IJFANS
International Journal of Food And Nutritional Sciences

Volume 4, Issue 5, Oct-Dec 2015, www.ijfans.com e-ISSN: 2320-7876

INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES

IMPACT FACTOR ~ 1.021

Official Journal of IIFANS

e-ISSN 2320 –7876 *www.ijfans.com*
Vol.4, Iss.5, Oct-Dec, 2015

Research Paper *Open Access*

STUDIES ON ENCAPSULATED ENZYMES TO ACCELERATE PROTEOLYSES IN CHEDDAR CHEESE

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Received on: 7th September, 2015 **Accepted on: 29th December, 2015**

ABSTRACT

In this study, exogenous enzymes were encapsulated in gum acacia, sodium alginate and butyrate phthalate using as an emulsion and extrusion techniques and were then added in cheese milk together with rennet. The effects of the encapsulating material and ripening period on physic-chemical, textural and sensory characteristics of cheddar cheese were investigated. The study demonstrated that gum acacia, sodium alginate and butyrate phthalate could successfully be used as enzymes carrier systems to accelerate the protein breakdown process during the ripening of cheddar cheese. Those samples treated with sodium alginate, capsules showed the highest rate of proteolysis compared to those treated with gum acacia and butyrate phthalate capsules.

Keywords*:* Cheese Ripening, Exogenous Enzymes, Encapsulated Enzymes, Cheddar Cheese.

INTRODUCTION

Over the years, little change has been made in hastening development of full flavour in Cheddar cheese and similar varieties of cheese; the conventional long-time ripening process for the finished cheese is still the prevailing custom. An urgent need exists for manufacturing and ripening techniques which will both accelerate and provide positive control over development of flavour in Cheddar cheese (Rynne et.al., 2004). Manufacture of full-flavoured cheddar cheese is made more and more uncertain, due to partially changes in the production and handling of milk, the increasing use of milk of Grade a quality for cheese manufacturing, and the adoption of regulations requiring pasteurization of all milk for cheese. Currently, the cheese industry is faced with an increasing demand for cheddar cheese of high flavour intensity the prepared by food industries. Controlled and accelerated ripening of cheddar cheese has been a long-time goal of cheese investigators. Generally, the approaches have involved use of selected inoculums, additives, and enzymes preparation with ripening of the cheese curd in the conventional manner (Oberg et.al., 1991). This report presents initial findings of a study of a new approach to curd ripening. The process results in a slurry cheese product of intense, sharp, balanced cheddar cheese flavour and will, with suitable modification, produce products possessing other cheese flavours as well. Several attempts have been made to reduce the ripening period by the addition of individual and mixed exogenous enzymes, some of which have been reported to halve the normal maturation period of cheese.

Direct addition of individual and mixed exogenous enzymes to the cheese milk was not successful due to loss of enzymes in the whey, poor enzyme distribution, reduced yield and poor-quality cheese. Incorporation of encapsulated enzymes eliminated the problems associated with direct enzymes addition (Fox, 1993). The use of encapsulated enzymes has been proposed to circumvent these drawbacks. Enzymes encapsulate physically separate the enzyme from the substrate in the curd and the enzyme is only released into the curd upon capsule breakdown during ripening (Sheu and Marshall, 1993).

Vegetable gels such as Konjac, liposomes, milk fat, some food gums, hydrophilic and hydrocolloids are used for enzyme encapsulation materials. The use of liposomes as enzymes encapsulating substances has some drawbacks. They may be expensive and are generally not regarded as safe and edible. A group of substances that exhibit excellent encapsulating abilities includes food gums or hydrophilic and hydrocolloids (Kheadr et.al., 2000). Limited information is available on the accelerated ripening of cheddar cheese using encapsulated enzymes.

The objective of this work was to study the effects of encapsulated exogenous enzymes added to cheddar cheese milk on the physic-chemical, rheological, and organoleptic characteristics of the cheese during ripening.

MATERIALS AND METHODS

EXOGENOUS ENZYMES, GUMS AND CULTURE

Promod (promod^{TM}215): This enzyme used for flavor development was supplied by Biocatalysts and Triforest Industrial Estate, Ponty, Pridd, CF37 SVO, UK. Lipomod (Lipomod^{TM}215): This enzyme is a specially formulated mixed fungal lipase designed to give slightly blue cheese flavour of enzyme modified cheese. It can be used in combination with promod^{TM}215 to obtain good flavour.

Gum acacia, sodium alginate and butyrate phthalate Sodium alginate, were supplied by Sigma Chemicals (Delhi, India). Freeze dried mother culture of LF-40 (159) was obtained from division of Diary Bacteriology, National Dairy Research Institute (NDRI) Karnal (India) the starter cultures containing *Lactococcus lactis* subsp. *lactis* and *L. lactis* subsp. *Cremoris* . All other reagents used were of analytical grade.

PREPARATION OF GUM CAPSULES

Sodium alginate and butyrate phthalate capsules were prepared by a modified method (Akin, 2012). The suspended solution consisting 1.5 g sodium alginate and 0.5 butyrate phthalate with addition of 50 ml de-ionized water and heated to 80°C, stirred for 20 min until dissolve the polymer completely. Then the solutions were cooled to 40°C and mixed with 11.5 ml of exogenous enzymes solution (Promode 2.5mg and Lipomod 2.5mg) then the mixture was rapidly poured into 150 ml of soybean oil containing 0.2% emulsifier in a beaker maintained at 40°C by immersion in a water bath while stirring (2000 rpm) with a marine impeller to produce of capsules. The emulsions were cooled to 25°C to allow the gum droplets to gel by centrifugation (100xg, 2 min). The gel beads were washed twice with distilled water, and the capsules were separated from the supernatant by sieving. The beads formed were hardened by soaking in 0.07% calcium chloride solution for 2 hr.

PREPARATION OF GUM ACACIA CAPSULES BY USING EMULSION AND EXTRUSION TECHNIQUES

A 2gm gum acacia mixture containing 2gm Hi-maize resistant starch added with 11.5 ml of exogenous enzymes solution (Promode 2.5mg and Lipomod 2.5mg) was prepared. The mixture was dropped into oil containing Tween 80 (0.02%). After dropping the mixture was stirred vigorously until it was emulsified and appeared creamy. A solution of 0.1 M calcium chloride was added quickly along the side of the beaker then the phase separation of the oil /water emulsion then occurred. The mixture was left to stand for 30 min to allow the sodium-alginate beads to separate and settle at the bottom of the calcium chloride layer. The oil layer was drained, and beads were collected by low-speed centrifugation (350×g, 15 min), washed once with 0.9% saline solution containing 5% glycerol, and stored at 4°C. Size separation of the beads was performed using 500 µm and 150 µm steel sieves and beds were extruded by technique of Krasaekoopt et al., 2003.

CHEESE MAKING

Cheese production was done in the Department of Food Science & Technology at G.B.Pant University of Agriculture & Technology. Five kilograms of standardized milk was used for each batch (1 control and 4 treatments). The fat content of the milk was standardized to 2.5%. All batches were pasteurized at 72°C for 30 sec and then cooled to 35°C. Starter culture (1%) and CaCl2 (0.02%) were then added. For the experimental Sample A was the control no addition enzyme capsules. Enzyme capsules made of gun acacia by emulsion techniques (Sample B), gum acacia by extrusion techniques (Sample C), sodium alginate (Sample D) and butyrate phthalate (Sample E), were introduced into the cheese milk at 35°C, just before the addition of rennet, and the samples were coded B, C, D and E, respectively.

When the pH of the milk reached 6.2 to 6.3, rennet diluted with pure water was added. Cutting was performed 30 min later. The curd was cut with a curd knife into cubes of 1 cm3. The cut curd was allowed to settle for 15 min. The cooking was performed by increasing the temperature from 35 to 40°C over 30 min. At the end of cooking, a third of the whey content was drained from each batch. At the same time, the cheese curd was agitated. The cheese curd was fermented until it reached a pH level of 5.0. The remaining whey was then drained. Cheese whey was collected during the manufacturing and strained using a 120 µm stainless steel sieve.

The capsules were collected on the sieve and re-added to the curd. The curd was hand-stretched in at 6% brine at 74°C for 2 min for all the cheeses studied. Brine was strained using a 120 µm stainless steel sieve and the capsules were collected on the sieve and re-added to curd. The curds were placed into cylindrical stainless steel moulds and turned 30 min later to provide a flat surface. All cheeses were cooled at room temperature, and the moulds were removed. Then, the cheeses were allowed to gain their yellow colour for 24 h at 15±2°C. Cheese samples were taken for chemical and sensory analyses on the 1st, 7th, 14th and 20th days of storage. Cheese was manufactured in triplicate for each group.

CHEMICAL ANALYSIS

The pH of the milk and cheeses (BIS, 1981 was measured using a digital pH-meter (model of Orion 250 A, Orion Research Inc., Boston, USA). The protein content of the milk and cheeses were determined by the Kjeldahl method AOAC (1990). The total fat and dry matter contents of the cheese samples were determined using the method proposed by Gerber and gravimetric methods, respectively. The salt content of the cheeses was determined by the Mohr titration method.

DETERMINATION OF PROTEOLYSIS

Cheese protein (casein) degradation during ripening was evaluated after1st, 7th, 14th and 20th days using by mini urea polyacrylamide gel electrophoresis (Urea-PAGE). Electro-phoresis was carried out on a vertical slab unit (Bio-Rad Laboratories, Inc. 1000 Alfred Nobel Drive, Herculus, California, USA) and the stacking gel system described by Craemer (1991).

Table 1- Chemical composition of control and exogenous enzymes treated cheeses on day of manufacture

Chemical Parameter**	Cheese Samples				
	A	B	C	D	E
pH	5.35±0.02a	5.27±0.02b	5.28±0.02b	5.22±0.03c	5.15±0.04d
Titratable acidity (% L.a.*)	1.17±0.021d	1.31±0.042c	1.30±0.031c	1.33±0.021b	1.36±0.020 a
Moisture (%)	46.50±0.32a	48.55±0.33c	47.25±0.43b	48.22±0.53c	48.35±0.35c
Protein (%)	22.50±0.34a	23.33±0.32b	24.71±0.25a	24.44±0.15a	23.66±0.20b
Fat in dry matter (F/D)	52.88±0.23b	52.77±0.31b	53.77±0.22a	52.44±0.28b	53.22±0.40a
Salt (%)	1.77±0.05a	1.73±0.06c	1.75±0.04b	1.81±0.06b	1.66±0.05d

A, Control cheese (no added encapsulated enzymes); B, cheeses contain exogenous enzymes in gum acacia capsules produced by emulsion techniques; C, cheeses contain exogenous enzymes in gum acacia capsules produced by extrusion techniques; D, cheeses contain exogenous enzymes in sodium alginate capsules; E, cheeses contain exogenous enzymes in butyrate phthalate capsules .
**Different letters following numbers in the same row denote significant differences ($p<0.05$). * Lactic Acid

TEXTURE ANALYSIS

The textural properties of cheddar cheese were evaluated by the textural profile analysis (TPA) method (Kuchroo and Fox, 1982). TPA was performed on cheese samples by using a double compression test (TA-XT2i Texture Analyzer; Stable Micro Systems, NY, USA).

SENSORY ANALYSIS

The samples were organoleptically assessed by ten panellists. The panel was made up of staff members and postgraduate students from the G.B.Pant University of Agriculture & Technology, Department of Food Science & Technology, who had previous experience in sensory evaluation. A 5-point hedonic scale was used to evaluate flavour, texture, odour and appearance. General acceptability was the sum of flavour, texture, odour and appearance scores.

STATISTICAL ANALYSIS

Each cheese experiment was repeated three times. The experiment was designed according to a 5×8×3 factorial design. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) statistical software program (version 5.0).

RESULT AND DISCUSSION

ENZYME ENCAPSULATION

The encapsulation efficiencies for the four capsulants were significantly different from each other ($p<0.01$). The ionic strength of the capsule hardening solution (calcium chloride) may have had an effect on the activity of enzyme (Kailasaphaty and Lam, 2005).

CHEMICAL COMPOSITION

The gross chemical composition of the control and experimental cheeses is given in Table 1. Significant differences were observed between the control and experimental cheeses. The cheese curds had a significantly higher moisture content and titratable acidity but lower pH contents as compared to the control ($p<0.01$). The high moisture content of the exogenous enzymes-treated cheese curds was due to the hydrophilic nature which retained moisture in the
cheeses. The protein and fat contents of the experimental cheeses were close to each other ($p>0.05$). Salt content of the experimental cheeses were slightly lower than those of the control ($p<0.05$). Similar results were reported for enzymes-treated cheeses by Yun *et al* (1995).

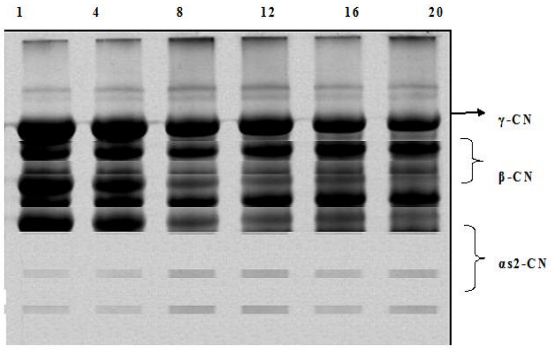

Figure 1-Electrophoretograms of control cheeses during 20 day

PROTEOLYSIS

There were significantly ($p<0.01$) higher levels of proteolysis in exogenous enzymes treated cheeses as compared to the control cheese (Figures 1 to 5). Cheeses enzymes treated with sodium alginate capsules showed a high rate of increase in β- and αs1- casein degradation. The higher rate of β- and αs1- casein hydrolysis in the sodium alginate capsules enzymes treated cheeses was probably due to the lower stability of sodium alginate gels in solutions with acidic pH (Kuchroo and Fox, 1982). On the other hand, no report is available in the literature about the effect of the exogenous enzymes encapsulated on cheese properties, to which a part of this work has been addressed. The observed slower rate of β- and αs1-casein degradation in cheese treated with gum acacia capsules suggests that these capsules probably release their enzyme contents very slowly. This implies that butyrate phthalate capsules remain relatively stable within the cheese curd.

An increasing trend for β- and αs1- -casein degradation was observed during the 35th day of ripening period for all cheeses ($p<0.01$). This was expected because amino groups are produced in cheese as a consequence of protein breakdown during ripening (De *et.al.*, 2007). Thus an increase in proteolysis in exogenous enzymes treated cheese over that of control at any given time during ripening indicates an acceleration of ripening by enzymes treated (Fox, 1993).

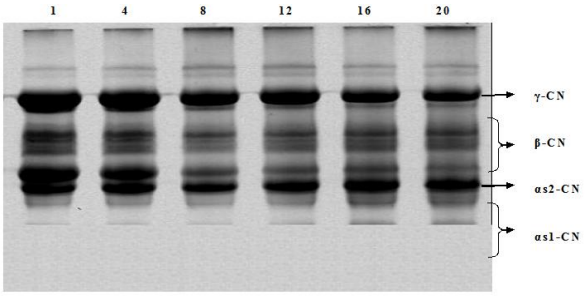

Fig 2- Electrophoretograms of cheeses contain exogenous enzymes in gum acacia capsules produced by emulsion techniques during 20 days of ripening

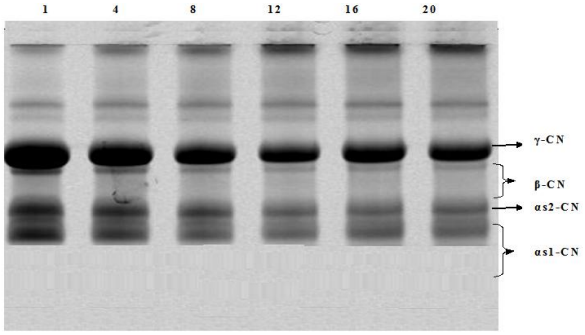

Figure 3-Electrophoretograms of cheeses contain exogenous enzymes in gum acacia capsules produced by extrusion techniques during 20 days of ripening

TEXTURAL PROPERTIES

The introduction of exogenous enzymes into the cheese matrix, as well as the ripening process, affected the textural properties of experimental cheeses ($p<0.01$). Exogenous enzymes treated cheeses exhibited noticeable differences in their textural properties beginning from the day of manufacture compared to the control cheeses [15]. The changes in textural properties (the parameters studied were hardness, cohesiveness, springiness, gumminess and chewiness) during the ripening of the control and experimental cheeses are shown in Table 2.

On the day of manufacture, the experimental cheeses had significantly ($p<0.01$) lower hardness values compared to the control. This was found to be correlated to the higher moisture content of the capsule enzymes treated cheeses. Based on the TPA hardness, two distinct phases were observed: an initial hardening period up to 20 days and a softening period after 20 days.

The cohesiveness and springiness of the control cheeses increased slower than that of the capsule enzymes treated cheeses throughout the ripening period ($p<0.01$). The higher cohesiveness and springiness of the control cheeses might be due to lower moisture content.

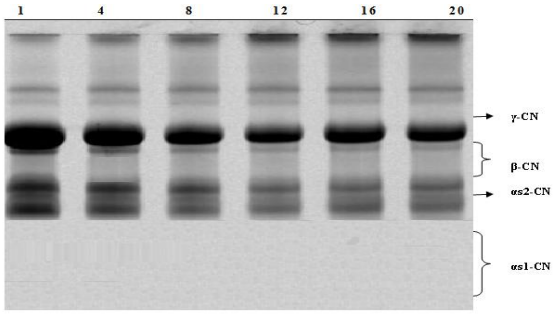

Figure 4- Electrophoretograms of cheeses contain exogenous enzymes in sodium alginate capsules during 20 days of ripening.

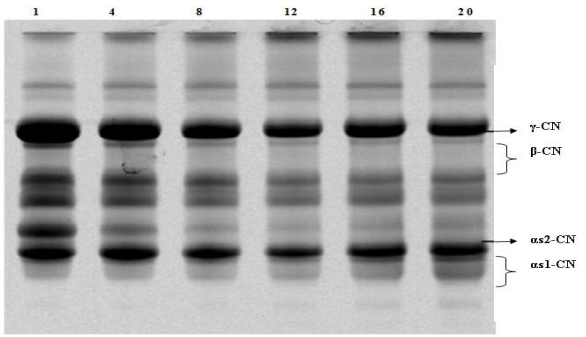

Figure 5 -Electrophoretograms of cheeses contain exogenous enzymes in butyrate phthalate capsules during 20 days of ripening

Table 2- Textural properties of control and exogenous enzymes treated cheeses during 20 days ripening (n=3).

Cheese	Ripening Period Day)***	Properties **				
		Hardness	Cohesiveness	Springiness	Gumminess	Chewiness
A	1	15.50±0.39a1	0.766±0.006a1	0.884±0.013a1	11.15±0.28a3	8.61±0.36 a3
	6	25.81±0.84 a1	0.756±0.021a1	0.844±0.043a1	18.76±0.84a1	9.87±0.59 a2
	12	21.30±0.77 a1	0.768±0.028a2	0.834±0.038a2	14.57±0.78 a2	10.95±0.59 a1
	20	13.87±0.45 a2	0.676±0.016a3	0.766±0.021a3	8.60±0.53 a4	7.87±0.41 a3
B	1	11.80±0.44a1	0.769±0.009a1	0.889±0.005a1	8.41±0.24 c3	6.23±0.48c2
	6	17.50±0.67a1	0.757±0.018b2	0.842±0.038b1	13.66±0.73c1	8.14±0.51c1
	12	13.13±0.49 a1	0.661±0.019b3	0.761±0.034b2	8.26±0.66 c2	8.60±0.43b1
	20	8.65±0.26 a2	0.540±0.010b4	0.675±0.011b3	5.90±0.29 b4	5.63±0.32 b3
C	1	15.26±0.25 a1	0.714±0.004b1	0.869±0.010a1	7.59±0.29b3	7.05±0.13 b2
	6	18.39±0.70 a1	0.749±0.016c2	0.877±0.042a1	14.75±0.81b1	8.62±0.49 b1
	12	15.97±0.64 a1	0.655±0.022b3	0.766±0.033b2	8.51±0.44 b2	8.23±0.56 b1
	20	9.10±0.27 a2	0.566±0.012c4	0.633±0.015b3	5.91±0.42 b4	5.12±0.32 b3
D	1	12.66±0.32a1	0.744±0.006c1	0.833±0.010b1	11.11±0.21a2	8.56±0.37a2
	6	18.02±0.61b1	0.714±0.021c2	0.882±0.035b1	12.23±0.88d1	8.93±0.44b1
	12	14.03±0.68 b1	0.647±0.024c3	0.799±0.031c2	8.34±0.48 d3	8.12±0.64 b2
	20	7.87±0.35 a2	0.553±0.010e4	0.667±0.09 b3	3.69±0.30 c4	5.54±0.31 c3

E	1	12.70±0.13 a1	0.771±0.007c1	0.856±0.010b1	8.13±0.17b2	6.77±0.36 c2
	6	16.46±0.64 b1	0.788±0.022c1	0.843±0.041b1	10.12±0.68e1	8.77±0.62 c1
	12	13.02±0.44 b1	0.614±0.018c2	0.734±0.041c2	7.65±0.55 e3	8.15±0.55 b1
	20	7.78±0.23 a2	0.574±0.022d3	0.655±0.017b3	3.33±0.39 c4	5.49±0.30 b3

A, Control cheese; B, cheeses contain exogenous enzymes in gum acacia capsules produced by emulsion techniques; C, cheeses contain exogenous enzymes in gum acacia capsules produced by extrusion techniques; D, cheeses contain exogenous enzymes in sodium alginate capsules; E, cheeses contain exogenous enzymes in butyrate phthalate capsules.
**, different letters in the same column denote significant differences for capsule materials ($p<0.01$);
*** different numbers in the same column denote significant differences for storage period ($p<0.01$)

Table 3: Sensory scores of control and exogenous enzymes treated cheeses during 20 days ripening (n=3)

Cheese	Ripening period (day)***	Properties**				
A		**Appearance**	**Texture**	**Odour**	**Flavour**	**General acceptability**
	1	4.24±0.48a2	4.10±0.40a2	4.51±0.45 a1	4.01±0.36a3	21.28±0.52a3
	6	4.76±0.45 a1	4.74±0.26a1	4.60±0.40a1	4.50±0.25 a2	22.19±0.48a2
	12	4.83±0.22 a1	4.88±0.12a1	4.75±0.25 a1	4.80±0.20 a1	25.02±0.78 a1
	20	4.89±0.20 a1	4,72±0,20a1	4.68±0.32 a1	4.86±0.14 a1	24.87±0.78 a1
B	1	4.35±0.33 a2	3.80±0.25a3	4.40±0.30 a2	3.85±0.25 a3	21.14±0.46b3
	6	4.45±0.33 b2	4.20±0.24b2	4.60±0.32 a2	4.52±0.37 a2	22.25±0.42b2
	12	4.93±0.17 a1	4.60±0.30a1	4.85±0.06 a1	4.90±0.04 a1	23.16±0.64ac1
	20	3.97±0.31 b3	2,11±0,21b4	3.44±0.21 b3	2.32±0.31 b4	16.12±0.55 b4
C	1	3.91±0.30a3	3.70±0.26a3	4.80±0.35a2	3.80±0.28a3	21.00±0.52b3
	6	4.31±0.50b2	4.36±0.26b2	4.81±0.35a2	4.55±0.27a2	23.07±0.42b2
	12	4.92±0.20 a1	4.78±0.28a1	4.85±0.05 a1	4.90±0.06 a1	25.10±0.80a1
	20	3.75±0.29 b4	2,27±0,25b4	3.22±0.27 b3	2.76±0.24 b4	15.65±0.47 b4
D	1	3.98±0.27b3	3.61±0.37b3	4.55±0.25a2	3.64±0.29b3	20.32±0.56c3
	6	4.27±0.27 b2	4.15±0.37b2	4.61±0.21a2	4.58±0.29 a2	20.43±0.58c2
	12	4.67±0.30 a1	4.48±0.32a1	4.98±0.12 a1	4.70±0.10 a1	22.56±0.77b1
	20	3.49±0.22 c4	1,90±0,23b4	2.71±0.25 c3	2.19±0.25 c4	15.13±0.51 c4
E	1	4.13±0.31a3	3.60±0.39b3	4.58±0.38a2	3.90±0.35 b3	19.07±0.53b3
	6	4.36±0.21b2	4.22±0.39b2	4.72±0.35a2	4.40±0.22a2	20.79±0.43c2
	12	4.69±0.23 a1	4.46±0.24a1	4.82±0.08 a1	4.90±0.10 a1	22.86±0.74 a1
	20	3.29±0.30 c4	2,14±0,27b4	2.55±0.24 d3	2.16±0.27 c4	14.46±0.41 d4

A, Control cheese; B, cheeses contain exogenous enzymes in gum acacia capsules produced by emulsion techniques; C, cheeses contain exogenous enzymes in gum acacia capsules produced by extrusion techniques; D, cheeses contain exogenous enzymes in sodium alginate capsules; E, cheeses contain exogenous enzymes in butyrate phthalate capsules. **different letters in the same column denote significant differences for capsule materials ($p<0.01$); *** different numbers in the same column denote significant differences for storage period ($p<0.01$).

The springiness values of all cheeses studied continuously decreased as the storage time increased throughout for entire testing period of 20 days. The highest gumminess and chewiness values were observed in the control cheeses ($p<0.01$). The decreasing level of moisture in the cheeses may have produced the higher chewiness values in these treatments. A decreasing trend for gumminess and chewiness was observed during the 20 day of ripening period for all cheeses.

SENSORY EVALUATION

The mean sensory scores of the cheeses are shown in Table 3. The control cheese scored highest in appearance ($p<0.01$). Sodium alginate capsules enzymes treated cheeses gained the lowest score in appearance. This could be due to the soft and crumbly texture of this cheese compared to the other experimental cheeses. The appearance scores of all of the cheeses studied (except control) increased up to 12 days and decreased after 20 days.

The addition of encapsulated exogenous enzymes have a significant effect on the organoleptic texture scores ($p<0.01$). Nonetheless control cheeses were ranked higher for texture during ripening period. This could be due to the lower moisture content and lower level of proteolysis in the cheese as compared to the experimental cheeses. The lowest texture score was in the sodium alginate capsules enzymes treated cheeses. The texture scores of all cheeses increased up to 12 days and decreased after 20 days. Although the use of exogenous enzymes capsules resulted in accelerated ripening, the lower mean score for the textural parameters of the experimental cheeses compared to the control cheeses.

They may indicate a problem that affects product acceptance (Law, 2001). The lower mean score for the textural parameters of the experimental cheeses may have also been a result of moisture retention in the capsule

enzymes treated cheeses. Excessive moisture retention in cheese during manufacture is known to result in a soft and crumbly texture.

The main differences among treatments were found in the odour and flavour scores, given below. Sodium alginate capsules enzymes treated cheeses had the lowest odour and flavour scores. In addition, the strongest flavour was noted in cheeses enzymes treated with sodium alginate capsules. The addition of encapsulated exogenous enzymes slightly improved the odour and flavour intensities of the experimental cheeses, depending on cheese age. After 20 days, the experimental cheeses had higher odour and flavour scores than the control cheese due to higher proteolysis.

There were significant differences in the general acceptability ($p<0.01$) of the experimental and control cheeses. The most acceptable cheeses were the control cheeses, followed by sodium alginate produced by emulsion, sodium alginate produced by extrusion, gum acacia and butyrate phthalate capsule enzymes treated cheeses. The general acceptability of the experimental cheeses decreased after 20 days, probably due to the high level of proteolysis and poor textural properties.

CONCLUSION

This study demonstrates that sodium alginate, gum acacia and butyrate phthalate can be successfully used as exogenous enzymes carrier systems to accelerate ripening of cheddar cheese. The use of this system could be considered in the production of cheddar cheese with high flavour intensity in a relatively short time (20 days). Experimental cheeses ripened for 12 days, exhibited textural and sensory characteristics similar to those of control cheeses ripened for 20 days.

This study confirms that the impact of encapsulated enzymes in cheese ripening is influenced greatly by the nature of the encapsulating gums themselves. Cheeses enzymes treated with sodium alginate capsules showed the highest rate of proteolysis compared to those enzymes treated with gum acacia and butyrate phthalate capsules. Gum acacia and butyrate phthalate capsules disrupted under cheese manufacturing conditions appeared to be more suitable in accelerating cheese ripening than sodium alginate capsules. However, the easily ruptured gum capsules under cheese manufacturing conditions may lead to the rapid release of enzymes and excessive proteolysis during early ripening.

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