Incorporation of *Lactobacillus* adjuncts culture to improve the quality of *Feta*-type cheese made using buffalo milk

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Abstract *Feta*-type cheese was made from buffalo milk using commercial adjunct culture of *Lactobacillus helveticus* and *Lactobacillus casei* along with standard mesophilic cheese cultures. The sensory, biochemical and texture characteristics of the experimental cheeses were studied during ripening. Expert panellists observed, significant differences ($P<0.01$) between the control and the experimental cheeses. The pH, titratable acidity, soluble protein and free fatty acid content of the experimental cheeses were found to be significantly ($P<0.01$) higher than those of the control. The texture parameter values of the experimental cheeses were found to be significantly ($P<0.01$) lower than values of the control.

Keywords Buffalo milk · *Feta*-type cheese · Starter adjunct · Sensory characteristics · Textural characteristics

Feta cheese is one of the most popular varieties of white brined cheese. It originates from the Mediterranean and Middle-East regions, particularly in Greece and is traditionally made from ewe's milk or from a mixture with goat's milk. The production of ewe and goat milk is very limited and its production is around 2 % of total annual world's milk production (Pandya et al. 2011). Therefore, it becomes almost impossible to fulfil the growing demand for *Feta* cheese from ewe milk and goat milk mixtures. In order to fulfil the ever growing demand for *Feta* cheese worldwide, the technology for the manufacture of *Feta*-type cheese with acceptable quality from cow's milk has been developed in European countries. Since characteristics of this cheese are a white colour, cow's milk cheese has to be bleached, but bleaching can destroy β -carotene. Buffalo milk would be more suitable than

cow's milk, as no bleaching would be required to get the characteristic white colour of *Feta* cheese.

India is the largest milk producing country in the world, producing 121.8 million tonnes (NDDB 2012), out of which, more than half (57 %) of the total milk production comes from buffalo milk (IDF 2008). Therefore, there is a need to utilize buffalo milk by developing novel suitable technologies for the manufacture of new products.

Ripening of cheese is a complex process necessary for the overall development of cheese flavour and texture. Flavour development in buffalo milk cheese is considerably slower than that in cheese made from cows milk (Dastur 1956). The prolonged ripening period and slow flavour development in buffalo milk cheddar cheese is due to inherent qualitative and quantitative differences amongst the major and minor constituents of buffalo and cow milk (Kanawjia 1987; Kanawjia and Singh 1992). Syneresis of buffalo milk curd is considerably faster than that for cow's milk curd, probably due to the high calcium content of buffalo milk (Jha 1984) and varying type of casein micelles (Kanawjia and Singh 1992). The poor retention of moisture in buffalo milk curd manifests itself in slower acidity development during manufacture and ripening coupled with a relatively slower rate of proteolysis and lipolysis. Due to slow rate of these biochemical changes, buffalo milk cheese tends to be dry, hard, and has a crumbly body & texture and lack flavour (Kanawjia and Singh 1988; Rao 1991). In addition to the starter culture, various other proteolytic and lipolytic agents in cheese contribute to cheese ripening, including milk coagulant, indigenous milk enzymes and adjunct non- starter lactic acid bacteria (Fox 1993).

Adjunct cultures are non-starter lactic acid bacteria, which are used along with a standard starter culture to further improve and enhance the flavour of cheese by increasing the concentration of desirable flavour peptides and precursors of flavour volatiles (Fox et al. 1998; Fernandez and Steele 1993). *Lactobacillus* species are the most common reported adjunct

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cultures for enhancing the sensory quality of different varieties of cheese (Lee et al. 1992; Ardo et al. 1989; Skeie et al. 1995; Drake et al. 1997; Rao and Singh 2007; Hashemi et al. 2009). The most commonly used species of *Lactobacillus* are *L. casei*; *L. helveticus* and *L. delbrueckii* subsp *bulgaricus* (Drake and Swanson 1995). There is no information about the effect on the quality of buffalo milk *Feta*-type cheese of lactobacilli as adjunct cultures. Therefore, in the present study attempts were made to further improve the quality of *Feta*-type cheese from buffalo milk using two starter adjuncts *L. helveticus* (NCDC-5) and *L. casei* (NCDC-299). The starter adjuncts treated cheeses were compared for various quality attributes with control.

Materials and Methods

Milk Raw buffalo whole milk was procured (morning; 7 AM) at temperature 9 ± 1 °C and skimmed milk was obtained after separating buffalo milk at temperature 38 ± 2 °C using centrifugal cream separator from the Experimental Dairy of the National Dairy Research Institute (NDRI), Karnal.

Starter culture The starter culture including *Lactococcus lactis* subsp *lactis*; *Lactococcus lactis* subsp *cremoris* and *Lactococcus lactis* subsp *diacetylactis* (NCDC-149) was obtained from the National Collection of Dairy Cultures (NCDC), NDRI, Karnal. The starter culture was maintained in autoclaved reconstituted skimmed milk (12 g/100 ml) by sub-culturing once in a fortnight to maintain high activity.

Starter adjunct Freeze dried *Lactobacilli* cultures NCDC- 5 and NCDC- 299 were procured from the NCDC, Dairy Microbiology Division, NDRI, Karnal.

Coagulating enzyme Microbial rennet (Meito) commercially produced in granular form from *Mucor pusillus* var. *Lindt* was procured from M/s Meito Sangyo and Co. Ltd., Tokyo, Japan having strength 3,000 IMCU/g.

Salt Iodized, sodium chloride (Tata chemicals, Mumbai) was procured from local market of Karnal, Haryana (India).

Feta-type cheese from buffalo milk *Feta*-type cheese was made from standardized (casein/fat ratio 0.70) and pasteurized (63–65 °C, 30 min) buffalo milk according to the procedure described by Kumar et al. (2011a). The pasteurized milk was cooled to 32–35 °C and subsequently, was transferred into nine different cheese vats in equal volume (40 L). Three different cheese treatments; a control cheese (without adjunct culture), an experimental cheese with adjunct culture NCDC-5 (A) and another with NCDC-299 (B) in addition to the

regular mesophilic starter culture were prepared to give three replicate vats for each of the three treatments. Adjunct cultures NCDC-5 and NCDC-299 were added @ 0.5 % (v/v) before the addition of mesophilic starter culture (NCDC- 149, @ 1.5 % v/v).

The cheese milk was renneted at 31–32 °C after allowed to set for 40–50 min before the coagulum was cut. The curds were cut into approximately 1–2 cm³ cubes and left undisturbed for 10–20 min for drainage of the whey. The curds were transferred into perforated moulds lined with muslin cloth for further removal of whey and texturization of the cheese curd without pressure. The whey was collected and stored at 5 °C for making brine solution. Moulds were turned every 2–3 h to form a firm curd. After four or five turns, the moulds were left undisturbed overnight at temperature 10 ± 1 °C. The cheese blocks were cut into uniform size and transferred to the whey brine solution of 14 % at same temperature for about 22–24 h. The cheese blocks were then transferred into plastic packages for vacuum packaging. Finally, packaged cheese blocks were stored for maturation at 10 ± 1 °C and relative humidity of 80 % up to 60 days.

Packaging of Feta-type cheese *Feta*-type cheeses were vacuum packaged using an Indvac vacuum chamber machine (Saurabh Engineers, Ahmedabad, India) under a vacuum of 20 mm of Hg (<0.70 kpa).

Cheese analysis Samples from each type of *Feta*-type cheese were taken for analysis at 1, 15, 30, 45 and 60 days after production. All the analyses were replicated three times.

Compositional analysis Fat was determined by the Gerber method in milk and the fat content of cheese was determined by Mojonnier method (IS 1981). The casein content of milk was determined by Pyne (1932) method. The moisture of cheese was determined by drying to a constant weight at 102 °C (IDF 1982) and the salt content of cheese was determined by using the method of Kosikowski (1978). The titratable acidity (TA) was expressed in terms of % lactic acid and determined by the standard procedure of AOAC (1990). The pH of cheese was determined by a digital pH meter (LABINDIA, New Delhi, version I). The total protein content of cheese was estimated by micro-kjeldahl method (IDF 1982) and soluble protein was determined by the method of Kosikowski (1982), while lipolytic changes in cheese were measured in terms of free fatty acid (FFA) content using the method of Deeth and Fitz-Gerald (1976).

Sensory analysis The experimental *Feta*-type cheese at different stages of ripening was evaluated by a panel of seven trained judges selected from the Dairy Technology Division, National Dairy Research Institute, Karnal for sensory

evaluation. The 100 point Cheddar cheese score card (Bodyfelt et al. 1988) was modified as per characteristics of Feta-type cheese. Out of 100 point score card, 50, 35 and 15 points allocated for flavour, body & texture and colour & appearance, respectively.

Texture analysis Various objective texture parameters related to characteristics such as hardness, cohesiveness, springiness, gumminess and chewiness (Kumar et al. 2011b) were measured using a Stable Micro Systems Texture Analyzer (Model TA.XT2i Stable Micro systems, double cycle compression, fitted with 25 kg load cell, combined with Texture Expert Exceed Software). A cylindrical shape of experimental cheese samples of 1 cm diameter and 1 cm height was used for determining the textural characteristics. A data acquisition rate of 200 pps with probe P 75, was used and samples were compressed twice to 80 % of their height. Probe speeds of 2.5 mm / s during test, and 2.5 mm / s for pre- test and 5.0 mm / s for post- test were used throughout the study. All measurements of samples were carried out at 25 ± 1 °C.

Data analysis The data were statistically analyzed using the SYSTAT Software (version 6.01) and expressed as means and standard deviation (SD). In all the experiments, analysis of variance (ANOVA) with subsequent least significant difference (LSD) test was applied for multiple sample comparison. This was done to test for any significant differences ($P < 0.05$ or 0.01) in the mean value of all the groups as described by Snedecor and Cochran (1989).

Results and Discussion

Composition

The effect of starter adjunct along with standard cheese culture on composition and yield of fresh *Feta*-type cheese are presented in Table 1. The yield of cheese increased with the supplementation of starter adjuncts. Furthermore, the fat and protein content of these experimental cheeses decreased,

while the moisture, salt and salt in moisture (S/M) increased with the augmentation of adjunct cultures.

Bio-chemical changes

pH The effect of starter adjunct on the pH of cheeses was found to be significant ($P < 0.01$) and is illustrated in Fig. 1(i). The maximum pH of 5.30 was found in cheese B, while the minimum pH of 5.19 was found in control cheese and the pH of cheeses A and B was significantly ($P < 0.01$) higher than that of the control cheese at all stages of ripening. The proteolysis in terms of soluble protein (%) in the control cheese (1.37 %), cheese A (1.68 %) and cheese B (1.82) at 60 days of ripening. This is well correlated with the higher rate of proteolysis observed in experimental cheeses due to greater release of basic amino acids. Similar findings were reported by Malhotra (1991) and Das (1996), who found that pH of cheese with *L. helveticus* was higher than that of the control at all stages of ripening in Gouda and low fat Gouda cheese. It was also reported by Rao (1991) that a higher pH in cheese with *L. casei* was found compared to the control in the case of Cheddar cheese. A similar trend was also reported by Jha (1984) and Madkor et al. (2000). It is also evident (Fig. 1(i)) that the pH of all experimental cheeses decreased during the first 15 to 30 days and levelled off or increased slightly to the end of ripening period. Our finding was in agreement with the result of Hashemi et al. (2009) who observed a decrease in pH in first 15 days and thereafter, the pH increased at varied rates in Iranian white-brined cheese with *L. helveticus*. This may be due to the fact that adding viable *L. helveticus* as an adjunct culture led to a reduction in the metabolism residual lactose and acid production in cheese (Hashemi et al. 2009).

Titrateable Acidity The variation in TA due to the addition of starter adjunct along with a standard culture, during the ripening period and their interaction effect were found highly significant ($P < 0.01$). The maximum TA of 1.37 % lactic acid was found in cheese B and the minimum TA of 1.26 % lactic acid was found in the control cheese (Fig. 1(ii)). The TA of experimental cheeses increased as the ripening period increased, but cheeses A and B had a higher TA than the control cheese throughout the ripening period. Similar trends were

Table 1 Effect of starter adjunct on proximate composition of *Feta*-type cheese

Type of cheese	Yield (%)	Moisture (%)	Fat (%)	Protein (%)	Salt (%)	S/M (%)
Control	23.44 ^A ±0.13	61.13 ^A ±0.09	19.23 ^A ±0.05	15.36 ^A ±0.04	2.83 ^A ±0.30	4.62 ^A ±0.04
A	23.67 ^B ±0.06	61.37 ^B ±0.05	19.15 ^B ±0.04	15.30 ^B ±0.03	2.96 ^B ±0.02	4.82 ^B ±0.03
B	23.80 ^C ±0.03	61.56 ^C ±0.07	19.10 ^C ±0.03	15.26 ^C ±0.05	3.04 ^C ±0.06	4.92 ^C ±0.09

The values are mean±SD of three replicates ($n=3$), S/M Salt in moisture. Mean in a column with different superscripts (A, B, C) was significantly different (LSD test, $P < 0.01$) from each other

Fig. 1 Effect of type of starter adjunct on biochemical characteristics of Feta type cheese during ripening: **i** pH; **ii** TA(%); **iii** Soluble protein (%); and **iv** FFA (μeq/g)

also reported by Rao (1991); Malhotra (1991); Johnson et al. (1995); Das (1996); Hashemi et al. (2009). The maximum TA

of 1.82 % lactic acid was observed in cheese B at 60 days of ripening, while the minimum TA as 0.63 % lactic acid was observed in control cheese at 0 day (fresh). This increase in acidity can be attributed to the higher level of inoculum causing increased biological activity in cheeses A & B.

Soluble protein The effect of starter adjunct addition on soluble protein levels in cheese during ripening (Fig. 1(iii)) was found to be significant ($P<0.01$) and the maximum soluble protein of 1.36 % was found in cheese B, while the minimum soluble protein of 1.05 % was found in the control cheese. The soluble protein content of the experimental cheeses increased as the ripening period increased; however, the soluble protein content was always higher in cheese A and B than the control cheese throughout the ripening period. The interaction effect between starter adjuncts and ripening period was also found to be significant ($P<0.01$) and the maximum soluble protein level (1.82 %) was found after 60 days of ripening in cheese B, while the minimum soluble protein (0.63 %) were found in control cheese at 0 day(fresh). A general increasing trend of water soluble nitrogen (WSN) in *Feta* cheese was reported by Katsiari et al. (2000). They reported % WSN in *Feta* cheese from ewe's milk were 13.69 ± 0.45 and 19.21 ± 0.77 at 3 and 60 days of ripening, respectively. Bartels et al. (1987); Malhotra (1991) and Das (1996) reported an almost similar result to that reported here for Gouda and low-fat Gouda cheese with *L. helveticus*. Jha (1984) and Rao (1991) also reported a similar trend in Cheddar cheese while Hashemi et al. (2009) reported a similar trend for Iranian white-brined cheese. The higher levels of soluble proteins in both starter adjunct cheeses could be attributed to the higher overall inoculation rate as well as to higher proteolytic activity of the adjunct strains.

FFA The effect of starter adjunct addition on the FFA content of cheese during ripening (Fig. 1(iv)) was found to be significant ($P<0.01$) and the maximum FFA ($4.23\mu\text{eq/g}$) was found in cheese A, but the minimum FFA ($3.88\mu\text{eq/g}$) was found in the control cheese. The FFA content of the experimental cheeses increased consistently as the ripening period progressed. The interaction effect of starter adjuncts and ripening time was also found to be significant ($P<0.01$) and the maximum FFA ($4.23\mu\text{eq/g}$) was found at 60 days of ripening and the minimum FFA ($1.53\mu\text{eq/g}$) was found at 0 day. Our results were in agreement with the result of Jha (1984) and Rao (1991) for Cheddar cheese. Malhotra (1991) and Das (1996) had also reported similar trend in Gouda and low-fat Gouda cheese, respectively. Hashemi et al. (2009) also supplemented same trend in Iranian white-brined cheese. This positive effect on lipolysis could be attributed to the increased microbial load due to addition of starter adjuncts (NCDC-5 and NCDC-299) in large numbers after inoculation. In addition, it could also be due to the action of intracellular lipases produced by lactobacilli (Nakae et al. 1964). Our finding was

further supported by the finding of Georgala and Kaminarides (2006) that the acid degree value (ADV) of low-fat *Feta*-type cheese supplemented with adjunct culture was slightly higher than those of the control low-fat *Feta*-type cheese and the ADV increased continuously during cheese ripening.

Sensory characteristics

Flavour The effect of starter adjuncts on the flavour of *Feta*-type cheese was found to be significant ($P<0.01$) and is presented in Table 2. The flavour scores of the cheeses A and B were found to be significantly ($P<0.01$) higher than control. It is also revealed (Table 2) that flavour score of experimental cheeses was increased as the ripening period progressed up to 30 days, followed by a decrease towards the end of ripening period up to 60 days. However, cheese A and B were always found with significantly ($P<0.01$) higher flavour score than the control cheese throughout the ripening days up to 60 days. The flavour development in buffalo Cheddar cheese were faster when cheese culture was supplemented with *L. casei* (Kanawjia and Singh 1991) as was found in our results. The interaction effect between starter adjunct and ripening period on the flavour of cheese was also found to be significant ($P<0.01$) and showed that the maximum flavour score as 46.0 was found at 30 days of ripening in cheese B which described as a balanced pleasant flavour. The minimum flavour score as 39.66 was found at 0 day (fresh) in the control cheese due to flat flavour. Similar findings have been

reported by various workers (Vafopoulou et al. 1989; Rao 1991; Malhotra 1991; Johnson et al. 1995; Lynch et al. 1999; Hashemi et al. 2009) for hard, semi-hard and white brined cheese including *Feta* cheese.

Body and texture The effects of starter adjuncts on the body and texture of cheese were found significant ($P<0.01$) and is shown in Table 2. The maximum body and texture score as 32.78 was found in cheese B and the minimum body and texture score as 32.38 was observed with control cheese due to a slightly harder body and texture than cheese A and B. It is also apparent (Table 2) that the body and texture scores of experimental cheeses increased as the ripening period progressed up to 30 days, followed by a decrease trend up to 60 days of ripening. The interaction effect between type of starter adjuncts and the ripening period on body and texture was also found to be significant ($P<0.01$) and the maximum body and texture score of 34.0 was observed at 30 days in both cheese A and B, as both these *Feta*-type cheeses possessed the characteristic soft and smooth texture attributes, while the minimum body and texture score of 31.10 was found at 60 days of ripening in the control cheese. Similar trends have been reported by (Jha 1984; Kanawjia 1987; Vafopoulou et al. 1989; Rao 1991; Malhotra 1991; Johnson et al. 1995; Das 1996; Lynch et al. 1999; Hashemi et al. 2009) for hard, semi-hard and white brined cheeses.

Colour and appearance All the experimental cheeses were in normal range with respect to colour and appearance (Table 2).

Table 2 Effect of type of starter adjunct on sensory characteristics of *Feta*-type cheese

Sensory parameters	Type of cheese	Ripening periods (days)				
		0	15	30	45	60
Flavour						
	Control	39.66 ^{aA} ±0.15	41.73 ^{aA} ±0.20	45.33 ^{bA} ±0.15	43.13 ^{bA} ±0.32	41.70 ^{aA} ±0.10
	A	40.13 ^{aB} ±0.12	44.20 ^{bB} ±0.18	45.6 ^{bA} ±0.11	43.63 ^{cA} ±0.24	41.37 ^{aA} ±0.19
	B	40.30 ^{aB} ±0.13	44.80 ^{bB} ±0.14	46.0 ^{cB} ±0.12	43.93 ^{bA} ±0.21	40.80 ^{aB} ±0.14
C.D. (SA)=0.1629; C.D (R.P)=0.2103; C.D (SA*R.P)=0.3643						
Body and texture						
	Control	32.06 ^{aA} ±0.12	32.53 ^{aA} ±0.25	33.76 ^{bA} ±0.15	32.46 ^{bA} ±0.15	31.10 ^{cA} ±0.10
	A	31.20 ^{aB} ±0.11	32.90 ^{bA} ±0.21	34.00 ^{cB} ±0.14	32.75 ^{bB} ±0.14	31.5 ^{aB} ±0.15
	B	31.86 ^{aA} ±0.15	33.10 ^{bB} ±0.28	34.00 ^{cB} ±0.12	33.23 ^{bA} ±0.13	31.7 ^{aB} ±0.13
C.D. (SA)=0.1235; C.D (R.P)=0.1595; C.D (SA*R.P)=0. 2763						
Colour and appearance						
	Control	14.30 ^{aA} ±0.26	13.93 ^{aA} ±0.11	13.90 ^{aA} ±0.10	13.70 ^{aA} ±0.10	13.50 ^{aA} ±0.10
	A	14.30 ^{aA} ±0.21	14.06 ^{aA} ±0.09	13.83 ^{aA} ±0.11	13.50 ^{aB} ±0.14	13.46 ^{aA} ±0.11
	B	14.43 ^{aA} ±0.23	14.10 ^{aA} ±0.13	13.93 ^{aA} ±0.13	13.60 ^{aB} ±0.11	13.80 ^{aB} ±0.12
C.D. (SA)=0.0905; C.D (R.P)=0.1168; C.D (SA*R.P)=NS						

Values are mean±SD. C.D: Critical difference; SA: Starter adjunct; R.P: Ripening period. The values of 100-point score were divided for flavour, body and texture, and colour and appearance, viz. 50, 35 and 15, respectively. Mean in each row with different superscripts (a,b,c) was significantly different (LSD test, $P<0.05$) from each other. Mean in a column with different superscripts (A, B) was significantly different (LSD test, $P<0.05$) from each other

The colour and appearance score of experimental cheeses was decreased as the ripening period progressed up to 60 days of ripening. Kanawjia (1987) also reported that colour and appearance score in Cheddar cheese made with buffalo milk decreased with the progressive ripening period. The interaction effect between treatments and ripening time on colour and appearance was not significant.

Textural attributes

Hardness The effect of starter adjuncts on the hardness of *Feta*-type cheese is presented in Table 3 and reveals that hardness significant affected ($P<0.01$) by the type of starter adjuncts, ripening time as well as their interaction. The maximum hardness as 26.87 N was observed in cheese A, while the minimum hardness of 28.43 N was found in the control cheese. It was also observed (Table 3) that the hardness of the cheese decreased upto 30 days of ripening and thereafter, gradually increased up to the end of ripening (60 days). The early decrease in hardness (before 30 days) may be due to the hydrolysis of α_{s1} -casein to α_{s1} -l-casein. Creamer and Olson (1982) suggested that the hydrolysis of α_{s1} -casein to α_{s1} -l-casein is responsible for early softening of high moisture cheeses. Pappas et al. (1996) also suggested that increased degradation of α_{s1} -casein during ripening softens cheese texture. However, the fact that from 30 days onwards, the hardness of all the experimental *Feta*-type cheese increased could be due to the fact that the extent of proteolysis was probably not sufficient enough to compensate the loss of moisture in cheese towards the end of ripening period. A change in water activity could also be the reason for this development. It has been reported that when a peptide bond is cleaved, two new ionic groups are generated and each of these will compete for the available water in the system. Thus, the water previously available for solvation of the protein chain will become tied up with the new ionic group, leading to an increase in the hardness of cheese (Creamer and Olson 1982). The interaction effect between the type of starter adjuncts and ripening period also showed that the maximum hardness (31.67 N) was found after 60 days of ripening in control cheese, while the minimum hardness (23.36 N) was found after 30 days of ripening in cheese A. Our finding is in accordance with the result of Malhotra (1991) and Das (1996) who reported, a reduction in the hardness of Gouda cheese and low fat Gouda cheese made using freeze-shocked *L. helveticus* along with the normal cheese culture.

Cohesiveness The effect of type of starter adjunct on cohesiveness of *Feta*-type cheese during ripening was found significant ($P<0.01$) and revealed (Table 3) that the maximum cohesiveness (0.24) was found in control cheese and the minimum cohesiveness (0.21) was found in the cheese B. The cohesiveness of experimental cheeses decreased as the

ripening period progressed. Erdem (2005) also reported that cohesiveness of white brined cheeses decreased as the ripening period progressed. The interaction effect between the type of starter adjunct and the ripening period was also found to be significant ($P<0.01$) and showed that the maximum cohesiveness (0.33) was found at 0 day in control cheese, while the minimum cohesiveness (0.13) was found at 60 days of ripening in cheese B. This may be due to higher proteolysis in cheese A and B in comparison to the control cheese. However, Malhotra (1991) and Das (1996) reported that the addition of *L. helveticus* along with normal cheese culture improved the cohesiveness in Gouda and low fat Gouda cheese, respectively.

Springiness The springiness value of experimental cheeses decreased regardless of type of starter adjuncts including control cheese (Table 3). The release of calcium ions from mono-calcium and calcium para- κ -caseinate molecules and the hydrolysis of these molecules during ripening have been reported to be responsible for the springiness of cheese curd (Van Slyke and Price 1952). It has also been reported that proteolysis was responsible for decrease in springiness. Thus, the proteolysis in cheese is negatively correlated with springiness (Lawrence et al. 1987).

The interaction effect between the type of starter adjunct and the ripening period on springiness was also found to be significant ($P<0.01$) and showed that maximum springiness (0.75 mm) was found at day 0 in the control cheese, while the minimum springiness (0.34 mm) was found after 60 days of ripening in cheese B. Our results are in accordance with the finding of Malhotra (1991) and Das (1996) who reported that cheeses containing *L. helveticus* cells had lower springiness value than the control cheese (Gouda cheese from buffalo milk) at all stages of ripening. Addition of starter adjunct along with standard cheese culture comparatively increased proteolysis in these cheeses relative to the control cheese and this increased proteolysis may explain the greater decrease in the springiness of these cheeses. Lawrence et al. (1987) reported that cheese proteolysis had as significantly negative correlation with cheese springiness. Our finding was further supported by Erdem (2005), who also reported that the springiness Index of while brined cheeses decreased as the ripening period increased up to 3 months.

Gumminess The effect of starter adjunct on the gumminess attribute of *Feta*-type cheese during ripening was found to be significant ($P<0.01$) and revealed (Table 3) that the maximum gumminess (6.85 N) was found in control cheese, while the minimum gumminess (5.77 N) was found in cheese B. The gumminess of experimental cheeses decreased as the ripening period progressed upto 60 days. The interaction effect between the type of starter adjunct and the ripening period on

Table 3 Effect of type of starter adjunct on textural characteristics of *Feta*-type cheese

Textural characteristics	Type of cheese	Ripening periods (days)				
		0	15	30	45	60
Hardness (N)						
	Control	31.16 ^{aA} ±0.29	26.65 ^{bA} ±0.17	24.72 ^{cA} ±0.11	27.92 ^{dA} ±0.14	31.67 ^{aA} ±0.17
	A	30.26 ^{aB} ±0.22	25.12 ^{bB} ±0.19	23.72 ^{cB} ±0.17	26.17 ^{bB} ±0.18	29.09 ^{aB} ±0.14
	B	29.92 ^{aC} ±0.27	24.47 ^{bC} ±0.23	23.36 ^{bC} ±0.15	25.40 ^{cC} ±0.21	28.26 ^{aC} ±0.18
C.D. (SA)=0.1511; C.D (R.P)=0.163; C.D (SA*R.P)=0.365						
Cohesiveness						
	Control	0.33 ^{aA} ±0.01	0.28 ^{bA} ±0.01	0.22 ^{cA} ±0.06	0.19 ^{dA} ±0.03	0.16 ^{eA} ±0.03
	A	0.31 ^{aB} ±0.02	0.27 ^{bB} ±0.01	0.21 ^{cB} ±0.04	0.18 ^{dB} ±0.05	0.14 ^{eB} ±0.02
	B	0.30 ^{aB} ±0.04	0.26 ^{bC} ±0.02	0.21 ^{cB} ±0.05	0.17 ^{dC} ±0.07	0.13 ^{eC} ±0.01
C.D. (SA)=0.0024; C.D (R.P)=0.0033; C.D (SA*R.P)=0.0069						
Springiness (mm)						
	Control	0.75 ^{aA} ±0.04	0.71 ^{bA} ±0.02	0.53 ^{cA} ±0.01	0.46 ^{dA} ±0.02	0.39 ^{eA} ±0.03
	A	0.74 ^{aB} ±0.03	0.69 ^{bB} ±0.01	0.52 ^{cB} ±0.02	0.43 ^{dB} ±0.01	0.35 ^{eB} ±0.02
	B	0.73 ^{aC} ±0.02	0.68 ^{bC} ±0.01	0.50 ^{cC} ±0.01	0.42 ^d ±0.01	0.34 ^e ±0.01
C.D. (SA)=0.0019; C.D (R.D)=0.0025; C.D (SA*R.P)=0.0043						
Gumminess (N)						
	Control	10.31 ^{aA} ±0.04	7.54 ^{bA} ±0.02	5.66 ^{cA} ±0.01	5.49 ^{cA} ±0.02	5.25 ^{cA} ±0.03
	A	9.43 ^{aB} ±0.02	6.87 ^{bB} ±0.01	5.13 ^{cB} ±0.01	4.72 ^{dB} ±0.01	4.33 ^{dB} ±0.02
	B	9.12 ^{aC} ±0.03	6.38 ^{bC} ±0.02	4.95 ^{cC} ±0.02	4.46 ^{cB} ±0.04	3.94 ^{dC} ±0.02
C.D. (SA)=0.0682; C.D (R.D)=0.0881; C.D (SA*R.P)=0.1526						
Chewiness (N.mm)						
	Control	7.82 ^{aA} ±0.11	5.36 ^{bA} ±0.16	3.03 ^{cA} ±0.10	2.54 ^{dA} ±0.12	2.05 ^{dA} ±0.09
	A	7.00 ^{aB} ±0.12	4.75 ^{bB} ±0.12	2.67 ^{cB} ±0.13	2.06 ^{cB} ±0.11	1.52 ^{dB} ±0.10
	B	6.70 ^{aC} ±0.15	4.34 ^{bC} ±0.11	2.52 ^{cC} ±0.09	1.90 ^{dC} ±0.13	1.35 ^{eC} ±0.11
C.D. (SA)=0.050; C.D (R.D)=0.0650; C.D (SA*R.P)=0.1125						

Values are mean±SD. C.D: Critical difference; SA: Starter adjunct; R.P: Ripening period. Mean in each row with different superscripts (a,b,c,d,e) was significantly different (LSD test, $P<0.05$) from each other. Mean in a column with different superscripts (A, B,C) was significantly different (LSD test, $P<0.05$) from each other

gumminess is also significant ($P<0.01$) and showed that the higher gumminess (10.31 N) was found at 0 day, while the minimum gumminess (3.94 N) was found at 60 days of ripening in cheese B. Our finding is in accordance with the results of Malhotra (1991) and Das (1996), who reported a decrease in the gumminess of cheese supplemented with *L. helveticus* at all stages of ripening. The decrease in the gumminess of the experimental cheeses could be due to increased proteolysis towards the end of the ripening.

Chewiness The effect of type of the starter adjunct on the chewiness of *Feta*-type cheese during ripening was found to be significant ($P<0.01$) and showed (Table 3) that the maximum chewiness (4.16 N.mm) was found in control cheese and the minimum chewiness (3.36 N.mm) was found in cheese B. The chewiness of all experimental cheeses decreased as the ripening period progressed up to 60 days of ripening. The interaction effect between type of starter adjunct and ripening

period was also found to be significant ($P<0.01$) indicating that the maximum chewiness (7.82 N.mm) was found at day 0 in the control cheese, while the minimum chewiness (1.35 N.mm) was found after at 60 days of ripening in cheese B. This may probably be due to the higher level of proteolysis in cheese supplemented with starter adjunct. Similar result was reported by Malhotra (1991) and Das (1996) in cheese supplemented with *L. helveticus* at all stages of ripening of Gouda cheese.

Conclusions

Addition of adjunct cultures (NCDC-5 and NCDC-299) along with the standard cheese culture (NCDC-149) significantly ($P<0.01$) improved the sensory, compositional and textural characteristics of buffalo milk *Feta*-type cheese during the

ripening period. The pH of experimental cheeses was found higher than that control cheese at all stages of ripening. Furthermore, the TA, soluble protein and FFA increased consistently during the ripening but were higher in cheese treated with adjunct culture. The adjunct cultures also resulted in lower hardness, cohesiveness, springiness, gumminess and chewiness in treatment samples as compared to control.

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