

*Encapsulation in an alginate–goats’ milk–
inulin matrix improves survival of probiotic
Bifidobacterium in simulated
gastrointestinal conditions and goats’ milk
yoghurt*

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1 **Encapsulation in alginate-goat milk-inulin matrix improves survival of the**
2 **probiotic *Bifidobacterium* in simulated gastrointestinal conditions and**
3 **probiotic goat milk yoghurt**

4

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10

11 Abbreviated running headline: **Probiotic capsulation in goat milk-inulin matrix**

12

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24

25 **Abstract**

26 In this work, a new encapsulating matrix alginate-goat milk-inulin was used to encapsulate
27 *Bifidobacterium animalis* subsp. *lactis* BB-12. The addition of inulin resulted in capsules with
28 compact structure and higher probiotic cell count under simulated gastrointestinal conditions
29 and in probiotic goat milk yoghurt during refrigerated storage. Encapsulation of bacteria led to
30 slower post-acidification yoghurts. The results of this study showed that alginate-goat milk-
31 inulin matrix has a potential to be utilised as a new encapsulation material to encapsulate
32 probiotics to be used in goat milk-based probiotic fermented dairy products avoiding the cross-
33 contamination caused by using capsules based on cow milk.

34

35 **Keywords:** *Bifidobacterium*; Encapsulation; Goat milk; Survival; Refrigeration; Post
36 acidification

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50 **1. Introduction**

51 Functional foods can be defined as food products which are developed using natural food
52 additives and they are used to provide additional health benefits to the consumer exceeding the
53 basic nutrition (Prosapio *et al.*, 2016). The demand for functional foods is increasing around
54 the world which is due to awareness of consumer about the relationship between consumption
55 of functional foods and health benefits (Fabersani *et al.*, 2018; Martins *et al.*, 2018; Sperry *et*
56 *al.*, 2018;). Five main sectors can be identified in relation to the functional food market namely
57 dairy, beverage, breakfast cereals and bakery, and the dairy sector is considered as the largest
58 functional food market around the world (Pinto *et al.*, 2014). Most of the functional dairy
59 products contain probiotic bacteria and these products have become popular and widely
60 available in functional food markets (Granato *et al.*, 2010). This specific market shows a rapid
61 growth and there is a huge competition among producers in introducing new probiotic dairy-
62 based products (Balthazar *et al.*, 2018; Dantas *et al.*, 2016).

63

64 Probiotics are described as “live microorganisms that, when administered in adequate amounts,
65 confer a health benefit on the host” (Hill *et al.*, 2014) . The most of probiotic strains have been
66 selected and researched from the genera *Bifidobacterium* and *Lactobacillus*. Bifidobacteria are
67 commonly used in manufacturing of fermented dairy products (Ranadheera *et al.*, 2010).
68 Consumption of products containing probiotic bifidobacteria has been reported to exert health
69 benefits in relation to lowering of serum cholesterol level, enhancing immune system,
70 alleviation of diarrhoea, reduction of lactose intolerance, modulation of gut microflora, and
71 prevention of allergy (Prasanna *et al.*, 2014). However, survival of probiotics in the product
72 and inside the digestive tract depends on many factors such as acidity, culture combination,
73 sugar concentration, temperature, and oxygen concentration in a particular product. In addition,
74 higher acidity level in the digestive system can suppress survival of probiotic bacteria

75 (Ranadheera *et al.*, 2014). Therefore, different techniques have been evaluated to enhance
76 probiotic viability in food systems and the digestive tract, including strain selection, use of
77 oxygen impermeable packaging systems, two-step fermentation, supplementation with
78 micronutrients, and encapsulation; the last one is considered as the most effective (Martín *et*
79 *al.*, 2015).

80

81 Prebiotics are defined as 'a substrate that is selectively utilized by host microorganisms
82 conferring a health benefit' (Gibson *et al.*, 2017). Inulin is the most popular prebiotic which is
83 commonly used in dairy products and it has been shown to enhance the viability of
84 bifidobacteria in the large intestine (Nazzaro *et al.*, 2012). In addition, there are some reports
85 that prebiotics can improve the stability of alginate-based capsules containing probiotics in
86 different food products and the digestive system (Krasaekoopt and Watcharapoka, 2014). In
87 addition, there is a greater interest in using synbiotic which is a combination of prebiotic and
88 probiotic in food products where prebiotics could improve survival and colonization of
89 probiotics in the colon (Verruck *et al.*, 2017).

90

91 Encapsulation of different strains of *Bifidobacterium* has been used to improve their viability
92 in various food systems and in simulated gastrointestinal conditions (Fritzen-Freire *et al.*,
93 2013). Sodium alginate is a common material which is used to capsule probiotics. However,
94 this material is very easily disintegrated at low pH leading to the release of microorganisms
95 entrapped in beads to the environment (Krasaekoopt *et al.*, 2004). Therefore, alginate is mixed
96 with other materials to improve stability of alginate capsules in food systems (Etchepare *et al.*,
97 2016). Probiotics encapsulated in alginate-cow milk matrix were shown to improve their
98 performances in simulated gastrointestinal conditions and in different food systems (Gbassi *et*
99 *al.*, 2009; Rajam *et al.*, 2012; Shi *et al.*, 2013). Milk proteins have a higher buffering capacity

100 and these have been shown to increase count of probiotics during digestion (Würth *et al.*, 2015).
101 In addition, encapsulation of probiotics in milk based materials could improve their viability
102 in dairy foods (Ranadheera *et al.*, 2016). In our previous study, encapsulated *Bifidobacterium*
103 *longum* subsp. *infantis* CCUG 52486 in alginate-goat milk based matrix was observed to
104 increase their survival rate in simulated gastrointestinal conditions, goat milk and cow milk
105 (Prasanna and Charalampopoulos, 2018).

106

107 Goat is considered as an important livestock species in rural areas many developing countries
108 around the world. They can live in harsh environmental conditions where cattle cannot be
109 reared. Therefore, goat farming is popular in many remote parts of the world where they are
110 used for their milk, meat, and skin (Joshi *et al.*, 2004). Dairy goats are basically used as a key
111 food source in low income countries of the Indian subcontinent and the industry is spreading
112 in the developed countries. The worldwide goat milk production has been doubled during the
113 last 50 years and it is predicted to increase by 53% by 2030 (Pulina *et al.*, 2018). Goat milk is
114 considered as an excellent food source; it is used as raw material in producing different cheeses,
115 ice cream and yoghurt (Milani and Wendorff, 2011). Consumption of goat milk is
116 recommended for children and elderly people and it is also recommended as an alternative milk
117 type for people showing allergy to cow milk (Ribeiro and Ribeiro, 2010). Goat milk is
118 considered to have similar properties to human milk. It has the higher amount of small fat
119 globules which are very important in human nutrition. However, goat milk produces a softer
120 curd during the fermentation process (Clark and García, 2017). Non-bovine dairy products
121 including goat milk are considered as excellent probiotic carriers and there is an increasing
122 demand for such products (Ranadheera *et al.*, 2018).

123

124 This new alginate-goat milk-inulin matrix may have an advantage that probiotics encapsulated
125 in the new material could be directly used as an inoculum for goat milk based products ensuring
126 minimum contamination with cow milk which is considered to cause cow milk allergy in some
127 consumers. In this study, we report on some properties of capsules made of new alginate-goat
128 milk-inulin matrix and survival of encapsulated probiotic *B. animalis* subsp. *lactis* BB-12 in
129 goat milk yoghurt stored at 4 °C for 28 days. Furthermore, the capsules were evaluated under
130 simulated gastrointestinal conditions (SGC).

131

132 **2. Materials and methods**

133 *2.1. Activation of microorganism*

134 *B. animalis* subsp. *lactis* BB-12 was provided by Chr. Hansen Company (Horsholm, Denmark)
135 and the freeze-dried culture was activated using MRS broth (Oxoid, Hampshire, UK), under
136 anaerobic condition at 37 °C for 18 h, using an inoculum at the rate of 1% (w/v). The preculture
137 was produced using two successive cultures of *B. animalis* subsp. *lactis* BB-12 where the
138 inoculum level of was 1% (v/v). Thereafter, 200 mL of Wilkins-Chalgren (WC) anaerobe broth
139 (Oxoid, UK) was inoculated with 1% (v/v) of the preculture and the incubation was completed
140 using the same conditions. The broth was centrifuged at 10,000 rpm for 10 min at 4 °C to
141 harvest cells. At the end of the centrifugation, sterile phosphate buffered saline (PBS) (Oxoid,
142 UK) was used to wash the pellet twice. The pellet was mixed with 10 mL of PBS to make the
143 concentrated cell suspension.

144

145 *2.2. Preparation of capsules*

146 Capsules were prepared using sterilized goat milk and sodium alginate (2%, w/v, low viscosity,
147 Sigma-Aldrich, UK). Five treatments were prepared by mixing sodium alginate and inulin at
148 the level of 0%, 0.5%, 1%, 1.5% and 2% (w/v) and the mixture were sterilized (121 °C for 15

149 min). The encapsulation mixture was prepared by mixing sodium alginate mixture and
150 sterilized goat milk at the ratio of 1.5/1 (v/v). Thereafter, each formulation was thoroughly
151 mixed with the concentrated cell suspension at the ratio of 4/1 (v/v). The capsules were
152 produced as described by Prasanna and Charalampopoulos (2018).

153

154 *2.3. Determination of encapsulation yield and size of capsules*

155 The encapsulation yield (EY) of different matrices and size of capsules were determined as
156 described previously (Prasanna and Charalampopoulos, 2018).

157

158 *2.4. Assessment of viability of free and encapsulated bacteria*

159 Bifidobacteria selective medium (BSM) agar (Sigma-Aldrich, UK) was used to enumerate free
160 bifidobacteria at 37 °C for 72 h under the anaerobic condition while the capsulated bacteria
161 were enumerated as reported by Prasanna and Charalampopoulos (2018).

162

163 *2.5. Viability of free and encapsulated bacterial cells during sequential incubation in SGC*

164 The method explained by Sun and Griffiths (2000) was used to prepare simulated gastric juice
165 (SGJ), by dissolving 0.2% NaCl (w/v) in 0.08 M HCl, at pH 2 whereas simulated intestinal
166 juice (SIJ) was prepared as described by Chávarri *et al.* (2010). The viability of free and
167 encapsulated bacteria under SGC were conducted as described by Krasaekoopt *et al.* (2004).
168 Glass tubes containing 9 mL of sterilized SGJ were mixed with capsules (1 g) or the free cells
169 (1 mL). The samples were placed and incubated in a water bath at 37 °C. Sampling was carried
170 out at 0, 30, 60 and 120 min, during the incubation. The capsules were separated by filtration
171 while free cells were separated using centrifugation (10,000 rpm for 10 min, at 4 °C).
172 Thereafter, the free cells or the capsules were placed in glass tubes containing 9 mL of SIJ and
173 the incubation was carried out at 37 °C for 120 min. After the incubation period, the free cells

174 and capsules were separated as described above. The free and the capsulated bacteria were
175 enumerated as described previously (Prasanna and Charalampopoulos, 2018).

176

177 2.6. Preparation of probiotic goat milk yoghurt

178 Probiotic goat milk yoghurts were produced as described by Costa *et al.* (2014). UHT goat
179 milk was inoculated with thermophilic yoghurt cultures (YoFlex, YC-X11, Chr. Hansen,
180 Hoersholm, Denmark) composed of *Streptococcus thermophiles* and *Lactobacillus delbrueckii*
181 subsp. *bulgaricus* at a rate of 1% (w/v). The inoculated milk was incubated at 43 °C, until the
182 pH reached ~ 4.5. Thereafter, 10 g of the encapsulated or 10 mL of the free cells of *B. animalis*
183 subsp. *lactis* BB-12 was separately mixed with 100 g of goat milk yoghurt in plastic cups and
184 the cups were stored at 4 °C for 28 days. The sampling was carried out on 0, 7, 14, 21 and 28
185 days to analyse pH and the viability of bifidobacteria. A sample (10 g) of each treatment was
186 collected from a well-mixed yoghurt cup. The sample was mixed with 90 mL of sterilized 50
187 mM sodium citrate (Sigma-Aldrich, UK) solution (pH, 7.5) in a stomacher. Bacterial cells were
188 separated and enumerated as reported by Prasanna and Charalampopoulos (2018).

189

190 2.7. Determination of pH of yoghurt during storage

191 The pH changes of probiotic yoghurts were measured weekly during the storage period using
192 a benchtop pH meter (Mettler Toledo, UK) as explained by Prasanna *et al.* (2013) and the
193 measurements were taken at room temperature.

194

195 2.8. Scanning electron microscopic (SEM) analysis of cross sections of capsules

196 Dehydration of capsules was carried out sequentially in a series of ethanol solutions (30, 50,
197 70, 80, 90, and 100%). For this purpose, capsules were soaked for 15 min. in each solution.
198 Thereafter, a critical point dryer (Balzers CPD 030, Liechtenstein, Germany) with liquid

199 carbon dioxide was used to dry capsules. Dried capsules were cut into two halves to obtain
200 cross sections using a sterilized scalpel. Coating of samples and examination of samples using
201 a scanning electron microscope (FEI, Quanta 600 F, USA) were carried out as described earlier
202 (Prasanna and Charalampopoulos, 2018).

203

204 *2.9. Statistical analysis*

205 The experiment was conducted in triplicate. One-way analysis of variance (ANOVA) with
206 Turkey's multiple comparison tests (SAS, version 9.2, SAS Institute Inc., Cary NC, USA) was
207 used to analyse size and EY of capsules. Split-plot in time design using the General Linear
208 Model (GLM) procedure of SAS was used to analyse results of viable count and pH of goat
209 milk yoghurt (version 9.2, SAS Institute Inc., Cary NC, USA).

210

211 **3. Results and discussion**

212 *3.1. Size, EY and surface morphology of cross sections of capsules*

213 As shown in Table 1, mixing of inulin into alginate-goat milk based matrix significantly
214 ($p < 0.05$) increased the size of capsules compared to the control (0% inulin); more specifically,
215 the capsule sizes increased as the inulin concentration increased. For example, capsule sizes
216 were increased from 2.98 to 3.4 mm for 0.5% inulin and 2% inulin respectively. This may be
217 due to changes in viscosity of five different matrices where a higher level of inulin
218 concentration can lead for higher viscosity which can result in larger capsules as describe by
219 Cheow *et al.* (2014). This observation is consistent with the findings of Chávarri *et al.* (2010)
220 and Krasaekoopt and Watcharapoka (2014) who observed that prebiotic addition into alginate-
221 based material resulted in larger capsular size.

222

223 The results further revealed that the incorporation of inulin into alginate-goat milk based matrix
224 had no significant ($p>0.05$) influence on the EY of capsules (Table 1). Values of EY ranged
225 from 87 – 91%. Moreover, this high encapsulation yield reveals that alginate-goat milk-inulin
226 is a compatible matrix which can be used to encapsulate probiotics such as *B. animalis* subsp.
227 *lactis* BB-12. Our results are consistent with findings of Shi *et al.* (2013) during the
228 microencapsulation of probiotic *Lactobacillus buguricus* with alginate milk microsphere,
229 where the EY values were around 100%. It was observed that the addition of prebiotics and
230 milk proteins in the matrix can lead to higher EY (Soukoulis *et al.*, 2014). In addition, the
231 higher encapsulation yield may be due to the mild conditions such as room temperature (25
232 °C) with all natural substances which have a minimum detrimental effect on the
233 microorganism.

234

235 Cross sections of capsules are shown in Fig.1 and each type of matrix showed a distinctive
236 morphology. The cross section of alginate-goat milk showed a porous structure [Fig.1, (a)].
237 The addition of inulin into alginate-goat milk resulted in more compact capsules with less
238 visible pores [Fig.1, (b), (c), (d) and (e)]; the most densely packed capsules were observed with
239 2% inulin [Fig.1, (e)]. This may be due to the ability of inulin to make a compact network with
240 proteins of alginate-goat milk matrix leading to densely packed capsules. In general, inulin is
241 a water-soluble fibre and it was observed to form complexes with proteins of goat milk leading
242 to a part of a strong structural network (Costa *et al.*, 2015). Similarly, de Souza Oliveira *et al.*
243 (2011) observed a reaction of inulin and dairy proteins leading for higher firmness of the
244 mixture. The compact structure of capsules observed with the mixing of inulin to alginate-goat
245 milk matrix is very important in food applications and during the digestion process since this
246 can limit exposure of highly vulnerable probiotic bacteria to the harsh external environmental
247 conditions. Furthermore, this property of new capsules may support to increase the survival of

248 bacteria in food products in the manufacturing process and storage of food items and to deliver
249 the probiotic to the colon at a higher survival rate.

250

251 3.2. Performance of free and encapsulated bifidobacteria during sequential incubation in SGC

252 Free and the encapsulated cells were exposed to *in vitro* SGC and the results are presented in
253 Table 2. A continuous reduction of number of free probiotic cells was observed and the cell
254 number dropped to a value which was undetectable ($< 10^1$ cfu mL⁻¹) after the sequential
255 exposure of free cells to SGJ (90 min) followed by SIJ (120 min).

256

257 Encapsulation has been recommended to deliver viable cells to the gastro intestinal track
258 (Champagne *et al.*, 2018). Addition of inulin to alginate-goat milk matrix during encapsulation
259 increased the resistance of the probiotic to the SGC, resulting in higher viable cell count than
260 without inulin under all conditions. Similarly, supplement of inulin to alginate during
261 encapsulation of *Lactobacillus acidophilus* 5 and *Lactobacillus casei* 01 was observed to
262 improve the survival of bacteria under SGC (Krasaekoopt and Watcharapoka, 2014). In
263 addition, a higher survival rate of *B. bifidum* and *B. longum* encapsulated in alginate-
264 fructooligosaccharides under SGC was reported by Chen *et al.* (2005). In another study, spray
265 drying was used to produce microcapsules containing *B. bifidum* BB-12 and the probiotic was
266 observed to improve their survival under SGC (Verruck *et al.*, 2017). Milk proteins have been
267 characterized to have a good buffering capacity which can protect probiotics from the harsh
268 environment which exists in the gastrointestinal tract (Anthony *et al.*, 2015). Guérin *et al.*
269 (2003) also described that milk-based proteins could improve survival of bifidobacteria
270 capsulated in pectin, alginate and whey proteins than free bacteria under the SGC.

271

272 Furthermore, it was reported that milk fat can play a role in protecting probiotics from the
273 acidic environment since fat can reduce diffusion of H⁺, organic acid and O₂ (Picot and Lacroix,
274 2004). As it was observed in this study using SEM micrographs [Fig.1 (b), (c), (d) and (e)],
275 inulin modified the capsule structure by interacting with proteins leading a compact alginate-
276 goat milk matrix which may limit exposure of bacterial cells to the external environment and
277 diffusion of chemical substances. Furthermore, the addition of inulin may improve the strength
278 of the matrix and reduce the dissolution of capsules, consequently protecting the probiotic cells
279 within the matrix.

280

281 *3.3. Changes of survival rate of encapsulated and free bacterial cells in probiotic goat milk* 282 *yoghurt at 4 °C*

283 The changes in the viable count of encapsulated and free probiotic in probiotic goat milk
284 yoghurts during the refrigerated storage for 28 d (Fig.2.). The results clearly revealed that there
285 was a significant ($p<0.05$) loss of the viable count of free bacteria over a period of 28 d where
286 there was 3.67 log cfu g⁻¹ loss in viable counts of free bacterial cells during the storage period.
287 Addition of inulin to the matrix led for better survival of probiotic bacteria in probiotic goat
288 milk yoghurt; specially there was an increase of cell concentration in yoghurts when inulin
289 concentration of capsules ranged from 0.5 to 2%. The cell concentration of yoghurt containing
290 encapsulated probiotics did not decrease below the recommended level (10^6 - 10^7 cfu/mL or g)
291 over 28 d of storage. The higher survival rate observed in inulin containing capsules in goat
292 milk yoghurt may be due to the better protection provided by compact structure of alginate-
293 goat milk-inulin matrices observed in SEM micrographs [Fig.1 (b), (c), (d) and (e)].
294 Furthermore, the higher viability of encapsulated bacteria in inulin-based matrices in the goat
295 milk yoghurt, may be due to the limited potential of passing capsule wall by growth inhibiting
296 substances which can be resulted during the fermentation process including acids and hydrogen

297 peroxide as reported by Krasaekoopt and Watcharapoka (2014). Furthermore, it was observed
298 that capsules containing prebiotics could provide the carbon and nitrogen sources for
299 encapsulated probiotics leading for higher survival rate of *Bifidobacterium* and *Lactobacillus*
300 in milk (Chen *et al.*, 2005). Similarly, other encapsulating materials such as alginate (Kebary
301 and Hussein, 1999), alginate-starch (Adhikari *et al.*, 2000) and κ -carrageenan were observed
302 to improve survival of probiotic *Bifidobacterium* species in fermented dairy foods under
303 refrigerated storage. Moreover, different prebiotics such as inulin (Akhiar and Aqilah, 2010),
304 fructooligosaccharides and raftilose (Iyer and Kailasapathy, 2005) with alginate-based
305 capsules have been shown to be effective in improving probiotic viability in some dairy
306 products. In addition, goat milk is considered as a suitable vehicle to deliver probiotic to
307 humans. The properties of goat milk including appropriate pH, higher nutrient content and
308 good buffering capacity lead for viability of probiotic during shelf life (Ranadheera *et al.*,
309 2018). Furthermore, the market share of functional yoghurt continues to grow and functional
310 yoghurt containing probiotics, prebiotics and various plant extracts are being developed and
311 introduced to satisfy consumer demand (Fazilah *et al.*, 2018). Therefore, this new goat milk
312 yoghurt containing a novel capsule containing probiotic may have a good market demand.

313

314 *3.4. pH Changes of probiotic goat milk yoghurt during storage*

315 Depending on the type of bacterial cells and the level of inulin supplementation during the
316 encapsulation, the pH of goat milk yoghurt changed (Fig. 3). All goat milk yoghurt types
317 showed a gradual decrease of pH during the storage period of 28 d. However, goat milk yoghurt
318 containing free bacterial cells recorded the lowest pH value from 7th day to the end of the
319 storage period. There were no significant differences ($p>0.05$) between final pH values of goat
320 milk yoghurts produced with encapsulated bacterial cells. The decrease of pH of all types of
321 goat milk yoghurt during storage is mainly due to growth and metabolic activity of yoghurt

322 starter cultures which are reported to produce lactic acid at refrigerated storage (Shah *et al.*,
323 1995). In the case of goat milk yoghurt containing free bifidobacteria, in addition to yoghurt
324 starter bacteria, cells of bifidobacteria are responsible acidifying goat milk yoghurt by
325 producing both lactic and acetic acids and they have been reported to produce these acids with
326 yoghurt starter cultures even at refrigerated storage (Samona *et al.*, 1996). Similarly, a decrease
327 in pH of cow milk yoghurt containing encapsulated *B. lactis* (Kailasapathy, 2006), *B. breve*
328 R070 (Picot and Lacroix, 2004) and *B. longum* (Adhikari *et al.*, 2003) was observed. The
329 results of this study revealed that post-acidification in probiotic goat milk yoghurt produced
330 with capsulated *B. animalis* subsp. *lactis* BB-12 was slower compared with probiotic goat milk
331 yoghurt containing free bacterial cells.

332

333 However, it is important to conduct a sensory evaluation to have a better understanding of the
334 effect of this new capsule on the sensory properties of probiotic goat milk yoghurts. This new
335 capsule may have the effect on sensory attributes of probiotic goat milk yoghurt such as
336 appearance, aroma, flavour and texture which have been established with some other functional
337 dairy products (Esmerino *et al.*, 2017; Janiaski *et al.*, 2018; Silva *et al.*, 2018). Therefore, a
338 sensory evaluation of the goat milk yoghurt containing the new capsule will be carried out to
339 assess its consumers' acceptability.

340

341 **4. Conclusions**

342 The present study showed that addition of inulin to alginate-goat milk during encapsulation
343 increased the size of capsules while it had no effect on EY. SEM micrographs revealed that
344 inulin could lead for compact interior structural characteristics. The addition of inulin to
345 alginate-goat milk capsules led for a better protection to probiotic cells in simulated
346 gastrointestinal condition. Inulin could improve the survival rate of capsulated probiotic cells

347 compared to capsules without inulin and free cells in probiotic goat milk yoghurt stored over
348 28 d. A slower post-acidification of probiotic goat milk yoghurt was observed with
349 encapsulated probiotic cells compared to that of free probiotic cells. The results revealed that
350 addition of 1% inulin (w/v) to alginate-goat milk mixture could be used to improve the survival
351 rate of *B. animalis* subsp. *lactis* BB-12 in probiotic goat milk yoghurt. Nevertheless, a sensory
352 evaluation should be conducted to have a clear idea about how capsules effect on the sensory
353 properties of probiotic goat milk yoghurt such as colour, texture, acidity and flavour.

354

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358

359 **The authors declare that they have no conflict of interest.**

360

361 **References**

362 Adhikari, K, Mustapha, A and Grün, I (2003) Survival and metabolic activity of
363 microencapsulated *Bifidobacterium longum* in stirred yogurt. *Journal of Food Science* **68** 275-
364 280.

365 Adhikari, K, Mustapha, A, Grün, I U and Fernando, L (2000) Viability of microencapsulated
366 bifidobacteria in set yogurt during refrigerated storage. *Journal of Dairy Science* **83** 1946-1951.

367 Akhiar, M and Aqilah, N S (2010) Enhancement of probiotics survival by microencapsulation
368 with alginate and prebiotics. In: *MMG 445 Basic Biotechnology eJournal*, pp. 13–18.

369 Anthony, N M, Jolyn, A and Sung, J L (2015) Microencapsulation of probiotic bacteria In:
370 *Beneficial microorganisms in food and nutraceuticals*, pp. 63-81. LIONG, M T ed. New York:
371 Springer.

372 Balthazar, CF, Silva, HL, Esmerino, EA, Rocha, RS, Moraes, J, Carmo, MA, Azevedo, L,
373 Camps, I, Abud, YK, Sant'Anna, C and Franco, RM (2018) The addition of inulin and
374 *Lactobacillus casei* 01 in sheep milk ice cream. *Food chemistry* **25** 246-464.

375 Chávarri, M, Marañón, I, Ares, R, Ibáñez, F C, Marzo, F and Del Carmen Villarán, M (2010)
376 Microencapsulation of a probiotic and prebiotic in alginate-chitosan capsules improves
377 survival in simulated gastro-intestinal conditions. *International Journal of Food Microbiology*
378 **142** 185-189.

379 Champagne, CP, da Cruz, AG and Daga, M (2018) Strategies to improve the functionality of
380 probiotics in supplements and foods. *Current Opinion in Food Science* **22** 160-166.

381 Chen, K N, Chen, M J, Liu, J R, Lin, C W and Chiu, H Y (2005) Optimization of incorporated
382 prebiotics as coating materials for probiotic microencapsulation. *Journal of Food Science* **70**
383 M260-M266.

384 Cheow, W S, Kiew, T Y and Hadinoto, K (2014) Controlled release of *Lactobacillus*
385 *rhamnosus* biofilm probiotics from alginate-locust bean gum microcapsules. *Carbohydrate*
386 *Polymers* **103** 587-595.

387 Costa, M P, Balthazar, C F, Franco, R M, Mársico, E T, Cruz, A G and Conte, C A (2014)
388 Changes on expected taste perception of probiotic and conventional yogurts made from goat
389 milk after rapidly repeated exposure. *Journal of Dairy Science* **97** 2610-2618.

390 Costa, M P, Frasco, B S, Silva, A C O, Freitas, M Q, Franco, R M and Conte-Junior, C A
391 (2015) Cupuassu (*Theobroma grandiflorum*) pulp, probiotic, and prebiotic: Influence on color,
392 apparent viscosity, and texture of goat milk yogurts. *Journal of Dairy Science* **98** 5995-6003.

393 Clark, S and García, MBM (2017) A 100-Year Review: Advances in goat milk
394 research. *Journal of Dairy Science* **100(12)** 10026-10044.

395 Dantas, AB, Jesus, VF, Silva, R, Almada, CN, Esmerino, EA, Cappato, LP, Silva, MC,
396 Raices, RS, Cavalcanti, RN, Carvalho, CC and Sant'Ana, AS (2016) Manufacture of probiotic
397 Minas Frescal cheese with *Lactobacillus casei* Zhang. *Journal of Dairy Science* **99(1)** 18-30.
398 De Souza Oliveira, R P, Perego, P, De Oliveira, M N and Converti, A (2011) Effect of inulin
399 as prebiotic and synbiotic interactions between probiotics to improve fermented milk firmness.
400 *Journal of Food Engineering* **107** 36-40.
401 Esmerino, EA, Ferraz, JP, Tavares, FER, Pinto, LP, Freitas, MQ, Cruz, AG and Bolini, HM
402 (2017) Consumers' perceptions toward 3 different fermented dairy products: Insights from
403 focus groups, word association, and projective mapping. *Journal of Dairy Science*. **100(11)**
404 8849-8860.
405 Etchepare, M A, Raddatz, G C, Cichoski, A J, *et al.* (2016) Effect of resistant starch (Hi-maize)
406 on the survival of *Lactobacillus acidophilus* microencapsulated with sodium alginate. *Journal*
407 *of Functional Foods* **21** 321-329.
408 Fabersani, E, Grande, MV, Araújo, MV, Zannier, ML, Sánchez, SS, Grau, A, Oliszewski, R
409 and Honoré SM (2018) Metabolic effects of goat milk yogurt supplemented with yacon flour
410 in rats on high-fat diet. *Journal of Functional Foods* **49** 447-57.
411 Fazilah, NF, Ariff, AB, Khayat, ME, Rios-Solis, L and Halim, M (2018) Influence of
412 probiotics, prebiotics, synbiotics and bioactive phytochemicals on the formulation of
413 functional yogurt. *Journal of Functional Foods* **48** 387-399.
414 Fritzen-Freire, C B, Prudêncio, E S, Pinto, S S, Muñoz, I B and Amboni, R D M C (2013)
415 Effect of microencapsulation on survival of *Bifidobacterium* BB-12 exposed to simulated
416 gastrointestinal conditions and heat treatments. *LWT-Food Science and Technology* **50** 39-44.
417 Gbassi, G K, Vandamme, T, Ennahar, S and Marchioni, E (2009) Microencapsulation of
418 *Lactobacillus plantarum* spp in an alginate matrix coated with whey proteins. *International*
419 *Journal of Food Microbiology* **129** 103-105.

420 Gibson, GR, Hutkins, R, Sanders, ME, Prescott, SL, Reimer, RA, Salminen, SJ, Scott, K,
421 Stanton, C, Swanson, KS, Cani, PD and Verbeke, K (2017) Expert consensus document: The
422 International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus statement
423 on the definition and scope of prebiotics. *Nature Reviews Gastroenterology and*
424 *Hepatology* **14(8)** 491-502.

425 Granato, D, Branco, G F, Cruz, A G, Faria, J a F and Shah, N P (2010) Probiotic Dairy Products
426 as Functional Foods. *Comprehensive Reviews in Food Science and Food Safety* **9** 455-470.

427 Guérin, D, Vuilleumard, J C and Subirade, M (2003) Protection of bifidobacteria encapsulated
428 in polysaccharide-protein gel beads against gastric juice and bile. *Journal of Food Protection*
429 **66** 2076-2084.

430 Hill, C, Guarner, F, Reid, G, Gibson, GR, Merenstein, DJ, Pot B, Morelli, L, Canani, RB, Flint,
431 HJ, Salminen, S and Calder, PC (2014) Expert consensus document: The International
432 Scientific Association for Probiotics and Prebiotics consensus statement on the scope and
433 appropriate use of the term probiotic. *Nature Reviews Gastroenterology and Hepatology*. **11(8)**
434 506-514.

435 Iyer, C and Kailasapathy, K (2005) Effect of co-encapsulation of probiotics with prebiotics on
436 increasing the viability of encapsulated bacteria under *in vitro* acidic and bile salt conditions
437 and in yogurt. *Journal of Food Science* **70** M18-M23.

438 Joshi, M B, Rout, P K, Mandal, A K, Tyler-Smith, C, Singh, L and Thangaraj, K (2004)
439 Phylogeography and origin of Indian domestic goats. *Molecular Biology and Evolution* **21** 454-
440 462.

441 Janiaski, DR, Pimentel, TC, Cruz, AG and Prudencio SH (2016) Strawberry-flavored yogurts
442 and whey beverages: What is the sensory profile of the ideal product?. *Journal of Dairy*
443 *Science* **99(7)** 5273-5283.

444 Kailasapathy, K (2006) Survival of free and encapsulated probiotic bacteria and their effect on
445 the sensory properties of yoghurt. *LWT-Food Science and Technology* **39** 1221-1227.

446 Kebary, K M K and Hussein, A S (1999) Improving viability of bifidobacteria by
447 microentrapment and their effect on some pathogenic bacteria in stirred yoghurt. *Acta*
448 *Alimentaria* **28** 110-132.

449 Krasaekoopt, W, Bhandari, B and Deeth, H (2004) The influence of coating materials on some
450 properties of alginate beads and survivability of microencapsulated probiotic bacteria.
451 *International Dairy Journal* **14** 737-743.

452 Krasaekoopt, W and Watcharapoka, S (2014) Effect of addition of inulin and
453 galactooligosaccharide on the survival of microencapsulated probiotics in alginate beads
454 coated with chitosan in simulated digestive system, yogurt and fruit juice. *LWT-Food Science*
455 *and Technology* **57** 761-766.

456 Martín, M J, Lara-Villoslada, F, Ruiz, M A and Morales, M E (2015) Microencapsulation of
457 bacteria: A review of different technologies and their impact on the probiotic effects.
458 *Innovative Food Science & Emerging Technologies* **27** 15-25.

459 Martins, AA, Santos-Junior, VA, Elson Filho, RT, Silva, HL, Ferreira, MVS, Graça, JS,
460 Esmerino, EA, Lollo, PC, Freitas, MQ, Sant'Ana, AS and Costa, LEO (2018) Probiotic Prato
461 cheese consumption attenuates development of renal calculi in animal model of
462 urolithiasis. *Journal of Functional Foods* **49** 378-383.

463 Milani, F X and Wendorff, W L (2011) Goat and sheep milk products in the United States
464 (USA). *Small Ruminant Research* **101** 134-139.

465 Nazzaro, F, Orlando, P, Fratianni, F and Coppola, R (2012) Microencapsulation in food science
466 and biotechnology. *Current Opinion in Biotechnology* **23** 182-186.

467 Pulina, G, Milán, MJ, Lavín, MP, Theodoridis, A, Morin, E, Capote, J, Thomas, DL,
468 Francesconi, AHD and Caja, G (2018). Invited review: Current production trends, farm

469 structures, and economics of the dairy sheep and goat sectors. *Journal of Dairy Science* **101(8)**
470 6715-6729.

471 Picot, A and Lacroix, C (2004) Encapsulation of bifidobacteria in whey protein-based
472 microcapsules and survival in simulated gastrointestinal conditions and in yoghurt.
473 *International Dairy Journal* **14** 505-515.

474 Pinto, D, Castro, I, Vicente, A, Bourbon, A I and Cerqueira, M Â (2014) Functional Bakery
475 Products. In: *Bakery Products Science and Technology*, pp. 431-452. West Sussex: John Wiley
476 & Sons, Ltd.

477 Prasanna, P H P and Charalampopoulos, D (2018) Encapsulation of *Bifidobacterium longum*
478 in alginate-dairy matrices and survival in simulated gastrointestinal conditions, refrigeration,
479 cow milk and goat milk. *Food Bioscience* **21** 72-79.

480 Prasanna, P H P, Grandison, A S and Charalampopoulos, D (2014) Bifidobacteria in milk
481 products: An overview of physiological and biochemical properties, exopolysaccharide
482 production, selection criteria of milk products and health benefits. *Food Research International*
483 **55** 247-262.

484 Prasanna, PHP, Grandison, AS and Charalampopoulos, D (2013) Microbiological, chemical
485 and rheological properties of low fat set yoghurt produced with exopolysaccharide producing
486 *Bifidobacterium* strains. *Food Research International* **51(1)**, 15-22.

487 Prosapio, V, Reverchon, E and De Marco, I (2016) Production of lysozyme microparticles to
488 be used in functional foods, using an expanded liquid antisolvent process. *The Journal of*
489 *Supercritical Fluids* **107** 106-113.

490 Rajam, R, Karthik, P, Parthasarathi, S, Joseph, G and Anandharamakrishnan, C (2012) Effect
491 of whey protein–alginate wall systems on survival of microencapsulated *Lactobacillus*
492 *plantarum* in simulated gastrointestinal conditions. *Journal of Functional Foods* **4** 891-898.

493 Ranadheera, C S, Baines, S K and Adams, M C (2010) Importance of food in probiotic efficacy.
494 *Food Research International* **43** 1-7.

495 Ranadheera, C S, Evans, C A, Adams, M C and Baines, S K (2014) Effect of dairy probiotic
496 combinations on *in vitro* gastrointestinal tolerance, intestinal epithelial cell adhesion and
497 cytokine secretion. *Journal of Functional Foods* **8** 18-25.

498 Ranadheera, C S, Liyanaarachchi, W S, Chandrapala, J, Dissanayake, M and Vasiljevic, T
499 (2016) Utilizing unique properties of caseins and the casein micelle for delivery of sensitive
500 food ingredients and bioactives. *Trends in Food Science & Technology* **57** 178-187.

501 Ranadheera, CS, Naumovski, N and Ajlouni, S (2018) Non-bovine milk products as emerging
502 probiotic carriers: Recent developments and innovations. *Current Opinion in Food Science* **22**
503 109-114.

504 Ribeiro, A C and Ribeiro, S D A (2010) Specialty products made from goat milk. *Small*
505 *Ruminant Research* **89** 225-233.

506 Samona, A, Robinson, R K and Marakis, S (1996) Acid production by bifidobacteria and
507 yoghurt bacteria during fermentation and storage of milk. *Food Microbiology* **13** 275-280.

508 Shah, N P, Lankaputhra, W E V, Britz, M L and Kyle, W S A (1995) Survival of *Lactobacillus*
509 *acidophilus* and *Bifidobacterium bifidum* in commercial yoghurt during refrigerated storage.
510 *International Dairy Journal* **5** 515-521.

511 Shi, L E, Li, Z H, Li, D T, *et al.* (2013) Encapsulation of probiotic *Lactobacillus bulgaricus* in
512 alginate–milk microspheres and evaluation of the survival in simulated gastrointestinal
513 conditions. *Journal of Food Engineering* **117** 99-104.

514 Silva, HL, Balthazar, CF, Silva, R, Vieira, AH, Costa, RG, Esmerino, EA, Freitas, MQ and
515 Cruz, AG (2018) Sodium reduction and flavor enhancer addition in probiotic prato cheese:
516 Contributions of quantitative descriptive analysis and temporal dominance of sensations for
517 sensory profiling. *Journal of Dairy Science* **101(10)** 8837-8846.

518 Sperry, MF, Silva, HL, Balthazar, CF, Esmerino, EA, Verruck, S, Prudencio, ES, Neto, RP,
519 Tavares, MI, Peixoto, JC, Nazzaro, F and Rocha RS (2018) Probiotic Minas Frescal cheese
520 added with *L. casei* 01: Physicochemical and bioactivity characterization and effects on
521 hematological/biochemical parameters of hypertensive overweighted women–A randomized
522 double-blind pilot trial. *Journal of Functional Foods* **45** 435-443.

523 Soukoulis, C, Behboudi-Jobbehdar, S, Yonekura, L, Parmenter, C and Fisk, I (2014) Impact of
524 milk protein type on the viability and storage stability of microencapsulated *Lactobacillus*
525 *acidophilus* NCIMB 701748 using spray drying. *Food and Bioprocess Technology* **7** 1255-
526 1268.

527 Sun, W and Griffiths, M W (2000) Survival of bifidobacteria in yogurt and simulated gastric
528 juice following immobilization in gellan–xanthan beads. *International Journal of Food*
529 *Microbiology* **61** 17-25.

530 Verruck, S, De Carvalho, M W, De Liz, G R, *et al.* (2017) Survival of *Bifidobacterium* BB-12
531 microencapsulated with full-fat goat’s milk and prebiotics when exposed to simulated
532 gastrointestinal conditions and thermal treatments. *Small Ruminant Research* **153** 48-56.

533 Würth, R, Hörmannsperger, G, Wilke, J, Foerst, P, Haller, D and Kulozik, U (2015) Protective
534 effect of milk protein based microencapsulation on bacterial survival in simulated gastric juice
535 versus the murine gastrointestinal system. *Journal of Functional Foods* **15** 116-125.

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543 **Figure captions**

544 Fig.1. Scanning electron micrographs showing the cross section of different capsules. a:
545 capsules were prepared using alginate and goat milk at a ratio of 1.5:1 (v/v). b: capsules were
546 prepared using alginate and goat milk at a ratio of 1.5:1 (v/v) and inulin 0.5% (w/v). c: capsules
547 were prepared using alginate and goat milk at a ratio of 1.5:1 (v/v) and inulin 1% (w/v). d:
548 capsules were prepared using alginate and goat milk at a ratio of 1.5:1 (v/v) and inulin 1.5%
549 (w/v). e: capsules were prepared using alginate and goat milk at a ratio of 1.5:1 (v/v) and inulin
550 2% (w/v). (magnification 10,000×). White → shows the bacterial cells.

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552 Fig.2. Survival of free and encapsulated *B. animalis subsp. lactis* BB-12 in goat milk yoghurt
553 at 4 °C for 28 days. Vertical lines represent standard deviations. ^{ABC}Means with different
554 uppercase are significantly different ($p<0.05$) between each time, for each type of alginate-
555 goat milk capsule during the storage. ^{abcd}Means with different lowercase are significantly
556 different ($p<0.05$) between each type of alginate-goat milk capsule, for a particular day of the
557 storage period. Free: Free bacterial cells. 0%: capsules were prepared using alginate and goat
558 milk at a ratio of 1.5:1 (v/v). 0.5: capsules were prepared using alginate and goat milk at a ratio
559 of 1.5:1 (v/v) and inulin 0.5% (w/v). 1: capsules were prepared using alginate and goat milk at
560 a ratio of 1.5:1 (v/v) and inulin 1% (w/v). 1.5: capsules were prepared using alginate and goat
561 milk at a ratio of 1.5:1 (v/v) and inulin 1.5% (w/v). 2: capsules were prepared using alginate
562 and goat milk at a ratio of 1.5:1 (v/v) and inulin 2% (w/v). Free: Free cells.

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564 Fig.3. Changes in pH of goat milk yoghurt containing free and encapsulated bacterial cells at
565 4 °C for 28 days. Vertical lines represent standard deviations. ^{ABCDE}Means with different
566 uppercase are significantly different ($p<0.05$) between each time, for each type of alginate-
567 goat milk based capsule during the storage. ^{abcdef}Means with different lowercase are

568 significantly different ($p<0.05$) between each type of alginate-goat milk based capsule, for a
569 particular day of the storage period. For legend explanations see Fig. 2.

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593 **Tables**

594 Table 1. Influence of different concentrations of inulin on the size and encapsulation yield of
595 different capsules

Concentration of inulin (% w/v)	Size of capsules (mm)	Encapsulation yield (%)
0	2.79 ± 0.33 ^b	90.84 ± 3.10 ^a
0.5	2.98 ± 0.23 ^{ab}	91.67 ± 1.76 ^a
1	3.11 ± 0.58 ^{ab}	91.94 ± 3.88 ^a
1.5	3.32 ± 0.35 ^a	90.57 ± 2.04 ^a
2	3.41 ± 0.44 ^a	87.45 ± 2.06 ^a

596 ^{ab}Mean values (±standard deviation) within the same column not sharing a common superscript
597 differ significantly (P < 0.05).

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612 Table 2. Survival of free and encapsulated *B. animalis* subsp. *lactis* BB-12 after incubation in
 613 simulated gastric juice (pH 2) at 37 °C for 30, 60, 90 and 120 min and in simulated intestinal
 614 juice pH (7.5) at 37 °C for 2h (Value represents both after gastric and intestinal digestion *in*
 615 *vitro*)

Type of cells	Concentration of inulin (%)	Number of viable cells (log cfu mL ⁻¹ / log cfu g ⁻¹)				
		0	30	60	90	120
Free		9.43 ± 0.08 ^{A a}	7.37 ± 0.32 ^{B b}	3.49 ± 0.09 ^{C c}	ND	ND
Encapsulated	0	9.49 ± 0.12 ^{A a}	8.22 ± 0.10 ^{B b}	8.11 ± 0.11 ^{B b}	8.09 ± 0.09 ^{B b}	8.07 ± 0.03 ^{B b}
	0.5	9.47 ± 0.11 ^{A a}	8.28 ± 0.26 ^{B ab}	8.21 ± 0.21 ^{B ab}	8.14 ± 0.12 ^{B b}	8.11 ± 0.18 ^{B b}
	1	9.45 ± 0.23 ^{A a}	8.38 ± 0.07 ^{B ab}	8.33 ± 0.05 ^{B ab}	8.28 ± 0.18 ^{B a}	8.14 ± 0.11 ^{B a}
	1.5	9.45 ± 0.14 ^{A a}	8.62 ± 0.16 ^{B ab}	8.52 ± 0.18 ^{BC a}	8.43 ± 0.07 ^{C a}	8.41 ± 0.19 ^{C a}
	2	9.44 ± 0.11 ^{A a}	8.70 ± 0.22 ^{B a}	8.54 ± 0.06 ^{BC a}	8.46 ± 0.15 ^{C a}	8.44 ± 0.10 ^{C a}

616 ^{ABCD}Means in the same row without common letter differ significantly ($p < 0.05$) for each type
 617 of capsules. ^{abcde}Means in the same column for each type of capsule without common letter
 618 differ significantly ($p < 0.05$) for a particular time. Data are expressed as mean ± standard
 619 deviation. ND: Not detected.

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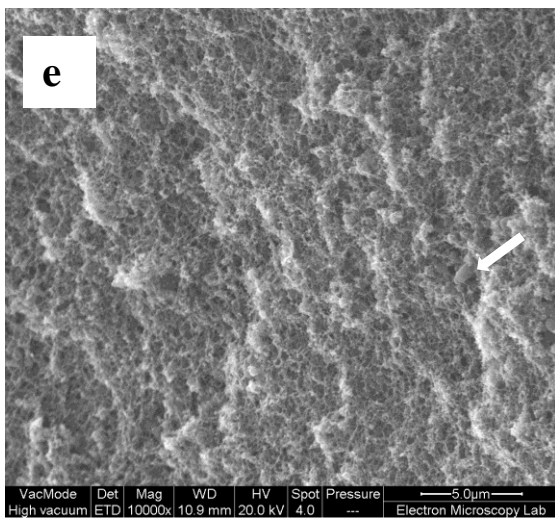
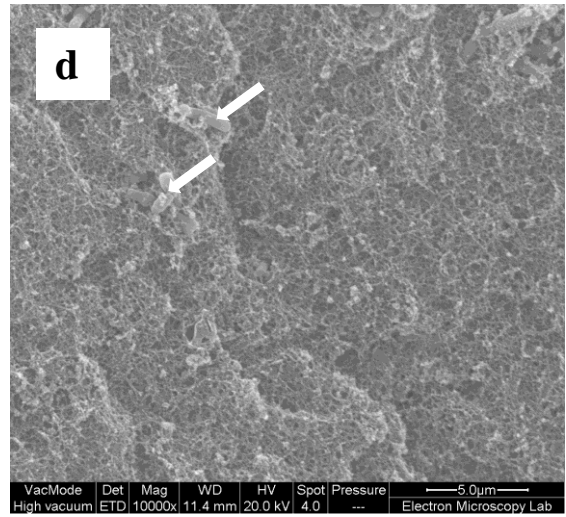
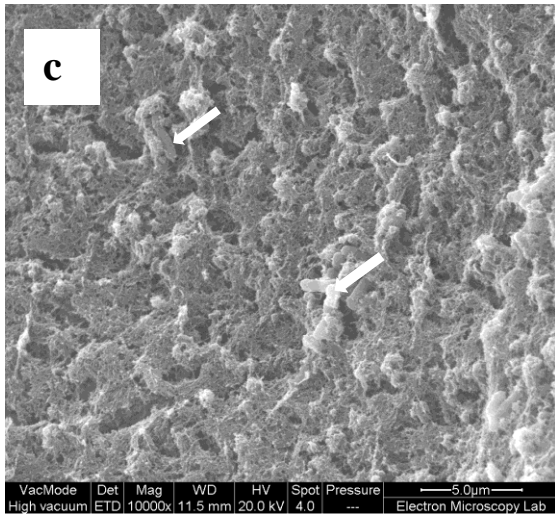
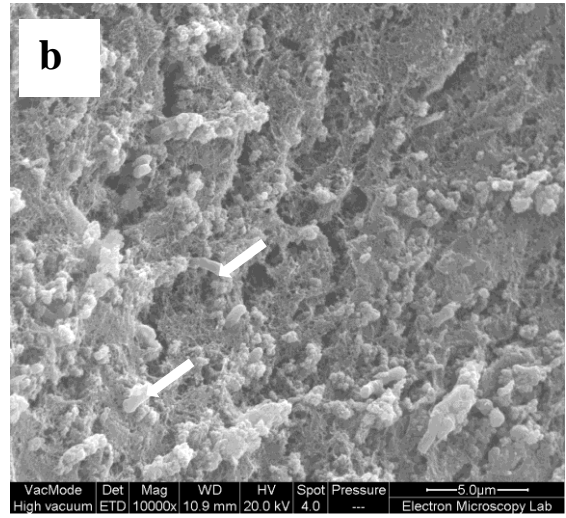
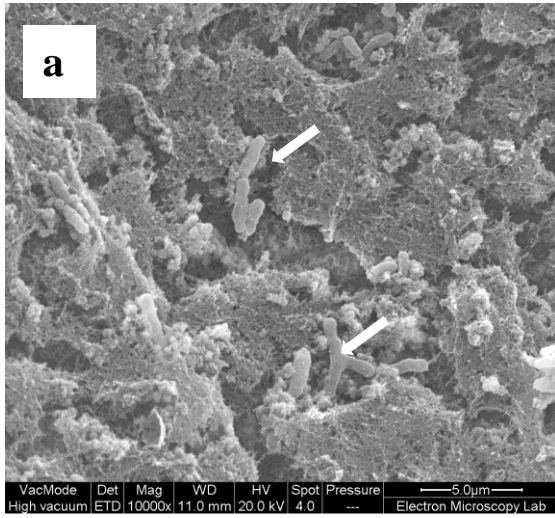


Fig.1.

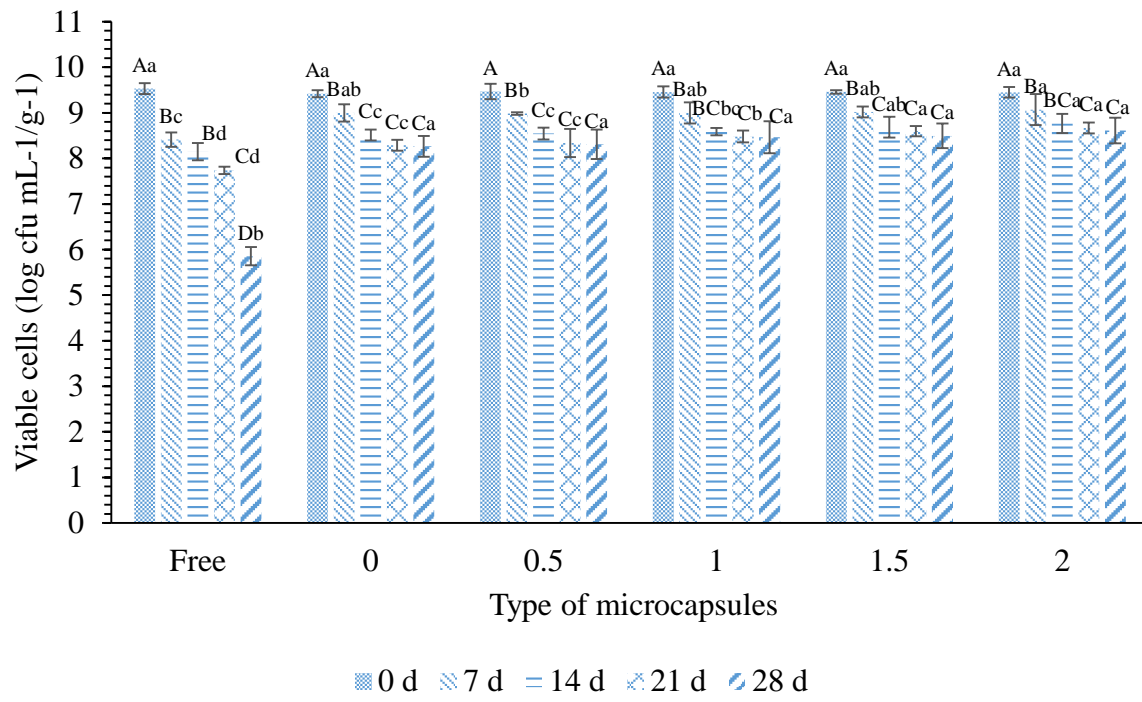


Fig. 2.

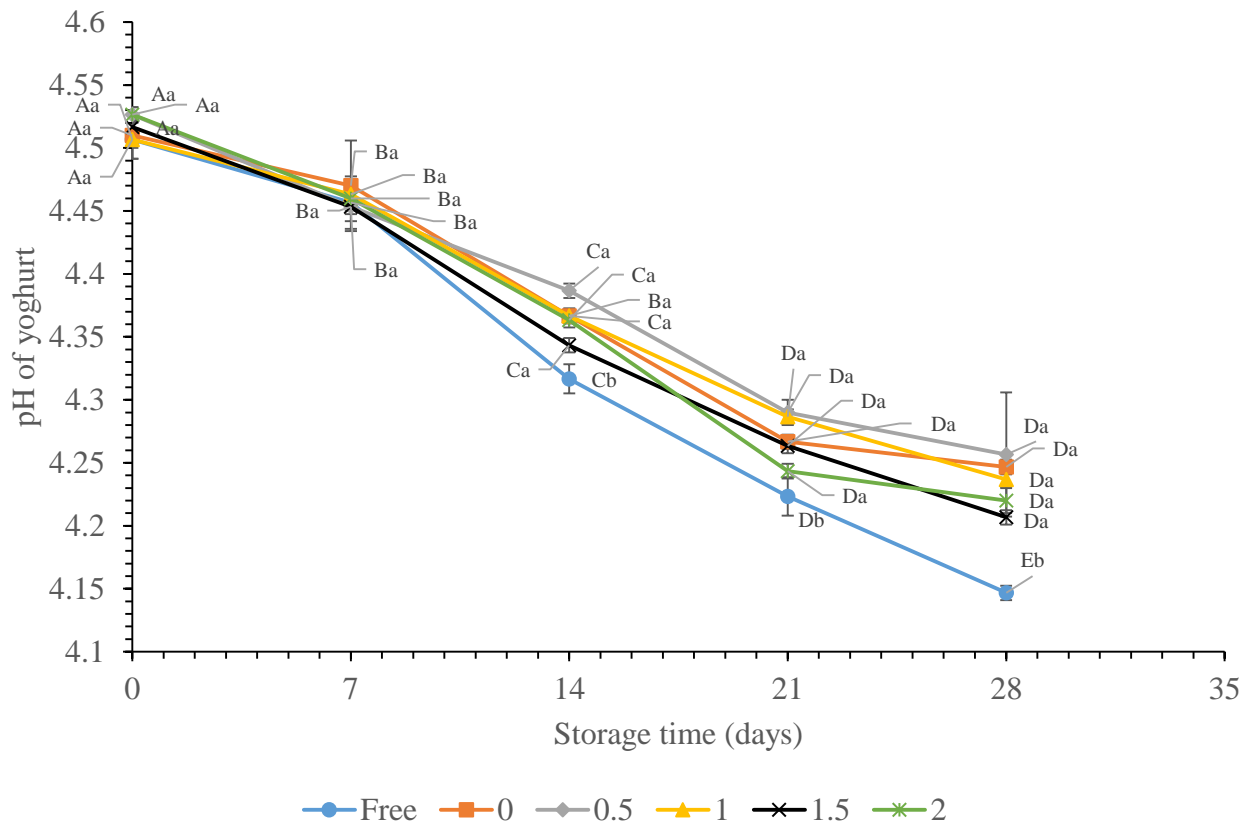


Fig.3.