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Item-level Radio-Frequency IDentification for the traceability of food products: application on a dairy product

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Abstract

In the food industry, radio-frequency identification systems could be exploited for traceability, logistics as well as for anti-counterfeit purposes. In this paper, a complete item-level radio-frequency (RF) traceability system is presented for a high-value, pressed, long-ripened cheese. The main contribution of this paper consists in experimenting with different techniques for fixing tags to the cheese and solutions for automatic identification adapted to handling procedures as implemented in a dairy factory. All item movements are thus automatically recorded during the production, handling in the maturing room and warehouse, delivery, packing and selling phases.

Fixed and mobile RF devices operating at low, high and ultra-high frequency bands were considered for both static and dynamic identification of single/multiple cheese wheels. Factors such as tag type and shape, required power, antennas polarization and orientation, fixing method and ripening duration were considered in order to verify their effect on reading performance and system reliability.

Keywords: RFID, traceability, cheese

1. Introduction

Large food companies need supply chain management and logistics improvements to enhance their costs/benefits objectives (e.g. adopting pull marketing strategies, introducing lean strategies, reducing inventories and labour costs) and, at the same time, to guarantee the

34 highest level of traceability efficiency in terms of quality and safety. The application of
35 innovative systems and technologies to collect information at item or batch level at
36 affordable costs enables manufacturing enterprises both to better control the production
37 process and to share quality and traceability data in supply chain collaborative networks
38 (Bechini *et al.,* 2008; Barge *et al.,* 2009). The availability of a system which could
39 continuously update inventories at supply chain level could lead to a reduction of costs tied
40 to high inventory-to-sales ratios (Golan *et al.*, 2004; Varese *et al.,* 2008; Costa *et al.,* 2013).

41 To our best knowledge, cheese traceability is currently managed at lot level and documented
42 by written records. In the most favourable cases, the information is inserted in a local
43 database. The application of innovative systems and technologies to automate information
44 collection related to the single product unit could improve the performance of traceability
45 systems (Dabbene and Gay, 2011) and optimize warehouse management and logistics
46 (Alfaro and Ràbade, 2009), thereby reducing costs.

47 Moreover, by means of traceability data sharing along the whole food supply chain, food
48 safety would be increased and, in case of a recall, product withdrawal would be very rapid.
49 In all cases, when data sharing is put in place, privacy issues should be attentively
50 considered and managed (Lee and Park, 2010; Jacobs, 1996; Kumar and Budin, 2006).

51 In the near future, due to the high risk of counterfeiting of labelled and certified products
52 (e.g. the "made in Italy" products), new initiatives are expected to preserve the identity of
53 valuable, high quality local products. Considering long-ripened protected designation of
54 origin (PDO) cheese, the high value of the product is related to the preservation of credence
55 attributes that cannot be perceived directly by the consumer, but can only be guaranteed by
56 an effective, item-level, traceability system (Golan *et al.,* 2004). Identity preservation at item
57 level is also important in case of special productions such as, for example, Kosher and Halal
58 food or military supplies (Dabbene *et al*., 2013).

59 Single wheel identification by traditional methods (e.g. labels or brands), through the
60 production process and during the maturing period, is critical due to cheese chemical
61 composition (moisture, pH, fat and salt content), physical characteristics (texture, rind
62 surface condition), environmental conditions during the different processing phases (curd
63 moulding, pressing, dry or brine salting, ripening), and frequent product handling (e.g. daily
64 turning, brushing and scraping during ripening).

65 Radio-frequency identification (RFID) systems have already been adopted for traceability

66 purposes in many food supply chains (Nambiar, 2010), combining optimization (Sarac *et al.,*

67 2010; Tajima, 2007) with real-time monitoring (Abad *et al.,* 2009; Wang *et al.,* 2010). In

68 spite of today's wide diffusion of RFID in animal identification (by ear tag or endoruminal

69 bolus, e.g. Eradus and Jansen, 1999; Gay *et al.,* 2008; Jansen and Eradus, 1999; Barge *et al.,*

70 2013 and references therein) and in livestock feeding and milking management (Trevarthen

71 and Michael, 2008), RFID adoption in the cheese industry is rarely deployed and is often

72 limited to packed products kept in boxes and/or stacked on pallets (Wamba and Wicks,

73 2010).

74 When properly coated by special resins or plastic materials approved for food contact, RFID

75 transponders could be directly inserted in long-ripened cheese, allowing the assignment of a

76 unique numerical identifier, stored in the tag, for each wheel of cheese. This application,

77 however, is faced with various problems, among which the persistence and readability of the

78 tag from pressing to ripening and delivery. In addition, the high moisture content of the

79 cheese could strongly attenuate the RF signal, thereby limiting, or even compromising,

80 reading performances.

81 Preliminary studies have been conducted by applying tags to Spanish PDO cheese (Pérez-

82 Aloe *et al.,* 2007; Pérez-Aloe *et al.,* 2010), and to the high-value Italian cheese *Parmigiano*

83 *Reggiano* (Regattieri *et al.,* 2007). In 2007, through a European project conducted by the

84 Department of Logistics at the University of Dortmund, a traceability system based on

85 RFID technology was developed for *Queso Cabrales* (a famous PDO Spanish cheese).

86 Nevertheless, to our best knowledge, a complete study on the reliability of an RFID tracking

87 system for cheese identification in an industrial context is not yet available. Some aspects,

88 like the persistence of the different types of tags on the cheese and the reading performances

89 at different frequencies, should be determined and considered when integrating the system in

90 the traceability management of a dairy factory.

91 The aim of this paper is to investigate the effectiveness of RFID technology in tracing single

92 cheese wheels, from curd making to final packaging and delivery. RFID systems, operating

93 at low, high and ultra high frequencies (LF, HF and UHF respectively), were tested and

94 compared with the aim of evaluating the performances and limits of each solution at

95 different stages of the production process. Performance evaluation of RFID systems requires

96 RF measurements that have to be conducted in strictly controlled conditions (Derbek *et al*.,

97   2007). The dielectric properties and shape of food matrices usually affect tag reading ranges

98   (i.e. the longest tag-to-reader antenna distance that still guarantees tag activation, data

99   processing and answer transmission), reading zones (i.e. the region where the tag is detected)

100   and the transmitted power required for tag activation. The reliability of RF identification

101   needs to be evaluated for each category of food product, in the production and logistics

102   phases as well as in the different environments.

103   The assessment of the coverage zones and of the transmitted power required for transponder

104   activation in the laboratory as well as in the cheese factory will be used to identify the

105   potentialities of different RFID solutions in each cheese production phase. The issue of the

106   proper design of the facilities required for cheese wheel identification as well as the

107   positioning of the reader antennas will be discussed on the basis of experimentation results

108   which have been obtained in a local dairy factory, and regard *Toma Piemontese*, a typical

109   PDO cheese that can be considered representative of most medium and long-ripened cheeses

110   in Piedmont.

111   The paper is structured as follows: in Section 2 the joined production process and

112   information flow are analysed in order to define strategic points in the dairy factory where

113   products have to be identified to guarantee continuity through traceability. Section 3 reports

114   the materials and the protocols used in the experimentation. The results of the

115   experimentation are discussed in Section 4. The proposal for an RFID system for item-level

116   traceability in a cheese factory is described in Section 5. Finally, conclusions are drawn in

117   Section 6. Supplementary materials, consisting of a set of additional figures, hereafter

118   indicated as S1 to S7, are available online alongside the electronic version of the paper.

119

120   **2. Products & information flow in a dairy factory**

121

122   To determine the points and phases where/when the product has to be identified, a dairy

123   factory (Valle Josina, NW of Italy), was considered as a sample. The factory transforms

124   about 50 tons of milk daily to produce four kinds of long-ripened cheese (*Bra Tenero*, *Bra*

125   *Duro*, *Raschera* and *Toma Piemontese*). The PDO cheese considered in this paper (*Toma*

126   *Piemontese*) is a long-ripened, pressed, semi-fat, semi-hard texture cheese obtained from

127   whole cow milk, raw or pasteurized (D.P.C.M., 1993). Following the standards for *Toma*

128   *Piemontese* cheese, the wheels are moulded in cylindrical moulds of 30 cm in diameter and

129   8-9 cm in height. Ripening lasts 60 days. The dairy factory currently adopts an internal

130   cheese traceability system at lot-level. Fig. 1, in the middle column, reports the flow chart of

131   the cheese production process while, on the left of Fig. 1, the related information flow of the

132   already existing traceability system is described. On the right of Fig. 1, the proposed RFID-

133   based traceability system is depicted and is further discussed in Section 5.

134   The traceability of milk presents the same criticalities as other liquid or bulk products, which

135   are usually stored in tanks and progressively merged during the production process. As

136   discussed in Comba *et al*. (2013), traceability during the processing of these kinds of

137   materials can be guaranteed by combining the information of the supplied lots, according to

138   the mixing rules. This methodology generates, whenever necessary, new traceability units

139   (TU) of homogeneous products (see Moe, 1998, for a formal definition of TU).

140   For milk, TUs generated during the collecting phase are typically rather small, allowing

141   incentive premiums on the milk price on the basis of quality parameters (e.g. pH, presence of

142   antibiotic residues, protein and fat content, somatic cells number and total microbial count).

143   In the considered dairy factory, a new TU – the dairy milk lot – resulting from the blending

144   of several farm milk lots, is then defined. Here, the traceability system links information

145   about input milk and dairy lots. From each dairy lot a batch of about 110 cheese wheels is

146   obtained by pasteurization and curdling. Traceability information is manually noted on a

147   form and on a paper ticket which report the milk lot, the cheese lot number and curdling

148   parameters as well as the milk enzymes and the rennet type, the process temperatures, the pH

149   level, the curd pieces dimensions and the type of salting. When the whey removal process is

150   finished, the whole fresh broken curd is cut in rectangular chunks which are then placed into

151   a circular stainless steel mould where they will be pressed for 24 hours. From this point, in

152   the dairy traceability system, cheese lot identification is guaranteed by the cheese batch

153   traceability ticket which reports the product type, the production date, the lot number, the

154   number of cheese wheels in the lot, the milk lot tank number and the date of the expected

155   end of maturing period. This ticket follows the cheese lot through all production stages.

156   After the pressing phase, the cheese wheels are moved to the salting zone (Fig. S2, on the

157   left) where cheese salting can be done according to two procedures: dry or brine salting. In

158   brining, the cheese wheels are immersed in a saturated brine solution for 24 h while dry

159   salting is carried out by pouring salt on each cheese side with wheels arranged on shelves for

160   48 h (24 hours for each cheese face).

161 In this phase, traceability is highly critical as the lot identification paper card isn't applied to
162 the product but is kept near the brine tank, leading to potential errors. After 24 hours of
163 brining or 48 hours of dry salting, cheese wheels are ripened at 8–10 °C for up to 60 days. In
164 the ripening rooms, traceability is kept by the paper ticket placed nearby the first wheel of
165 the lot, while the following are identified only by their position according to an established
166 pattern.
167 At the end of the maturing period, each wheel of the batch is brushed, packed and stored into
168 a loading area. The identifier of the whole lot is the paper ticket. In case the lot is
169 disassembled, traceability of each item is guaranteed by maintaining the individual lot
170 physically separated in the loading area, where the sold items are progressively picked.
171 Before shipping, each cheese wheel is scanned by a metal detector and labelled. A delivery
172 note detailing the quantity and the type of products must be filled.
173
174 **3. Materials and methods**
175
176 **3.1 Radio-frequency identification systems**
177 As the readability of passive tags attached on food items is strongly influenced by the
178 wavelength of the RF signals, systems at different frequencies (LF, HF and UHF) were
179 tested and compared in order to determine solutions that could be effectively applied to
180 cheese tracking during the manufacturing, warehousing, packaging and distribution phases.
181 Different types of passive transponders were selected (Table 1), apart from the operating
182 frequency, on the basis of their ruggedness in the harsh environment and their compatibility
183 with food contact. Some tag models (*a, b,* and *c*) were coated by materials suitable for food
184 contact and resistant to mechanical shocks, while in the rest, normally used for other
185 purposes (e.g. logistics), the inlay was only covered by a plastic film. Some tag antennas (*e,*
186 *g,* and *h*) were prototypes employed in previous experimental works (not cited).
187 Two different handheld devices were tested for static tag reading in cheese factory trials: a
188 PDA Psion Teklogix – Workabout PRO equipped with an LF or HF frequency range
189 module, and an Id Isc Ant 200/200 I-Scan mobile antenna, composed of a reader worn at the
190 waist of the operator and coupled to a square loop HF antenna (200 x 200 mm). Both devices
191 were tested for the identification of cheese wheels positioned on shelves. LF tests were

192   performed using a BlueBox Soltec reader (version FW 1.11) linked to a Bluebox 125 kHz

193   panel antenna (200 x 200 x 15 mm).

194   Two different fixed HF systems were tested: a commercial long-range system (Obid, 15693

195   and 18000-3 ISO standards compliant, with a panel antenna of 600 x 800 mm) and a self-

196   constructed prototype antenna with a circular loop customized on the basis of the cheese

197   wheel shape. The transmitter power output (TPO) was set to 2 W.

198   Fixed panel antennas were adapted to cheese wheels electronic identification in static

199   conditions during specific operations (e.g. transport, handling and/or packaging). The

200   circular HF antenna prototype was composed of a single loop of 138 cm of length (equal to

201    $\lambda/16$) built with an RG58 coaxial cable and connected to a dynamic antenna tuner (DAT) for

202   impedance matching with the HF reader (see Fig. S4, on the left).

203   Reading tests were then performed for *Toma* DOP cheese tracking at strategic points of the

204   production process. For this purpose, 18 *Toma* wheels were equipped and then electronically

205   identified by using twelve different passive transponder models (Tables 1, *a, b, c, e, f, g, h, i,*

206   *l, x, v, z*) positioned on the side of the cheese wheel or on the edge of the cheese curved

207   surface. Tags were applied during curd moulding (Fig. S1, on the right) and were covered

208   with or layered between one/two casein disks (Fig. S1, on the left) before the two pressing

209   phases expected for *Toma* production (Fig. S2). Half of the wheels were left in brine for 24

210   hours, while the remaining were dry salted for 48 hours (24 hours for each side). Finally, the

211   cheese was ripened for 60 days in refrigerated cells. Tag readability was checked after

212   salting and then periodically during cheese ripening by means of a palmtop handheld device.

213   Tag-to-PDA reading distances were recorded at the end of ripening.

214   As UHF RFID-systems performances are affected by water and metals, the proposed

215   systems were preliminarily studied in controlled conditions inside an RF semi-anechoic

216   chamber to eliminate any possible environmental interference and/or signal reflection. To

217   compare readability of the tag at different orientations, both linear and circular antennas

218   were considered and several tag and antenna combinations were tested to identify the most

219   favourable solution for item level identification. Then, the RFID interrogation in the UHF

220   band was carried out by using a Caen RFID R4300P standalone reader connected to

221   antennas generating circular polarized (Caen RFID, model Wantenna X005, 7 dB*i* gain) or

222   linear polarized (Caen RFID, model Wantenna X007, 8 dB*i* gain) fields. The reader was

223   controlled by a C# software specifically developed by using the CAEN Application

7

224 Programming Interface. This application allowed measuring of the minimum tag activation

225 power (P_{min}), defined as the minimum TPO required to activate and read the unique code

226 contained in the tag (Rao *et al.,* 2005). This was obtained by means of a power sweep

227 ranging from 0 to 2000 mW with 1 mW steps (Tortia *et al.*, 2012).

228 All the UHF devices used in the trial were EPC Class 1 Gen 2 protocol compliant.

229

230 **3.2. Interrogation area and maximum reading distance assessment methods**

231 Laboratory tests were set up to determine the interrogation zone with different tag/antenna

232 combinations in the LF and HF bands, firstly with tags applied on a polystyrene support and

233 then with tags applied to the cheese wheel surface. Tag orientation was always parallel to the

234 reader antenna. Cross-sections of the reading volume were determined by using the

235 transponders described in Table 1, with the purpose of evaluating solutions for static cheese

236 identification like, for example, integrating the antenna in a cutting board or under the

237 conveyor belt immediately after the metal detector before shipping (see Fig. S7). In the case

238 of cheese wheel identification, tags were attached on the cheese rind at the centre of one face

239 or on the outer edge. Moreover, tags were applied both on the cheese surface oriented

240 towards the antenna and on the opposite side to evaluate the effect of cheese mass on the

241 reading distance. Rectangular shaped tags were applied by orienting the longer edge along

242 the *y* axis.

243 The shape of the reading zone was obtained by approaching the transponder towards the

244 antenna till detection. To describe the shape in three dimensions, measurements are referred

245 to the *x, y* and *z* axes with the origin at the antenna geometric centre, with the *x* and the *y*

246 axes aligned along the shorter and longer sides of the antenna respectively*,* and the *z* axis

247 orthogonal to the antenna plane.

248 The maximum reading distance (D_{max}) between tag and antenna was measured along the *z*

249 axis at fixed *x*, *y* points on the antenna plane as proposed also by Porter and Billo (2004).

250 Different *xz* cross-sections at increasing *y* values were also determined. When the tag was

251 applied on the cheese outer edge, the cheese wheel face laid on the *xz* plane with the tag in

252 parallel orientation to the antenna, as in the aforementioned cases.

253 The maximum reading distance D_{max} at $x = y = 0$ was also determined with the tag on

254 polystyrene and on the cheese surface to evaluate the influence of the tag type and the

255 feasibility of tag detection across the cheese. Towards this aim, D_{max} was also recorded after

256 a 180 degrees rotation of the cheese wheel around the *y* axis. In this case the cheese remains

257 interposed between the antenna and the tag.

258 A plastic cutting board with an embedded HF RFID antenna was designed and implemented.

259 The reading volume of such a prototype of smart cutting board was determined in static

260 conditions by using the *c* tag model. The tag was applied both on the cheese surface and on

261 the outer edge respectively in parallel and perpendicular orientations to the antenna plane.

262 The performances of the system in dynamic conditions were evaluated by measuring the tag

263 detection rates *Dr%*, defined as the ratio between the number of successful identifications

264 and the total number of tests (100 repetitions per trial) which were performed manually by

265 placing the cheese wheel on the prototype of the HF cutting board in random position (Fig.

266 S4, on the right). The cheese was arranged on the antenna plane by ensuring the tag was

267 inside the cutting board perimeter and then moved outside the antenna reading volume

268 before the next repetition. The tests were performed using six RFID tag models (*c, e, f, g, i,*

269 *l*).

270

271 3.3 Characterization of UHF systems for cheese electronic identification in anechoic

272 chamber

273 The minimum power P_{min} that has to be delivered to the reader output to activate the tag and

274 receive the backward signal is described by the *Friss* transmission equation concerning RF

275 propagation between transmitting and receiving antennas. The power received by the tag

276 chip is a function of the distance separating the transmitting (reader) and receiving (tag)

277 antennas and of their respective gains (Rao *et al*., 2005; Nikitin *et al*., 2007). Factors that can

278 negatively affect reading distance are: tag chip-to-antenna impedance mismatching, tag

279 orientation, frequency detuning and hardware parts which determine losses.

280 As the reading range is not only dependent on the tag itself, but also on the tag support

281 material and on the shape of the antenna (e.g. meander-line, bow-tie, cross-dipole, U-shaped

282 slot antenna) which can react differently in contact with the cheese or other materials,

283 different tag antenna shapes were tested. The UHF reader was connected, in different

284 experiments, to the linear and circular polarized antennas at increasing tag-to-antenna

285 distances. The reading antenna and the tag centres were always aligned. To reduce the effect

286 of the environment and of possible external disturbances to a minimum, experiments were

287 conducted inside a semi-anechoic chamber (Fig. S5).

288   The developed software was used to determine P_{min} at different tag-to-antenna distances.

289   For each tag model, P_{min} was preliminarily measured with transponders applied on a

290   polystyrene support. Then, to evaluate the effects of the presence of *Toma*, P_{min} was recorded

291   with tags directly applied to the cheese wheels surface. Tests were carried out by using four

292   cheese wheels belonging to two production lots: two ready for sale (60 days of ripening) and

293   two ripened for 30 days. As the reading range was limited by the cheese, the tag-to-antenna

294   distance was set at 0.5 m. Experiments were repeated using a 3 mm thick plastic spacer

295   between tag and cheese, to evaluate possible reduction of the cheese absorbing effect on the

296   RF signal.

297   In the experiment design, results in terms of P_{min} for all the combinations of antenna

298   polarization (linear or circular), ripening duration (30 or 60 days), tag type (five tags), and

299   presence/absence of a spacer between tag and cheese factors were collected and statistically

300   analysed using SPSS® Statistics 17.0. The separate effects of the considered factors and their

301   interactions were evaluated by one-way analysis of variance procedure (UNIANOVA) for

302   regression and variance analysis of the dependent variable. A generalized linear model

303   (GLM) was adopted. Means were then compared by a post-hoc Tukey test.

304

305   **4. Results**

306

307   **4.1 Transponder persistence**

308   All the housings in different covering materials (Table 1) were apt to protect the tags

309   circuitry and antennas. In fact, in spite of the harsh environment and the cheese handling and

310   brushing, tag resistance to mechanical shock and to critical chemical and storage conditions

311   was enough to guarantee the correct reading of the transponders during the whole production

312   process.

313

314   **4.2 Detection zone of fixed and handheld LF and HF systems for cheese wheels**

315   **identification**

316   The reading zone of the 125 kHz LF panel antenna is represented by its *xz* cross-sections

317   (Fig. 2). The maximum reading distance D_{max} of tag *b* exceeded that of the smaller tag *a* by

318   about 60 mm in the case of tags applied on polystyrene. The presence of the cheese only had

319 a slight effect on the reading distance, as can be seen for the *y=0* cross-section for tag *a*

320 attached on the two different materials.

321 For tag *a* applied on the cheese, cross sectional areas at different *y* values are reported. The

322 main reading lobe shape resulted symmetric with respect to the *z* axis. When the tag was

323 reaching the border of the antenna, it was detected only when it was very close.

324 When a tag was placed between the antenna and the cheese wheel, the reading zone was a

325 circle of 100 mm radius. On the contrary, when the tag was placed on the opposite side of

326 the cheese wheel, whose thickness ranges between 90 and 100 mm, correct reading was

327 achieved inside a circle of only 60 mm radius around the *z* axis.

328 The shape of the reading zone for tag *b* was similar to the one obtained for tag *a*, but slightly

329 larger (data not reported). Tag *a* was correctly identified by the PDA handheld device only

330 with the RFID module in contact with the cheese surface, while tag *b* was detected at a

331 maximum distance of 70 mm (results reported in Table 2).

332 As determined in laboratory conditions, the shape and dimensions of the reading zone of the

333 rectangular Obid *i*-scan HF antenna differ depending on tag model, tag-to-antenna mutual

334 orientation and cheese wheel presence. The maximum reading distance D_{max} measured along

335 the *z* axis at $x = y = 0$ is reported, for each tag model, in Table 3.

336 On polystyrene, a direct proportionality relationship between tag dimension and tag-to-

337 antenna maximum reading distance could be clearly evinced. The maximum reading

338 distance of the smaller tag *c* resulted approximately equal to one third of the bigger one (tag

339 *l*). For rectangular tags, the maximum reading distance D_{max} resulted proportional to the

340 length of the longer edge of the tag, rather than to other tag parameters (e.g. tag area).

341 To compare the influence of cheese presence on the tag-reading zone, the information is

342 expressed as the ratio between D_{max} obtained when the tag was applied to the cheese surface

343 and D_{max} obtained on the polystyrene (%). Except for tag *c,* whose maximum reading

344 distance was not reduced at all by cheese presence, the maximum reading distance of all the

345 tags applied to the *Toma* cheese wheel was reduced to some extent. When the tag was lying

346 on the cheese face, the presence of the cheese affected D_{max} to a lesser extent than in the case

347 of a tag applied on the outer edge.

348 When the tag was attached on the cheese face, the effect of a 180 degrees rotation around the

349 *y* axis was null except for tags *d* and *f* which were the smallest among the rectangularly

350 shaped ones. In that case, the presence of the cheese wheel thickness among receiving and

351 transmitting antennas didn't affect tag antenna communication efficiency.

352 On the contrary, apart from tag *c*, tag application on the cheese outer edge significantly

353 decreased the maximum reading distance for all the considered tags and the 180 degrees

354 rotation further reduced D_{max} only for tags *d* and *m* (a square model).

355 Tag *d*, applied on the cheese outer edge with a 180 degrees rotation on the *y* axis, was not

356 even readable.

357 The *xz* cross-sections of the reading zone for tag *l* on the cheese surface (*y*=0) and on the

358 polystyrene at different *y* values can be observed in Fig. 3. For all the considered HF tag

359 models, without cheese, the reading cross-section area shape in parallel orientation at *y*=0

360 was constituted by three lobes. When the tag was applied on the cheese surface, both size

361 and shape of the antenna reading volume cross-section (*y*=0) were significantly reduced. In

362 particular, the side lobes resulted smaller, except for tag *l* (Fig. 3, dotted line). The reading

363 zone shape obtained in the presence of cheese was similar to that measured without cheese.

364 The shape of the reading area of the prototype HF cutting board (Fig. 4) is similar to a

365 spheroid with an equatorial radius R_a equal to 290 mm, and a distance from centre to pole

366 along the symmetry axis (L_b) of 195 mm if tag orientation is parallel. The embedded circular

367 loop antenna can then read the tag applied on both cheese faces placed on the whole cutting

368 board surface, with the exception of a non-reading area that corresponds to the tag alignment

369 with the antenna loop cable. This is due to the orientation of the electromagnetic field lines

370 of force typical of inductive coupling. When the tag was applied on the cheese outer edge, in

371 perpendicular orientation with respect to the antenna horizontal plane, the resulting reading

372 area was smaller and shaped like a torus having a minor radius R_e equal to 127 mm and a

373 major radius R_d equal to 216 mm. The radius R_c (Fig. 4) represents the distance between the

374 cutting board centre and the external limit of the torus reading area (i.e. $R_c = R_d$-R_e = 89 mm)

375 and represents the radius of the central no-reading zone. Consequently, tag reading is

376 possible only if the cheese wheel is well centred on the cutting board, when the tag remains

377 within the torus reading volume.

378 By handheld device, the reading distance of HF tags ranged between 50 and 130 mm as

379 shown in Table 2. When a handheld device was connected to a single loop portable antenna,

380 the reading distance ranged between 150 and 200 mm.

381

4.3 Detection rate of cheese wheels on an HF cutting board

Table 4 reports the results of dynamic repetitive positioning of the cheese wheel, at 2 W TPO, for the considered tag models. Detection rate $Dr\%$ was always the highest when tags were in parallel orientation and indifferently positioned on the upper or lower cheese face for all the considered tags. In the case of a tag placed on the cheese edge, perpendicularly oriented with respect to the antenna plane, $Dr\%$ decreased for tag models *c, g* and *f*, while it was null for tag type *e*. Conversely, tag *i* $Dr\%$ reduction was null when applied on the cheese wheel outer edge.

4.4 Effects of the cheese on tag readability in ultra high frequency identification

For each combination of reader antenna, tag type and support (polystyrene or cheese), an appropriate reading distance was chosen in order to obtain a measured power value in the required range. As the energy required to activate the integrated circuit is almost equal for any tag type, the effects on P_{min} could be ascribable to the contact with high dielectric materials such as products with high water content, which cause an alteration of the electrical characteristics of the tag antenna causing an impedance mismatch. Besides, emitted power is dissipated inside the cheese and part of the wave is reflected (Lorenzo *et al.,* 2011). Since the system is not linear (tag detection acts as a threshold), the lower P_{min} is required, the less these effects occur.

Moreover, as the tag antenna shapes are different, tag response in linear or circular polarization fields vary. On polystyrene, at 1.5 and 2.0 m distance between linear polarized antenna and tag, all tag types were detected at very low transmitted power. Measured P_{min} values resulted even lower than the lower threshold of the reader operating range ($\approx$ 43 mW), except for tag *o* which resulted not readable (out of range, P_{min} > 700 mW) at 2.5 m. For tags *n, p, q*, and *r*, the optimal reading distance was 2.5 m (Fig. 5).

Since the P_{min} values obtained at 2.0 m with the circular polarized antenna are higher and since the differences in P_{min} among the tags are more easily underlined, the optimal tag-to-reader antenna distance with the circular polarized antenna resulted equal to 2.0 m. At a 2.5 m distance, the minimum required power was high and the reading was very difficult for all the tags and only tags *n* and *p* (both dipoles) were detectable by the circular polarized antenna.

413 As a result, different tag designs and antenna polarizations led to different required P_{min} for

414 tag activation and correct signal backscattering. For all the considered transponders, P_{min} was

415 significantly higher with a circular polarized antenna whose gain is lower with respect to the

416 linear polarized antenna.

417 On polystyrene, tag o, which is a cross-dipole, was found to be activated only at higher

418 emitted power with both antennas. When the transponders were attached to the cheese

419 wheel, the power required to activate the tag and to have a response increased and, as a

420 consequence, the tag-to-reader antenna distances considered in the trials were reduced to 0.5

421 m.

422 Reading by handheld device at the beginning of ripening was not possible, while after two

423 months all tags were identified even if, in some cases (tag v), the antenna module of the

424 handheld device had to be in contact with the cheese (Table 2).

425

426 **4.5 Statistical analysis**

427 Table 5 reports the mean values of P_{min} required for tag activation on the cheese, calculated

428 by considering 156 readings and including the effects of all the factors, such as antenna

429 polarization, ripening period and spacer presence/absence. The lowest value of P_{min} when the

430 tag was applied on the cheese was registered for tag model n. In particular, cheese presence

431 affected readings for tags q and p, even if, on polystyrene, good results were achieved. On

432 the contrary, for tags o and r cheese presence ameliorated tag performances with respect to

433 polystyrene. The effect of the factors and the interactions between the factors on the variable

434 P_{min} as evinced from UNIANOVA are reported in Table 6.

435 The effects of the ripening duration factor were not significant for P<0.05. This could

436 probably be due to the fact that the first layers of the cheese rind lost moisture especially in

437 the first days (Goy *et al.*, 2012), however rind characteristics were already suitable for RF

438 identification after one month.

439 Other single factor effects (tag type, antenna polarization, spacer presence/absence) and their

440 interaction were significant for P<0.05. The statistical model coefficient R^2 was equal to

441 0.92. Means for the tag type factor were divided into homogeneous sub-sets by means of the

442 post-hoc *Tukey* test as indicated by the different letters in Table 5.

443 Fig. 6 illustrates by means of box plots the distribution of P_{min} values, comparing the antenna

444 type (linear or circular polarized) and the transponder type factors.

445   Considering the interaction between tag types and antenna polarization factors, all tag types
446   resulted more or less easily identified (thus requiring a lower P_{min}) by means of the polarized
447   linear reader antenna. The power required for the activation of tag n was also very low on
448   the cheese and the low variability and high significance of the results in the Tukey test
449   encourage the use of this tag both with circular and linear polarization antennas.

450   On the contrary, the use of tag p on the cheese should be avoided as mean P_{min} values were
451   the highest and a strong variability was observed, especially in the case of the circular
452   polarization antenna.

453   Means of the dependent variable P_{min} for tags o and r were not significantly different in the
454   Tukey test, but the effect of field polarization was not the same. For tag o, which is a double
455   dipole, the mean data for the circular and linear antennas were similar, but the linear
456   polarized field affected good repeatability of the data. On the contrary, for tag r, P_{min} values
457   were lower and less dispersed in the case of the linear polarization antenna.

458   The presence of a plastic spacer between tag and cheese face significantly decreased the
459   required power for correct tag functioning (Fig. 7). This is probably due to the fact that the
460   insertion of an electromagnetic inert material between the tag antenna and the cheese surface
461   could overcome the effects of gain penalty and antenna detuning (Lorenzo *et al.,* 2011;
462   Dobkin and Weigand, 2005). In particular, the presence of the spacer clearly improves tag p
463   readability by a strong reduction of P_{min}. For this tag, the presence of the spacer also led to
464   the reduction of data variability in comparison to the P_{min} values measured without the
465   spacer.

466   Generally, the spacer allowed P_{min} reduction for all the considered tags, except in the case of
467   tag n for which the activation power remained constant both with and without the spacer,
468   even if without the spacer a higher variability was observed.

469

470   **5. Proposed reading methods at strategic points in the cheese production process**

471

472   The results reported in the previous section led to the definition of a layout for an RFID
473   traceability system, which is reported on the right-side of Fig. 1. The system design
474   guarantees item-level RFID identification of single cheese wheels by tracking their
475   movements along the whole production process. At the beginning of daily production, the
476   traceability software links information about the TU "dairy milk lot" to the cheese

477 processing parameters. The TU "cheese lot", comprehensive of all the cheese wheels

478 produced during the day, is thus formed. All the cheese wheels of such lot share this initial

479 information. At this point, each single cheese wheel, identified by a unique code number

480 jointly stored in the affixed tag (LF, HF or UHF) and in the dairy factory data base,

481 constitutes a new TU that inherits the "cheese lot" information. The information concerning

482 the specific path followed by each single cheese wheel in the next phases (ripening etc.) will

483 be stored at item level. During tag application, an additional phase can be considered in

484 order to crosscheck the tag code. The HF and LF transponders resulted already readable by a

485 PDA immediately after application on the curd. On the contrary, due to the high water

486 content, UHF technology is not suitable for cheese identification during the earlier cheese

487 making process phases. Unlike traditional food traceability systems, where during some

488 operation on raw or bulk materials the paper identifier must be physically separated from the

489 product, engendering potential traceability errors, the tag assures the reliability of single item

490 tracking. At this stage, traceability can be guaranteed by tracking the single item movements

491 by means of static and dynamic RFID identification stations. To register the transfer into

492 storage, cooling or ripening rooms, handheld devices as well as static RF readers can be

493 envisaged.

494 By handheld device, the use of a portable loop antenna that could be inserted between two

495 adjacent shelves facilitates the reading of the tag both on the face and on the edge of the

496 cheese wheels (see Fig. S3, on the left), while the PDA alone allows only the detection of

497 tags on the edge (Fig. S3, on the right). Single wheel identification could also be performed

498 in the ripening rooms by using devices like the proposed cutting board, but this could be

499 practically carried out only if paired with other operations, as for instance brushing,

500 performed either automatically or manually.

501 The simultaneous and multiple identification of several food items should be very useful in

502 updating the inventory without human intervention. For this purpose, fixed RFID systems

503 could be integrated with equipment used for handling. An LF or HF panel antenna, for

504 instance, could be integrated in the trolley used to transport the cheese by using the same

505 method (loop antenna) proposed for the cutting board, simply by adapting the antenna

506 dimensions to the number, the position and the shape of the collected items.

507   Multiple dynamic identification is usually applied in logistics to simultaneously identify

508   several objects transiting through a gate, whose width ranges between 2 – 2.5 m, allowing

509   the passage, for instance, of a trolley transporting a pallet.

510   For cheese wheels however, considering the coverage of the antennas, the HF and UHF

511   portal width should not exceed 1 m, which is problematic for trolley transit. With an HF gate

512   composed of two antennas, the tags can be identified even through one or two cheese wheels

513   but, in our experience, the speed should be very low (not exceeding $0.2 \div 0.4$ ms^{-1}).

514   Using UHF systems in the food industry implies reading difficulties which can be overcome,

515   for example, with a good position of the items with respect to the receiving antenna. To

516   obtain good readability, the options of applying tags on the cheese wheel edge or on its face,

517   has to be evaluated during the whole process by considering the optimal orientation during

518   handling and transport on trolleys, belts, etc.

519   To reduce rind ruptures and limit the unwanted development of mould under the tag,

520   positioning the transponder between two casein disks was found to be the most suitable

521   solution for single cheese wheel identification. The tags remain well inserted in the cheese

522   rind even after repeated brushing phases. The use of two casein disks limits cheese surface

523   damage during the tag-recovering phase, which can be performed at any time, typically at

524   the end of the supply chain, depending on the customer requests. A first option for cheese

525   tracking is to remove, sanitize and recycle the tag. In this case, at the weighing, cutting and

526   packaging station, the last RFID identification of the cheese wheel occurs before removing

527   the tag and the traceability information is then linked to other types of cheaper identifiers

528   (bar code, label, an additional and cheaper tag, etc.) which will reach the consumer (see Fig.

529   S6 on the right). Another option in food traceability is to leave the transponder on the

530   product till the point of sale. In this case, tag recycling is more difficult and the use of

531   disposable low-cost tags is recommended.

532   In the case of cheese, the tag or the casein disk should be brightly coloured thus helping

533   visual detection in order to remove the tag without risk of swallowing by the consumer.

534   Tag persistence must be preliminarily evaluated in function of the tag application methods:

535   the use of only one casein disk positioned on the tag (see Fig. S1, on the left), which was

536   directly applied on the cheese surface, enhances tag persistence on the external cheese

537   surface but it was observed that this option promotes mould formation on the cheese rind.

538   Conversely, when the tag was included in two casein disks, mould formation on the rind was

539 prevented and, especially in the case of small tags, the visual impact of the small hole left on
540 the rind was minimal (see, for instance, the case of tag *c*, Fig. 8, on the right).
541 Recent literature on RFID systems for cheese traceability reports that, on the contrary, other
542 tag types which are anchored to the cheese by a plastic screw, caused ruptures in the rind
543 which led to mould developing during ripening, altering cheese quality (Papetti *et al.*, 2012).
544

545 **6. Conclusions and future research directions**
546

547 RFID systems can be exploited for single matured cheese wheels electronic identification,
548 reducing the traceability unit size and lowering the granularity of the tracing system. In
549 particular, identification reliability by an RFID transponder was assessed for a pressed and
550 long-ripened PDO cheese. Tags resulted apt to resist to the environmental conditions and to
551 the operations typically performed in ripening rooms. Product quality wasn't affected by tag
552 insertion. Cheese presence strongly influences the reading zone, especially at higher
553 frequencies (UHF band) and in the first processing phases when cheese water content is
554 high.
555 For this reason, before introducing an RFID system for tracking cheese, an accurate
556 evaluation of the technical solutions should be compared in terms of frequency band and
557 tag/antenna coupling to track the cheese in different situations: for this purpose, the
558 operations which must be tracked, structural limits, environmental conditions and cheese
559 composition, which continuously evolves during the process, must be considered.
560 The systems which proved more suitable for identification of the single TU through all the
561 considered phases in the tracking path were those operating in the HF band, which can be
562 used by handheld or mobile devices and in fixed stations, where antennas are easily adapted
563 to structures and procedures performed at each tracking point. However, with the HF
564 systems employed in this paper, dynamic and/or multiple identification can be performed
565 only by modifying the methods used in routine cheese processing operations such as, for
566 example, cheese wheel positioning, trolleys speed and gates width. Physical and
567 microbiological damage to the cheese rind proved minimal for the smaller HF tag if
568 compared with other tags.
569 When adopting LF technology, in order to obtain equal reading distances, the transponder
570 size should be increased by widening the shape of the hole after transponder removal, which

571 could lead to a major risk of mould formation on the cheese rind and visual alterations which
572 might not be appreciated by the consumer. LF systems did not prove suitable with dynamic
573 and multiple cheese wheels tracking in the considered production process.

574 UHF systems are not suitable for cheese wheels identification during the cheese production
575 process as the signal can be transferred from tag to reader only during ripening, warehousing
576 and distribution. This implies that the choice of a UHF system should especially regard cases
577 where the tag is delivered to the point of sale, attached to the cheese wheel.

578 The integration of a UHF identification system in dairy factories implies a very careful
579 selection of both reader and tag type as well as the assessment of good practice methods for
580 reliable reading rates. The study allowed to conclude that the successful integration of an
581 RFID system in a food production process depends on multiple factors related not only to the
582 RFID devices features, but also to the production process layout.

583 The costs/benefits ratio in the implementation of an RFID system is difficult to estimate.
584 While fixed and variable costs are normally available, the challenge is to quantify benefits
585 that are more or less hidden in the production process and along the whole supply chain. For
586 instance, advantages due to labour reduction, automation, transparency in inventory
587 locations, lower risk of inventory shortage, the risk to overpass the ripening period thereby
588 altering quality, easier supply chain management, improved logistics organisation and
589 availability of real time synchronized data are hidden in the process and difficult to quantify
590 (Kumar *et al.,* 2011).

591 Considering the two options envisaged in the proposed RFID system for single cheese wheel
592 traceability involving tag recycling or cheese tracking till the point of sale, preliminary cost
593 analysis should be performed by considering LF, HF or UHF systems. Variable costs can be
594 contained by recycling transponders using covering materials that can be sanitized and
595 reattached to another cheese wheel.

596 In this case, the information is linked to the whole cheese wheel or to the packed cuttings by
597 a cheaper identifier such as an optical code or an RFID at a lower cost (UHF).

598 In perspective, future research should be carried both to further improve the system
599 performance and reliability for ripened cheese wheels as well as to extend the RFID
600 technologies implementation to other cheese types.

601 The improvement of UHF tags and the design of inlays that minimize RF transmission
602 inefficiency due to the contact with the cheese could enhance the overall system
603 performance at lower costs.
604 Finally, a well-assessed costs/benefits analysis should be performed for the introduction of
605 RFID in cheese traceability at item level and lot level by verifying the potential added value
606 to the supply chain.
607

608 **7. Acknowledgements**
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613 **References**
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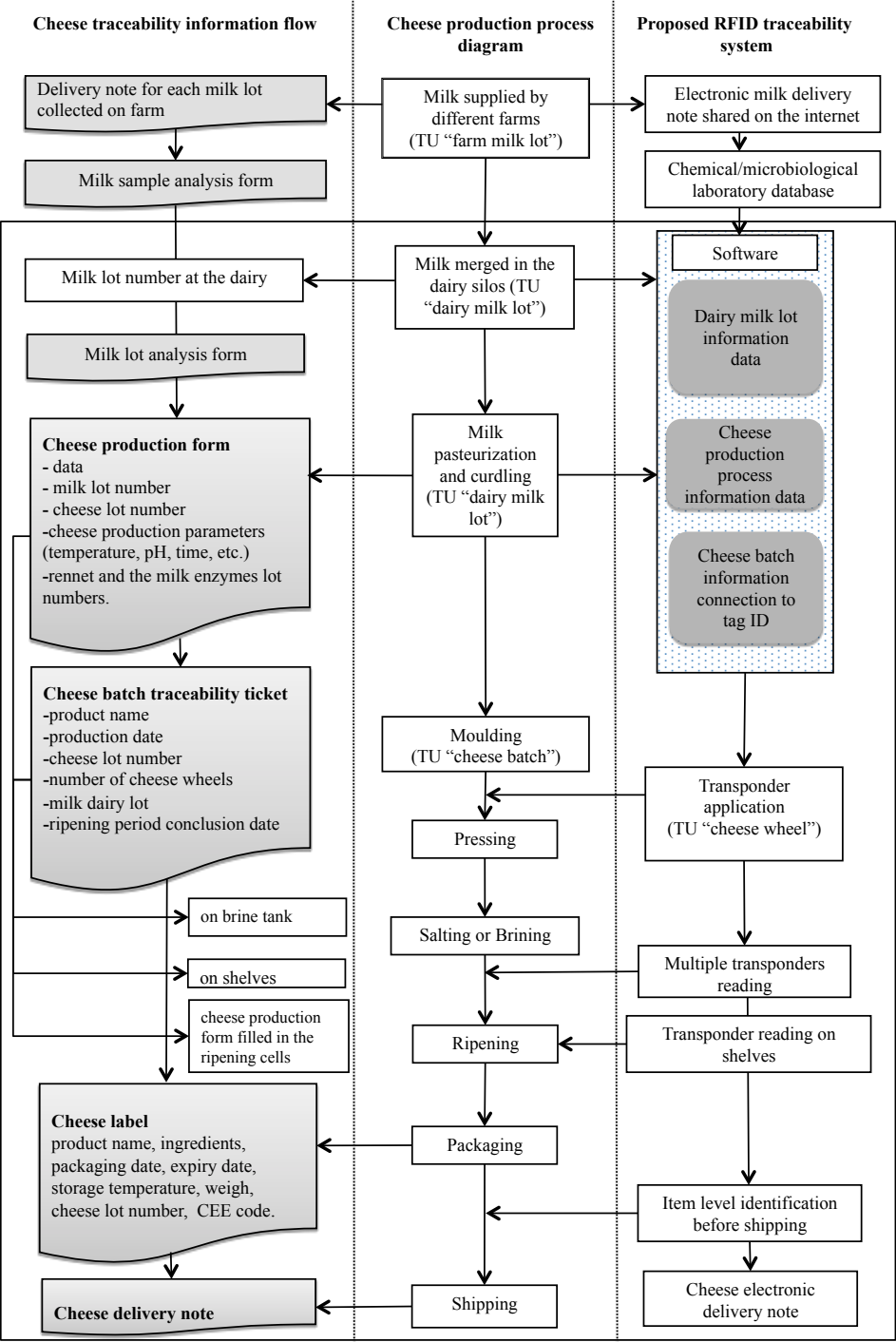773
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Notation

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λ	Wavelength [m]
DAT	Dynamic Antenna Tuner
D_{max}	Maximum reading distance [m]
$Dr\%$	Tag detection rate defined as the ratio of number of successful identifications on the total number of tests (100 repetitions per trial).
EPC	Electronic Product Code
GLM	Generalized Linear Model
HF	High Frequency
ID	Identification number of tag (ISO18000-6C compliant)
ISO	International Organization for Standardization
L_b	Distance from the centre to pole of the HF cutting board reading area with tag in parallel configuration [m]
LF	Low Frequency
PA6	Polyamide 6 (*Nylon*)
PDA	Personal Digital Assistant
PDO	Protected Designation of Origin
PET	Polyethylene terephthalate
P_{min}	Minimum TPO requested to activate and read the ID tag [W].
R_a	Equatorial radius of the HF cutting board reading area with tag in parallel configuration [m]
R_c	Distance between the HF cutting board centre and the external limit of the torus reading area [m]
R_d	Major radius of the HF cutting board reading area (m) with tag in perpendicular configuration
R_e	Minor radius of the HF cutting board reading area with tag in perpendicular configuration [m]
RFID	Radio-Frequency IDentification
TPO	Transmitter Power Output [W]
TU	Traceability Unit
UHF	Ultra High Frequency
UNIANOVA	In statistics, one-way analysis of variance

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Figures

Cheese traceability information flow

Cheese production process diagram

Proposed RFID traceability system

Cheese traceability information flow	Cheese production process diagram	Proposed RFID traceability system

Delivery note for each milk lot collected on farm

Milk supplied by different farms (TU "farm milk lot")

Electronic milk delivery note shared on the internet

Milk sample analysis form

Chemical/microbiological laboratory database

Milk lot number at the dairy

Milk merged in the dairy silos (TU "dairy milk lot")

Software

Dairy milk lot information data

Milk lot analysis form

Cheese production form
- data
- milk lot number
- cheese lot number
-cheese production parameters (temperature, pH, time, etc.)
-rennet and the milk enzymes lot numbers.

Milk pasteurization and curdling (TU "dairy milk lot")

Cheese production process information data

Cheese batch information connection to tag ID

Cheese batch traceability ticket
-product name
-production date
-cheese lot number
-number of cheese wheels
-milk dairy lot
-ripening period conclusion date

Moulding (TU "cheese batch")

Transponder application (TU "cheese wheel")

on brine tank

Pressing

on shelves

Salting or Brining

Multiple transponders reading

cheese production form filled in the ripening cells

Ripening

Transponder reading on shelves

Cheese label
product name, ingredients, packaging date, expiry date, storage temperature, weigh, cheese lot number, CEE code.

Packaging

Item level identification before shipping

Cheese delivery note

Shipping

Cheese electronic delivery note
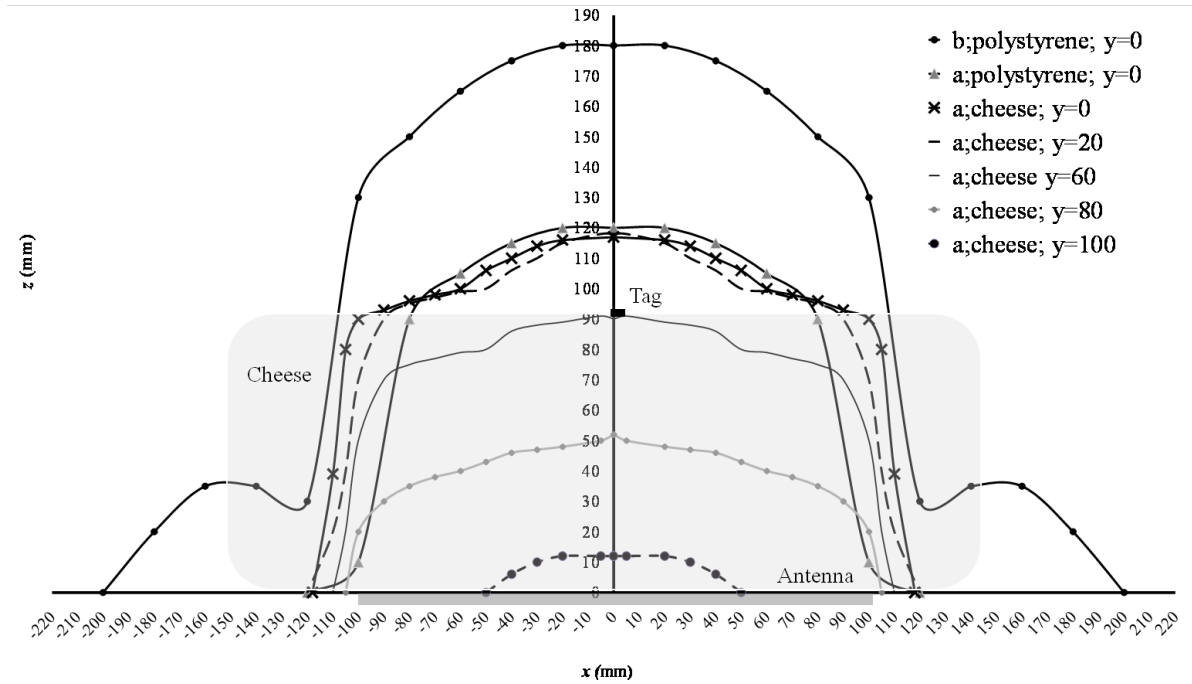
796

Fig. 1. The current production flow chart at the dairy (in the middle), the traceability information flow (on the left) and the proposed RFID traceability system (on the right).
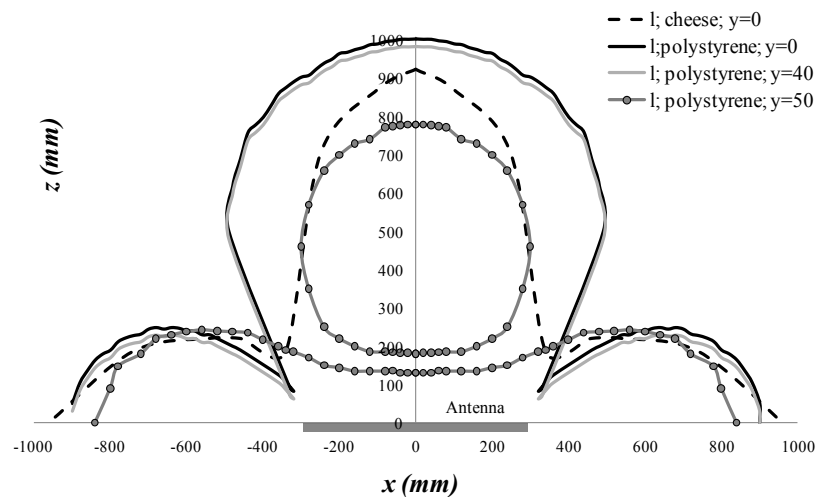
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802 *Fig. 2. Reading zone xz cross-sections of the LF (125 kHz) panel antenna for tag 'a' (INTAG*
803 *200) and 'b' (INTAG 300). Tags were applied on cheese surface in parallel orientation. To*
804 *evaluate the effect of cheese, the reading volume cross-sections with tags applied on the*
805 *polystyrene support are also reported.*

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808

809   *Fig. 3. Reading volume xz cross-sections of HF Obid-i-Scan antenna using tag 'l' applied on*

810   *cheese surface in parallel orientation with respect to the antenna plane. Results with tag on*

811   *polystyrene support are also reported as reference.*

812

813   Reading volume section in tag-antenna parallel configuration

       Reading volume section in tag-antenna parallel configuration
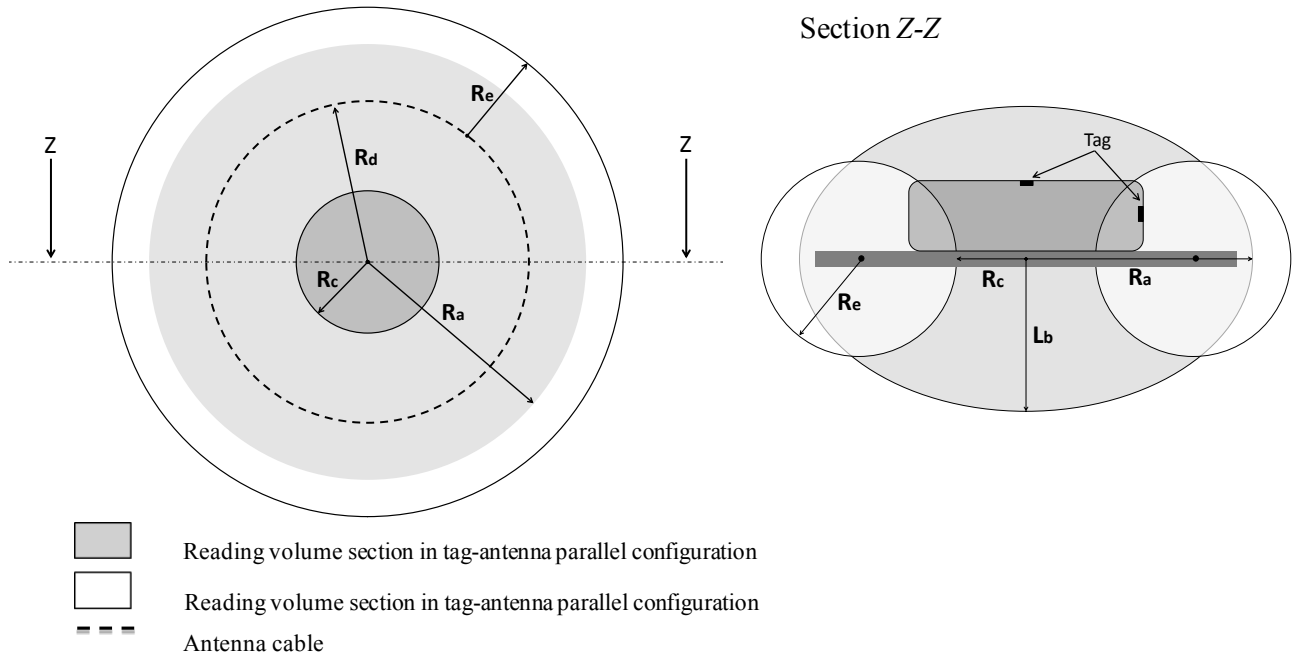
       Antenna cable

814

815   *Fig. 4. Cutting board for HF identification of cheese wheels. Reading volume section*

816   *determined with tag 'c' applied on the cheese face (in parallel orientation) or on the cheese*

817   *outer edge (in perpendicular orientation) are reported.*
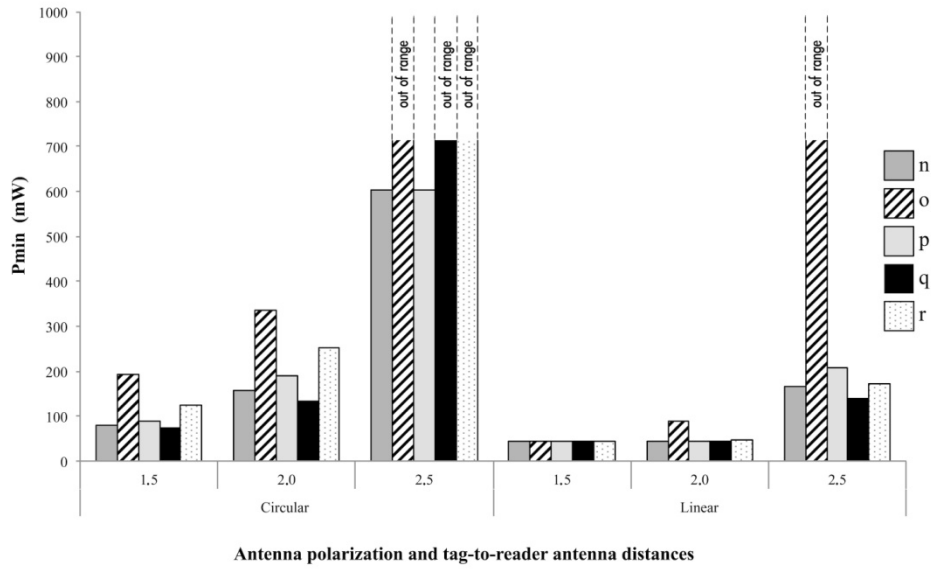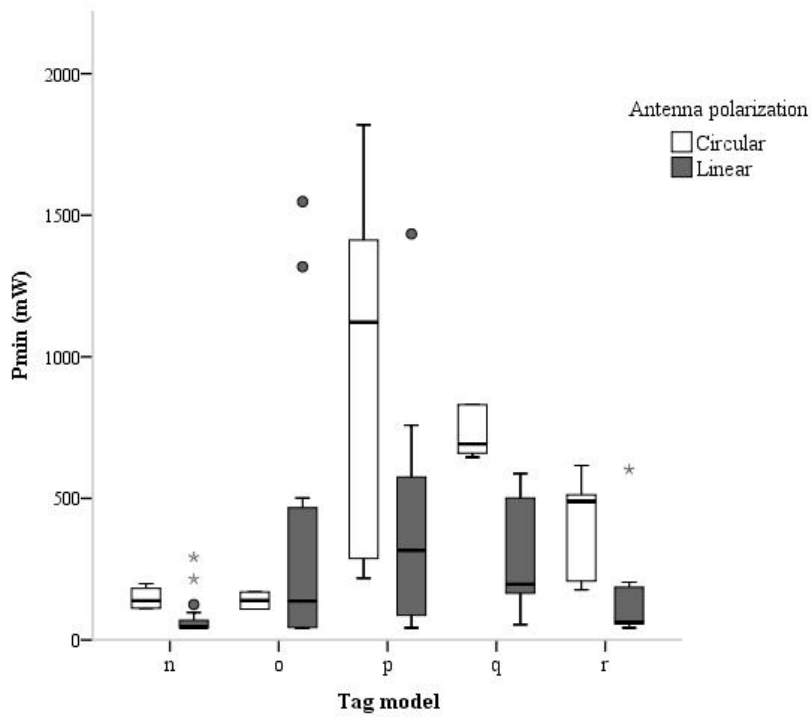
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821 *Fig. 5. Minimum power (P_{min}) required for tag activation at different tag-to-reader antenna*

822 *distances (m) with linear and circular polarized antennas. Tags were applied on a*

823 *polystyrene support.*

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825

826   *Fig. 6. Box plot of distribution of P_{min} values for antenna polarization and tag type factors,*

827   *when tags were applied on cheese surface. Tag-to-reader antenna distance was set to 0.5 m.*

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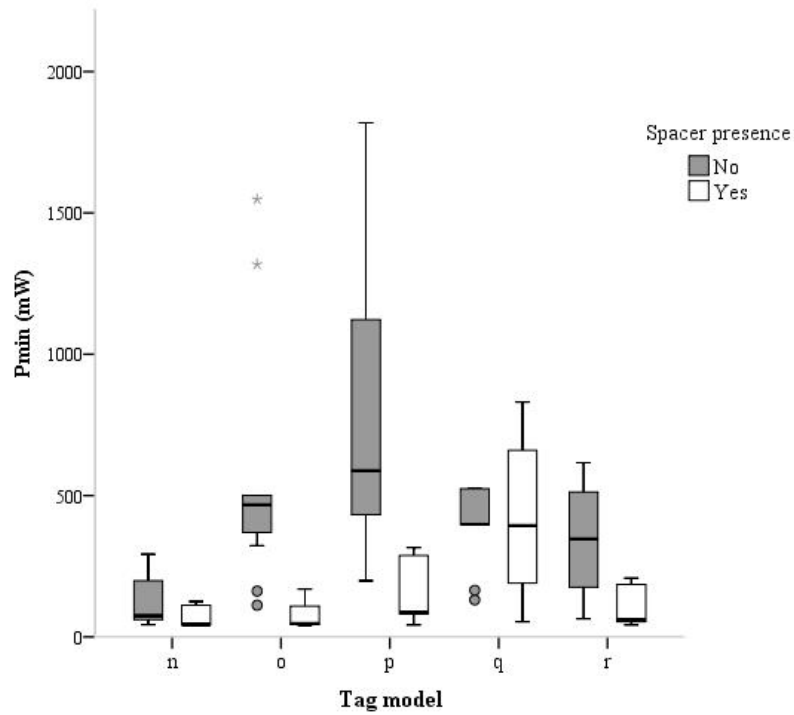
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831   *Fig. 7. Box plot of distribution of P_{min} values for "spacer presence" and "tag type" factors,*

832   *when tags were applied on cheese face. Tag-to-reader antenna distance was set to 0.5 m.*

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| Before brushing | After brushing | Tag removal |

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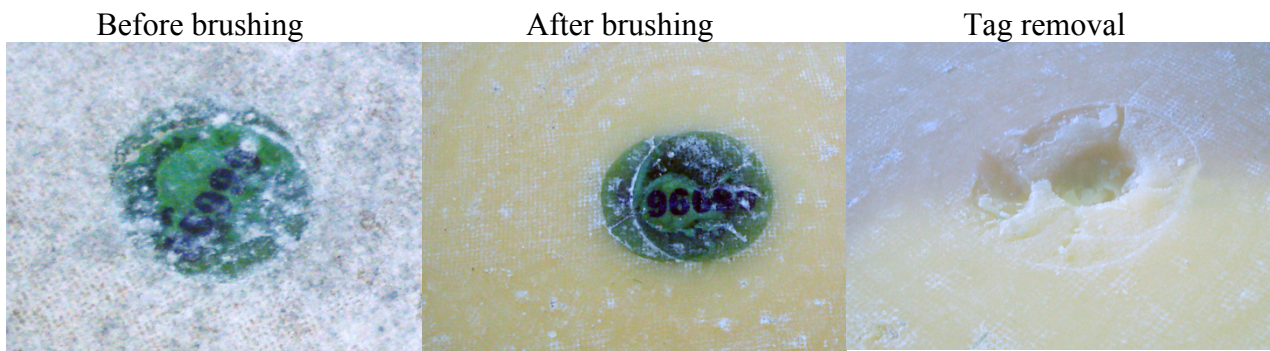
Fig. 8. Cheese wheel and transponder aspect before and after the brushing phase (on the left and at the centre, respectively) and the tag removal (on the right).

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Tables

856 *Table 1. RFID transponders used in cheese factory and in laboratory trials. For each tag*

857 *operating frequency, tag type, producer, model, shape, coil size, tag thickness, material and*

858 *chip type are reported.*

859

Operating frequency	Tag type	Producer	Model	Shape	Coil size (mm)	Tag thickness (mm)	Covering Material	Chip type
LF 125 kHz	a	Sokymat	INTAG 200	Circular	Ø = 20.0	2.5	PA6 Modified	Unique
	b	Sokymat	INTAG 300	Annulus	Ø = 30.0	2.5	PA6 Modified	Hitag S
HF 13.56 MHz	c	Sokymat	Logi Tag 161	Circular	Ø = 16	2.9	Modified thermoplastic	Philips I-Code SLI
	d	UPM Raflatac's	MiniTrack	Rectangular	14 x 31	0.15	Adhesive paper card	Philips I-Code SLI
	e	-	-	Circular	Ø = 32	0.1	Modified thermoplastic	-
	f	LAB ID	K.M9. 2.5 A	Rectangular	19 x 38	0.15	PET	Philips I-Code SLI
	g	-	-	Circular	Ø = 24	0.65	Modified thermoplastic	-
	h	-	-	Annulus	Ø = 88	0.3	Modified thermoplastic	-
	i	LAB ID	K.M. 1.5 BV3	Rectangular	24 x 59	0.3	PET	Philips I-Code SLI
	l	LAB ID	IN523	Rectangular	45 x 76	0.65	PET	Philips I-Code SL2 ICS20
	m	GAO RFID	Paper label 113002	Square	43 x 43	0.25	Adhesive paper card	Philips I-Code SLI
UHF 865 MHz	n	LAB ID	UH100	Rectangular	94 x 7.8	0.15	PET	Impinj Monza 4U
	o	LAB ID	UH3D40	Square	40 x 40	0.1	PET	Impinj Monza 4QT
	p	LAB ID	UH331	Rectangular	95 x 7.2	0.15	PET	Impinj Monza 5
	q	ALIEN	9634	Rectangular	46 x 44	0.25	PET	Alien Higgs-3
	r	ALIEN	9662	Rectangular	70 x 17	0.25	Adhesive label	Alien Higgs-3
	x	UPM Raflatac	DogBone	Rectangular	93 x 23	0.10	Adhesive paper card	Impinj Monza 3

v	UPM Raflatac	Short Dipole	Rectangular	92 x 11	0.15	Adhesive paper card	NXP U-Code
z	UPM Raflatac	Frog	Square	68 x 68	0.15	Adhesive paper card	Impinj Monza 3

860 *Table 2. Tag-to-PDA maximum reading distances (mm) with tag applied on cheese surface*

861 *after 60 days ripening. In this table are summarized the results at LF (125 kHz), HF (13.56*

862 *MHz) and UHF (865 MHz) frequencies.*

863

Operating frequency	*Tag type*	*Maximum reading distance (mm)*
LF	a	In contact
	b	70
HF	d	70
	f	50
	i	70
	l	130
UHF	x	40
	v	In contact
	z	130

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865

866 *Table 3. Maximum reading distance, D_{max} (mm), between HF tag models and the OBID I-*
867 *scan Long Range antenna. Each tag was attached on the cheese wheel in different*
868 *orientations.*
869 *The influence of cheese presence is shown by the rate (%) of D_{max} with tag applied to the*
870 *cheese surface and the D_{max} with tag applied on the polystyrene support.*
871

Tag type	D_{max} on polystyrene (mm)	D_{max} on cheese/D_{max} on polystyrene (%)			
		Tag on the face		Tag on the edge	
		frontal	+180°	frontal	+180°
c	330	100%	100%	100%	100%
d	365	86%	79%	29%	*not readable*
f	510	93%	83%	80%	80%
i	775	92%	92%	39%	39%
l	1005	92%	92%	59%	59%
m	650	91%	91%	64%	54%

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888 *Table 4. Tag detection rate (Dr %) determined for six HF tag models by the HF cutting*

889 *board. Tag was in parallel (tag on cheese face) and in perpendicular configuration (tag on*

890 *the cheese wheel outer edge) with respect to the antenna plane. In case of parallel*

891 *configuration, test was conducted with tag in contact with the cutting board or attached on*

892 *the opposite cheese face to the board. On the contrary, in case of perpendicular*

893 *configuration, cheese wheel was placed randomly on the cutting board surface.*

894

Tag type	DR %		
	Tag on the face		*Tag on the edge*
	in contact	opposite side	random, perpendicular
c	100	100	78
e	100	100	0
f	100	100	89
g	100	100	93
i	100	100	100
l	100	100	-

895

896 *Table 5. P_{min} mean values (mW) determined for the different transponder models applied on*

897 *cheese. All the factors effects considered in the statistical model were included in the mean*

898 *calculation. The letters (a-d) indicate the homogeneous sub-sets for Tukey test at P <0.05.*

899 *Tag-to-reader antenna distance was set to 0.5 m.*

900

Tag type	Mean P_{min} (mW)	Tukey subset	Number of readings	SD	Minimum P_{min} value (mW)	Maximum P_{min} value (mW)
n	90.79	a	30	53.31	40	199
o	217.41	b	22	187.34	43	501
r	242.61	b	33	193.90	48	616
q	457.33	c	24	235.81	158	831

	p	600.69	d	47	492.43	81	1819
	Total	350.78		156	363.40	40	1819

901

902 *Table 6. Statistical analysis of the effect of factors and their interactions on the mean tag*
903 *P_{min} (mW) determined with tag applied on cheese surface at 0.5 m tag-to-reader antenna*
904 *distance.*

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Factor	DF	F-ratio	P-value
Tag type	4	109.88	0.000
Antenna polarization	1	287.48	0.000
Ripening duration	1	0.38	0.845
Spacer	1	322.79	0.000
Tag type * Antenna polarization	4	31.57	0.000
Tag type *Ripening period	4	6.24	0.000
Tag type* Spacer	4	47.57	0.000

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