistering, the number, size and shape of blisters are analyzed. Mozzarella prepared with heat sensitive starter cultures such as *Streptococcus salivarius* subsp. *thermophilus*, *Lactobacillus helveticus*, *Lactobacillus delbrueckii* ssp. *bulgaricus* etc. had the least tendency to brown, with minimal blisters. Free oil markedly affected blister appearance of cheese by impeding the moisture loss from such product [68].

The blistering and browning of Mozzarella cheese with different salt and moisture content were evaluated using machine vision and image analysis. The entire number of Mozzarella cheese samples tested had browning appearance that was similar to each other, especially due to similar galactose content. Mozzarella cheese possessing higher salt concentration (5.0 vs. 3.0% salt) was associated with minimal blisters on the pizza. Such pattern was due to the greater elasticity and stretch resistances of such pertinent (i.e. with high salt) cheeses [68].

Chroma Meter

An aliquot of the ground cheese sample (15.0 g) is taken into an aluminium pan (7.5 cm×1.5 cm), and then the pans containing the cheese samples are spread out in a preheated forced-draft oven at 100°C for 1.0 h. A Chroma meter is used to measure the color of cheeses prior to heating. The color of the cheeses after heating and cooling to 22°C is measured; this represented browning of cheeses. The L* (lightness), a* (red/greenness) and b* (yellow/blueness) values were noted for each cheese sample. A browning factor, defined as the ratio of L* value, before and after heating, is used to describe the browning property as [69]:

$$\text{Browning factor (\%)} = L^* \text{ value before heating} / L^* \text{ value after heating} \times 100$$

Validation of Tests through Comparison

Comparison of tests to know the baking characteristics of cheese is important to select the accurate one or the one that gives more reproducible results. Few tests have been compared to arrive at such conclusions as provided below.

Comparison of Computer Vision vis-à-vis Arnott and Schreiber Tests

To assess the suitability of traditional tests (viz. Arnott, Schreiber) vis-a-vis computer vision method (CVM), the methods were compared. The melting characteristics of different brands of

Mozzarella cheeses (four cheeses coded M1, M2, M3, M4) were tested (Table 4) [15]. The image processing and area measurement were performed using macros written in Optimas 6.51.

Based on segmented images, the area of cheese, before and after cooking, were measured as follows:
 $A = a \times n$

Where A= area of cheese, a= area of an individual pixel in the image, and n= number of pixels of the cheese part in the image.

The melting property of cheese as determined by the CVM is represented as the ratio of cheese area after and before cooking:

$$M_{cv}\% = A_f/A_i \times 100$$

Where, M_{cv} (%)= meltability of cheese determined with CVM; A_f and A_i = area (mm^2) of cheese after and before cooking respectively.

Table 4. Comparative Assessment of the Melting Properties of Mozzarella Cheese.

Mozzarella Cheese Coding	Test for Meltability of Cheese		
	Schreiber (%)	Arnott (%)	Computer Vision (%)
M1	3.4 ^b	56.9 ^{bc}	286.1 ^{bc}
M2	3.5 ^b	55.8 ^{bc}	298.3 ^b
M3	4.0 ^{ab}	65.1 ^b	348.7 ^{ab}
M4	3.8 ^b	61.9 ^{bc}	346.0 ^b

Note: Values within a column not sharing a common alphabet differs significantly (P<0.001) Source: Wang and Sun (2002b) [15].

The meltability determined using CVM was significantly (P<0.001) interrelated with the Arnott ($R^2=0.69$) and Schreiber ($R^2=0.88$) meltabilities; R^2 is the correlation coefficient. The CVM provided an accurate quantitative account of the physical changes in cheese during melting, revealing meltability differences between cheeses that were otherwise difficult to be distinguished by the traditional methods (viz., Arnott, Schreiber) [15].

Fat Ring Test and Its Correlation with Computer Vision Method

A cheese disc (17.0 mm diameter, 5.0 mm thick) is placed on Whatman No. 1 filter paper and heated in an oven at 110°C for 5.0 min. Free oil from the melted cheese disc gets absorbed into the filter paper, forming an oil ring. Area of the original cheese disc and the oil ring are determined with CVM, and the percentage area ratio was calculated as ‘fat leakage’ [41].

The fat leakage of Mozzarella cheese (stored at 5°C) was recorded as 163.0% as per the CVM. Percentage oil area was correlated to the fat leakage with an R value of 0.852 (before/after cooking oil area) and the parameters calculated under the computer vision could be correlated with the ‘fat ring’ test [67].

Recent Methods for Assessing the Baking Characteristics of Cheese

Common Computer Vision and Analysis Method for Meltability and Fat Leakage of Cheese

Cheese samples were scanned with a flatbed computer scanner and the images were processed using Image J 1.48v software. The scanner is placed in black box and samples are illuminated with scanner bottom LED light. Scanned 24-bit images of 300 dpi with dynamic range 3.4 are digitalized and stored in Tiff format. After image capturing, the images were digitized (i.e. image is divided into a two-dimensional grid of small regions containing picture elements defined as pixels using a ‘frame grabber’ and stored in the form of matrices). CVM is able to measure the external features (cheese colors, cheese defects, etc.) of products, to recognize objects and extract quantitative information from digital images. Computer vision and digital image analysis represented an efficient and non-invasive technique to investigate the cheese optical properties (viz., baking properties such as meltability, fat

leakage, browning and blister formation) and provide information concerning their composition and structure [70].

Quantification of Pizza Baking Properties by Image Analysis

Mozzarella cheese stored at 4°C for a month was shredded. Pizza base (~23.0 cm diameter; 1.0 cm thick) was stored in a freezer and thawed for 3.0 h at room temperature (30°C) prior to testing. A mass of 125.0 g of cheese shreds was spread evenly on the pizza base (21.0 cm diameter, 5.0 cm height) and baked in a convection oven under conditions of 232°C for 5.0 min. The retrieved pizzas were placed in a light box system and the images of pizza were taken with a video camera, under controlled illumination. A lens with a circular polarizing filter (35.5 mm B+W filter) and a light box (emulating D65 illumination) was used. The circular region of interest (ROI, in software) on the pizza images were selected based on the size of cheese spread on the base, avoiding the color of the pizza base. The color of each pizza was measured employing average L^* , a^* , and b^* of the area selected by ROI. By averaging the values of every pixel in the ROI, the different images were analyzed for varied properties such as oiling-off, elasticity, transition temperature and colour uniformity [71].

Polar Planimeter for Assessing the Meltability and Fat Leakage of Cheese

A cheese sample is prepared using number-10 cork borer and cut to 4.0 mm height. Four cheese discs are placed on Whatman No. 42 filter paper and then placed in the oven maintained at 100°C for 10.0 min. The area of the melted cheese discs is measured with a Planimeter. The area of the shape is proportional to the number of turns through which the measuring wheel of polar planimeter rotates. The meltability of cheese is expressed as the percentage difference (flow distance) between the melted and the original disc. Fat leakage is computed by precisely measuring the area of oil leakage visible in the vicinity of the melted cheese disc as compared to the area of the original cheese disc [72].

Some data generated on the baking characteristics of Mozzarella cheese in some studies have been collated in a consolidated form in Table 5.

Table 5. Objectively Assessed Baking Properties of Mozzarella Cheese.

Baking Properties of Cheese					Reference
Shred	Melt	Fat Leakage	Stretch	Browning	
-	-	-	4.0 - 9.0 cm	-	[54]
-	-	-	58.3–72.0 cm	-	[57]
Minimum length, 2.0 cm	-	-	-	-	[28]
-	-	4.1 (% in cheese) 21.6 (% in cheese fat)	-	-	[50]
-	12.0–60.0 cm ²	-	-	-	[43]
-	-	60 to 180%	-	GV= 0 to 255 Browning factor =108% (200°C/3 min) Browning factor =97% (200°C/2 min)	[47, 67]

GV= Gray Value.

Survey of Mozzarella Cheese Quality at Restaurant End Use

A survey carried out by the scientists at University of Vermont, Burlington of several pizza restaurants revealed some degree of dissatisfaction by the users. The problems associated with Mozzarella cheese experienced either frequently or occasionally by $\geq 50.0\%$ of the respondents (where n = total number of respondents) during survey of pizza restaurants were: poor shredding properties (55.0%), excessive free oil (67.0%), soupy melted cheese (67.0%), and blistering (50.0%) [12].

CONCLUSIONS

Cheese is an extremely versatile food product that has a wide range of flavor, texture and end uses. The vast majority of cheese is eaten not by itself, but as a part of another food. As an ingredient in food, cheese is required to exhibit functional characteristics in the raw as well as in cooked forms. Shred ability, melting, stretching, free-oil formation and browning are some of the important functional traits of Mozzarella cheese. The unique characteristics of cheese play a significant role in the food products acceptability, when it is used as an ingredient in food system. Developing 'designer cheeses' involves manipulating few unique traits of cheese so as to acquire the requisite properties amenable for their end use applications. Evaluating the baking properties of Mozzarella and associated stretched curd cheese varieties is indispensable in maintaining the quality standards and helps in developing cheese with novel traits suiting the varied consumer's requirements. The unraveling of the basic functional traits of Mozzarella cheese can aid in the developing specialty cheese products. Development of dietetic, low-fat cheeses having more or less similar baking properties to those of full-fat cheese would require testing of the product for their requisite baking qualities. The modern and precise methods for testing the functional qualities (baking characteristics) of Mozzarella cheese should be adopted by the Indian cheese industry too.

REFERENCES

1. Banks JM. The Technology of Low Fat Cheese Manufacture. *Int J Dairy Technol.* 2004; 57(4): 199–207p.
2. Walstra P, Walstra P, Wouters JT, Geurts TJ. Cheese Manufacture. *Dairy Science and Technology*. 2nd edn. CRC Press; Boca Raton, FL, USA. 2005. 603–8p.
3. Jana Atanu Indian Cheese Industry: Status and Future Scope. 2015. Retrieved from <http://www.fnbnews.com/Top-News/indian-cheese-industry--status-and-future-scope-38262>
4. FSSAI. Food Safety and Standards Act (FSSAI). 2011. Retrieved from <http://www.fssai.gov.in>
5. Citro V. Atypical Local Product Obtained from Buffalo Milk: La Mozzarella. *Sci Tec Latt-Casearia*. 1981; 32(1): 263–7p.
6. IDFA. Cheese Fact. A Publication of the International Dairy Foods Association (IDFA); 2001. Retrieved from <http://www.idfa.org/news-views/media-kits/cheese/cheese-production>.
7. Kosikowski FV, Mistry VV. Soft Italian Cheese - Mozzarella and Ricotta. *Cheese and Fermented Milk Foods*. Edwards Bros., Cornell University; 1997; 174–93p.
8. Jana A. Mozzarella Cheese and Pizza: The Compatible Partners. *Beverage & Food World*. 2001; 28(10): 14–19p.
9. Jana AH, Mandal PK. Manufacturing and Quality of Mozzarella Cheese: A Review. *Int J Dairy Sci*. 2011; 6(4): 199–226p.
10. Pizza Market in India. Retrieved from www.mbarendezvous.com/general-awareness/pizza-market-in-India/
11. Rankin S, Chen CM, Sommer D, Esposito A. Mozzarella and Scamorza Cheese. *Handbook of Food Science, Technology and Engineering*. 2006, Hui YH (Ed.), Vol. 4, CRC Press, Boca Raton. 150p.
12. Pilcher SW, Kindstedt PS. Survey of Mozzarella Cheese Quality at Restaurant End Use. *J Dairy Sci*. 1990; 73(6): 1644–47p.
13. Wadhvani R, Mc Manus WR, Mc Mahon DJ. Improvement in Melting and Baking Properties of Low-Fat Mozzarella Cheese. *J Dairy Sci*. 2011; 94(4): 1713–23p.
14. Rudan MA, Barbano DM. A Model of Mozzarella Cheese Melting and Browning during Pizza Baking. *J Dairy Sci*. 1998; 81(8): 2312–19p.
15. Wang HH, Sun DW. Correlation between cheese Meltability Determined with a Computer Vision Method and with Arnott and Schreiber Tests. *J Food Sci*. 2002b; 67(2): 745–49p.
16. Kindstedt PS, Rippe JK, Duthie CM. Measurement of Mozzarella Cheese Melting Properties by Helical Viscometry. *J Dairy Sci*. 1989; 72(12): 3117–22p.
17. Mc Mahon DJ, Oberg CJ, Mc Manus W. Functionality of Mozzarella Cheese: Production, Processing, Properties, Quality. *Aust J Dairy Technol*. 1993; 48(2): 99p.

18. Savage AA, Mullan WM. Quality Perceptions and Expectations of Mozzarella Cheese Producers and Pizza Manufacturers. *Milchwissenschaft*. 1996; 51(12): 677–79p.
19. Guinee TP, Feeney EP, Fox PF. Effect of Ripening Temperature on Low Moisture Mozzarella Cheese: Texture and Functionality. *Le Lait*. 2001; 81(4): 475–85p.
20. Jana AH, Tagalpallewar GP. Functional Properties of Mozzarella Cheese for Its End Use Application. *J Food Sci Technol*. 2017; 54(12): 3766–78p.
21. Sheehan JJ, Huppertz T, Hayes MG, Kelly AL, Beresford TP, Guinee TP. High Pressure Treatment of Reduced-Fat Mozzarella Cheese: Effects on Functional and Rheological Properties. *Innov Food Sci Emerg Technol*. 2005; 6(1): 73–81p.
22. Gulzar N, Sameen A, Muhammad Aadil R, Sahar A, Rafiq S, Huma N, Nadeem M, Arshad R, Muqadas Saleem I. Descriptive Sensory Analysis of Pizza Cheese made from Mozzarella and Semi-Ripened Cheddar Cheese under Microwave and Conventional Cooking. *Foods*. 2020; 9(2): 214p.
23. Shenana ME, Hassaan HM, Sania MA, Nasr WI. Using Ultra-Filtered (UF) Retentate in Mozzarella Cheese Making. *Alexandria J Food Sci Technol*. 2008; 2(1): 45–60p.
24. Zisu B, Shah NP. Texture Characteristics and Pizza Bake Properties of Low-Fat Mozzarella Cheese as Influenced by Pre-Acidification with Citric Acid and Use of Encapsulated and Ropy Exopolysaccharide Producing Cultures. *Int Dairy J*. 2007; 17(8): 985–97p.
25. Bertola NC, Califano AN, Bevilacqua AE, Zaritzky NE. Effect of Freezing Conditions on Functional Properties of Low Moisture Mozzarella Cheese. *J Dairy Sci*. 1996; 79(2): 185–90p.
26. Childs JL, Daubert CR, Stefanski L, Foegeding EA. Factors Regulating Cheese Shreddability. *J Dairy Sci*. 2007; 90(5): 2163–74p.
27. Kindstedt PS. Factors Affecting the Functional Characteristics of Unmelted and Melted Mozzarella Cheese. In *Chemistry of Structure-Function Relationships in Cheese*. Boston, MA: Springer; 1995; 27–41p.
28. Banville V, Morin P, Pouliot Y, Britten M. Physical Properties of Pizza Mozzarella Cheese Manufactured under Different Cheese-Making Conditions. *J Dairy Sci*. 2013; 96(8): 4804–15p.
29. Ni H, Guansekaran S. Image Processing Algorithm for Cheese Shred Evaluation. *J Food Eng*. 2004; 61(1): 37–45p.
30. Banville V, Morin P, Pouliot Y, Britten M. Shreddability of Pizza Mozzarella Cheese Predicted Using Physico-Chemical Properties. *J Dairy Sci*. 2014; 97(7): 4097–110p.
31. Apostolopoulos C, Marshall RJ. A Quantitative Method for the Determination of Shreddability of Cheese. *J Food Qual*. 1994; 17(2): 115–58p.
32. Nasser SA, Emam AO. Effect of Salting Technique on Shred ability, Texture Profile and Microstructure of the Pre-Acidified Cow's Mozzarella Cheese. *Adv Dairy Res. (ADR)*. 2019; 7(3): 1–9p.
33. Paquet A, Kalab M. Amino Acid Composition and Structure of Cheese Baked as a Pizza Ingredient in Conventional and Microwave Ovens. *Food Microstructure (USA)*. 1988; 7(1): 93–103p.
34. Gunasekaran S, Ak MM. *Cheese Rheology and Texture*. Boca Raton, FL: CRC Press; 2003.
35. Cais-Sokolinska D, Pikul J. Cheese Meltability as Assessed by the Tube Test and Schreiber Test Depending on Fat Contents and Storage Time, Based on Curd-Ripened Fried Cheese. *Czech J Food Sci*. 2009; 27(5): 301–08p.
36. Poduval VS, Mistry VV. Manufacture of Reduced Fat Mozzarella Cheese Using Ultra Filtered Sweet Buttermilk and Homogenized Cream. *J Dairy Sci*. 1999; 82(1): 1–9p.
37. Koca N, Metin M. Textural, Melting and Sensory Properties of Low-Fat Fresh Kashar Cheeses Produced by Using Fat Replacers. *Int Dairy J*. 2004; 14(4): 365–73p.
38. Dai S, Jiang F, Shah NP, Corke H. Functional and Pizza Bake Properties of Mozzarella Cheese made with Konjac Glucomannan as a Fat Replacer. *Food Hydrocoll*. 2019; 92(2): 125–34p.
39. Banville V, Power N, Pouliot Y, Britten M. Relationship between Baked-Cheese Sensory Properties and Melted-Cheese Physical Characteristics. *J Texture Stud*. 2015; 46(5): 321–24p.
40. Rukke EO, Abrahamsen RK, Schuller RB. Rheology, Texture and Meltability of Different Types of Cheese. *Annual Transactions of the Nordic Rheology Society*. 2018; 26(2): 211–18p.

41. Park J, Rosenau JR, Peleg M. Comparison of Four Procedures of Cheese Meltability Evaluation. *J Food Sci.* 1984; 49(4): 1158–70p.
42. Richoux R, Roset G, Famelart MH, Kerjean JR. Diversité de quelques propriétés fonctionnelles chaud de l'Emmental français. *Le Lait.* 2001; 81(4): 547–59p.
43. Muthukumarappan K, Wang YC, Gunasekaran S. Modified Schreiber Test for Evaluation of Mozzarella Cheese Meltability. *J Dairy Sci.* 1999; 82(6): 1068–71p.
44. Ma X, James B, Zhang L, Emanuelsson-Patterson E. Correlating Mozzarella Cheese Properties to Production Processes by Rheological, Mechanical and Microstructure Study: Meltability Study and Activation Energy. *Procedia Food Sci.* 2011; 1(1): 536–44p.
45. Arnott DR, Morris HA, Combs WB. Effect of Certain Chemical Factors on the Melting Quality of Process Cheese. *J Dairy Sci.* 1957; 40(8): 957–63p.
46. Inayat S, Ayaz M, Pasha TN, Abdullah M, Waheed A. Evaluation of Commercially Available Mozzarella Cheese for Its Melt and Stretching Behaviour through Farinograph-E. *J Anim Plant Sci.* 2014; 24(3): 770–73p.
47. Wang HH, Sun DW. Melting Characteristics of Cheese: Analysis of Effect of Cheese Dimensions Using Computer Vision Techniques. *J Food Eng.* 2002a; 52(3): 279–84p.
48. Prow LA, Metzger LE. Melt Analysis of Process Cheese Spread or Product Using a Rapid Visco Analyzer. *J Dairy Sci.* 2005; 88(4): 1277–87p.
49. Wang YC, Muthukumarappan K, Ak MM, Gunasekaran S. A Device for Evaluating Melt/Flow Characteristics of Cheeses. *J Texture Stud.* 1998; 29(1): 43–55p.
50. Kindstedt PS, Rippe JK. Rapid Quantitative Test for Free Oil (Oiling Off) in Melted Mozzarella Cheese. *J Dairy Sci.* 1990; 73(4): 867–73p.
51. Kindstedt PS, Fox PF. Modified Gerber Test for Free Oil in Melted Mozzarella Cheese. *J Food Sci.* 1991; 56(4): 1115–16p.
52. Cavella S, Chemin S, Masi P. Objective Measurement of the Stretchability of Mozzarella Cheese. *J Texture Stud.* 1992; 23(2): 185–94p.
53. Ak MM, Gunasekaran S. Measuring Elongational Properties of Mozzarella Cheese. *J Texture Stud.* 1995; 26(2): 147–60p.
54. Hicsasmaz Z, Shippelt L, Rizvi SS. Evaluation of Mozzarella Cheese Stretchability by the Ring-and-Ball Method. *J Dairy Sci.* 2004; 87(7): 1993–98p.
55. Fife RL, Mc Mahon DJ, Oberg CJ. Test for Measuring the Stretchability of Melted Cheese. *J Dairy Sci.* 2002; 85(12): 3539–45p.
56. Vincent PI. The Necking and Cold-Drawing of Rigid Plastics. *Polymer.* 1960; 1(1): 7–19p.
57. Guinee TP, O' Callaghan DJ. The Use of a Simple Empirical Method for Objective Quantification of the Stretchability of Cheese on Cooked Pizza Pies. *J Food Eng.* 1997; 31(2): 147–61p.
58. Babcock EJ. Absorption Photography and X-Rays. *Sci Am.* 1896; 75(7): 155p.
59. Moyes BL. *Correlation between the USU Stretch Test and the Pizza Fork Test.* 2003. Cited from <https://www.digitalcommons.usu.edu>
60. USDA. *Specifications for Mozzarella Cheeses.* Retrieved from www.ams.usda.gov/sites/default/files/media/mozarella.pdf.
61. Ma X, James B, Zhang L, Emanuelsson-Patterson EA. The Stretchability of Mozzarella Cheese Evaluated by a Temperature Controlled 3-Prong Hook Test. *J Dairy Sci.* 2012; 95(10): 5561–68p.
62. Walsh CD, Guinee TP, Harrington D, Mehra RA, Murphy J, Fitzgerald RJ. Cheesemaking, Compositional and Functional Characteristics of Low-Moisture Part-Skim Mozzarella Cheese from Bovine Milks containing κ -casein AA, AB or BB genetic variants. *J Dairy Res.* 1998; 65(1): 307–15p.
63. Moynihan AC, Govindasamy-Lucey S, Jaeggi JJ, Johnson ME, Lucey JA, Mc Sweeney PL. Effect of Camel Chymosin on the Texture, Functionality, and Sensory Properties of Low-Moisture, Part-Skim Mozzarella Cheese. *J Dairy Sci.* 2014; 97(1): 85–96p.
64. Bley ME, Johnson ME, Olson NF. Factors Affecting Non-Enzymatic Browning of Process Cheese. *J Dairy Sci.* 1985; 68(3): 555–61p.
65. Thomas MA. Browning Reaction in Cheddar Cheese. *Aust J Dairy Technol.* 1969; 24(4): 185p.

-
66. Matzdorf B, Cuppett SL, Keeler L, Hutkins RW. Browning of Mozzarella Cheese during High Temperature Pizza Baking. *J Dairy Sci.* 1994; 77(10): 2850–3p.
 67. Wang HH, Sun DW. Assessment of Cheese Browning Affected by Baking Conditions Using Computer Vision. *J Food Eng.* 2003; 56(4): 339–45p.
 68. Ma X, James B, Balaban MO, Zhang L, Emanuelsson-Patterson EA. Quantifying Blistering and Browning Properties of Mozzarella Cheese. Part II: Cheese with Different Salt and Moisture Contents. *Food Res Int.* 2013; 54(1): 917–21p.
 69. Dai S, Jiang F, Corke H, Shah NP. Physico-Chemical and Textural Properties of Mozzarella Cheese Made with Konjac Glucomannan as a Fat Replacer. *Food Res Int.* 2018; 107(1): 691–99p.
 70. Lukinac J, Jukic M, Mastanjevic K, Lucan M. Application of Computer Vision and Image Analysis Method in Cheese Quality Evaluation: A Review. *Ukr Food J.* 2018; 7(2): 192–214p.
 71. Ma X, Balaban MO, Zhang L, Emanuelsson-Patterson EA, James B. Quantification of Pizza Baking Properties of Different Cheeses, and Their Correlation with Cheese Functionality. *J Food Sci.* 2014; 79(8): 1528–34p.
 72. Fernandez A, Kosikowski FV. Low Moisture Mozzarella Cheese from Whole Milk Retentates of Ultrafiltration. *J Dairy Sci.* 1986; 69(8): 2011–17p.