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1 **Food Provenance: Assuring product integrity and identity**

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5 **Abstract (250 words unstructured)**

6 Food supply chains are highly complex and involve numerous actors who influence food safety
7 and the integrity of products and processes, both at individual points in the supply chain and
8 more holistically throughout the chain as a whole. Provenance can relate to a particular source
9 or origin of a food and its individual ingredients and/or relate to claims on how the product is
10 produced and what marketing claims have been attached to the product. The aim of this review
11 is to consider the recent advances in developing transparent data systems to demonstrate food
12 provenance. One technological development is the use of Blockchain, a data handling structure
13 which provides a secure network of information that cannot be changed or destroyed,
14 distributed between supply chain actors. Other developments in information systems that can
15 be used to monitor a range of criteria include geographic information systems (GIS) which can
16 be linked with, for example, stable isotope analysis to provide an indication of provenance for
17 a given product or ingredient. This technology is used as a case study in this paper to
18 demonstrate the opportunities and limitations to such technological approaches. The review
19 reflects on aspects of provenance and the actions that can be taken at organisational and supply
20 chain level to demonstrate transparency so that consumers can have trust in those procuring,
21 processing and supplying food.

22 **Key words 3-7 keywords**

23 Food Provenance; Product integrity and identity; Private Standards; Blockchain; Geographic
24 information systems; Consumers and food provenance.

25 **Review methodology**

26 We searched the following databases: CAB Abstracts, Science Direct, Google Scholar, Google
27 (to include grey literature) to primarily consider current information on provenance, product
28 integrity and identity. The key search terms were provenance AND food AND integrity AND
29 product integrity AND product identity AND traceability AND geographic indication AND
30 packaging cues AND transparency AND trust AND blockchain. The terms were used in a range
31 of combinations of the search terms i.e. through an iterative literature review method. Iterative
32 literature review is grounded by a foundational literature search using a series of iterative
33 searches. In undertaking the searches for a given combination of search terms the first 100
34 items in each search are considered for relevancy and any duplication. All relevant papers were
35 then collected and the titles and abstracts read. The papers were then read in full (n=76) and
36 screened for relevance and value in supporting a discursive narrative and argument. Forty-
37 seven papers were used to support the narrative in the paper

38 **1. Introduction**

39 In the European Union (EU), Regulation No. 1169/2011 on the provision of food
40 information to consumers identifies the origin of a food as being either its country of origin or
41 its 'place of provenance'. Provenance encompasses the geographical origin of a product or its
42 ingredients, aspects of the farm production system, and demonstrable transparency with regard
43 to the product's journey from the farm to the consumer's table (Monahan et al. 2018).
44 Therefore, food provenance "relates to not only the geographic elements of where the
45 ingredients and the final food are grown, processed and finally manufactured, but also how that
46 food is produced and whether the methods of production and processes employed comply with
47 certain standards and protocols." (Manning, 2018: p121). Consumers' interest in food
48 provenance is influenced by patriotism, regional factors that affect culinary or organoleptic

49 qualities; interests in local, ethical and sustainable foods; or a decreased confidence in the
50 quality and safety of products produced outside a specific region or where the provenance of
51 the product is unknown (Camin et al. 2017; Soon and Wallace, 2017). Consumers too often
52 draw inference from provenance claims on packaging or associated marketing information such
53 as the use of sustainability labels on food (Grunert et al. 2014). Tangible (constructivist)
54 packaging cues e.g. tamper-evident seals, 3D QR codes, icons/badges, or anti-counterfeiting
55 holograms provide additional reassurance for consumers with regard to product integrity
56 (Kendall et al. 2019). However, maintaining integrity through these claims requires food supply
57 chains to manage information openly with transparent systems and protocols. In this context
58 transparency needs to go further than simply the development of systems to assure traceability.

59 The term traceability has also evolved in recent years to also include consideration of
60 food authenticity and integrity (Charlebois and Haratifar, 2015) and this creates confusion
61 when considered in the context of provenance. Traceability protocols which are linked to
62 logistics management and product specifications were initially developed as part of a quality
63 management system (Mol, 2014) so that customers could be assured of the inputs and outputs
64 in any given process or activity. Traceability processes from source (one attribute of
65 provenance) to final shelf provides security that in the event of a product recall a particular
66 batch of material or finished product can be identified, isolated and controlled (e.g. removed
67 from shelf or recalled, destroyed or reworked) and in so doing minimise food safety and quality
68 risk to consumers (Leat et al. 1988).

69 Many early, and current, approaches to assure provenance in food supply chains have
70 been based on quality management systems, including development of specifications, quality
71 assurance standards, supplier audit and 3rd party certification schemes (Wallace et al. 2018).
72 The need to assure food safety “up and down” the supply chain was a major driver towards 3rd
73 party certification, but the need to consider the potential for food fraud has extended

74 provenance requirements such that additional criteria and guidance have been included on
75 product authenticity and tighter supplier procurement controls in the associated market
76 standards (e.g. BRCGS, 2018; ISO, 2018). Business motivation for gaining 3rd party
77 certification has largely been seen as gaining market access whilst demonstrating control of
78 product safety (Manning et al, 2019); however, using factor analysis, Rincon-Ballesteros, et al.
79 (2019) identified that ethical and legitimacy considerations are two of the four groups of
80 motivating factors involved in Latin American food business decisions to achieve certification
81 to the BRC standard (BRCGS, 2018), demonstrating that the wish to demonstrate ethical supply
82 chains that meet governance and food safety requirements is crucial to business strategy.

83 Transparency within food supply chains enables informed action by all stakeholders
84 from primary producer through each stage until the final consumer. Transparent information
85 about how food is produced and details about the innate characteristics of food products is
86 essential. Information systems encompass data capture, storage, analysis and retrieval and,
87 from the point of view of food safety management will enable timely decision-making and
88 actioning of preventive or corrective action (McMeekin et al. 2006). Information systems can
89 combine information from databases, sensors and smart identification tools. This drawing
90 together of data from more than one source to give one result has also been termed *data fusion*
91 (Callao & Ruisánchez, 2018).

92 According to Zhao et al. (2019), almost all the systems applied to the agri-food value
93 chain are centralised, monopolistic, asymmetric and opaque, and this may result in serious trust
94 problems between supply chain actors and between the supply chain and consumers. Certainly,
95 food supply chains are highly complex and involve numerous actors (Figure 1). Multiple steps
96 and feedback loops may occur between animal and/or crop production stages and when the
97 finished food product reaches consumers via food-service, retail store or other distribution

98 channels. Thus, whilst trust is essential between all supply chain actors to assure integrity and
99 identity, the complexity and scale of food supply chains makes this difficult.

100 **Take in Figure 1**

101 The aim of this review is to consider the recent advances in developing transparent data
102 systems to demonstrate food provenance. One technological development of contemporary
103 interest is the use of Blockchain, a data handling structure which provides a secure network of
104 information that cannot be changed or destroyed, distributed between supply chain actors.
105 Other developments in information systems that can be used to monitor a range of criteria
106 include geographic information systems (GIS) which can be linked with, for example, stable
107 isotope analysis to provide an indication of provenance for a given product or ingredient. Thus
108 this technology is used as a case study in this paper to demonstrate the opportunities and
109 limitations to such approaches to offer potential for assurance of provenance and trust
110 throughout food supply chains. The remaining sections of this review will focus on provenance
111 in the food supply chain from three perspectives: consumers and provenance, management
112 systems and assurance, and finally the potential role for new technology in enabling trust.

113 **2. Consumers and Provenance**

114 Soon and Wallace (2018) investigated the role of provenance and ethical standards on
115 consumers' food choices and purchasing intentions and found that consumers recognised a
116 good selection of provenance and ethical standards and perceived animal welfare as the most
117 important aspect in ethical food products. Consumers also reported that they supported their
118 local economies and sustainable purchasing of food products but were undecided about
119 reducing food miles (Soon and Wallace, 2018). However conversion of recognition to
120 consumer purchasing behaviour is limited and mediated by a number of demographic and
121 cultural factors (Rees et al. 2019). Other studies have looked at consumer attitudes to

122 genetically modified foods (Prati et al. 2012; Frewer et al. 2013; McFadden and Smith, 2019),
123 food fraud (e.g. Kendall et al. 2019), local and sustainable foods (Ikerd, 2011; Birch et al. 2018)
124 and alternative food networks that challenge the role and power of large retailers (Watts et al.
125 2018). In a systematic review on public perception of agri-food applications of genetic
126 modification, including meta-analysis of 70 articles, Frewer et al. (2013) investigated the
127 constructs of concern about ethical issues, trust, risk and benefit perception, attitude as well as
128 intention and acceptance. The study found that, whilst the majority of studies focused on
129 Europe or North America, there were differences between these two regions, illustrated by
130 European consumers generally having more negative perceptions, attitudes and intentions to
131 purchase GM foods compared to North American consumers, possibly due to factors such as
132 increased availability of GM foods in the USA, and more negative press coverage and lower
133 citizen trust of regulators in Europe (Frewer et al. 2013). Birch et al. (2018) discuss the balance
134 of egoistic and altruistic motivations to purchase local food in ‘mindful consumers’ and
135 conclude that egoistic motivations, i.e. issues of self-interest such as health consciousness and
136 food safety, may influence local food consumption decisions more strongly than altruistic
137 motivations relating to wider social concerns such as environmental issues. It is clear therefore,
138 that provenance is a significant factor for food choice for some consumers and this creates
139 challenges for the food supply chain to go beyond simply achieving “one step forward and one
140 step back” traceability to demonstrating both proof of origin and proof of extrinsic methods of
141 production for certain products and ingredients. This relies on effective quality
142 management/assurance systems, certification schemes and, increasingly, on the use of
143 technology to support provenance claims.

144 **3. Management Systems and Provenance**

145 Supplier quality assurance programmes, generally including the use of multiple forms of
146 documentation assessment, validation, monitoring and verification activities to not only assure

147 food safety and product related quality attributes but increasingly assuring process criteria too.
148 The use of specifications, certificates of conformance and supplier audits, has been the
149 cornerstone of management approaches to provenance assurance in food supply chains.
150 Supplier audits have traditionally been performed routinely by customers or their agents;
151 however, the approach is resource-intensive and, therefore, not practical as a routine
152 verification activity for most companies and so risk-based assurance strategies have been
153 developed (Wallace et al. 2018). Risk evaluation criteria often include history of food safety
154 issues within the product category and consideration of whether the supplier is already working
155 with other companies who are anticipated to have similar requirements, e.g. multinationals, as
156 well as consideration of risks, e.g. hygiene standards, in the local supply context (Wallace et
157 al. 2018). Private food standards developed by various consortia of stakeholders have emerged
158 in the last few decades (Manning et al. 2019) and this has led to a growth in third party
159 certification. The focus of these standards is often food safety and quality assurance and the
160 difficulties of businesses needing to comply with many slightly different requirements in these
161 private standards has led to moves to standardise food safety requirements through the Global
162 Food Safety Initiative (GFSI) benchmarking scheme (www.mygfsi.com). Requirements of
163 private standards include aspects of food provenance such as traceability and prevention of
164 food fraud (e.g. BRCGS, 2018) and thus offer possible solutions for demonstrating provenance,
165 product identity and food integrity. However, challenges with audit-based verification systems
166 such as audit and auditor fatigue and the rigid use of checklists can lead to ‘evaluation myopia’
167 (Manning et al. 2019) leading to the inability of the auditor to identify the impacts and effects
168 of such approaches outside the strict line of questioning from a given systems checklist
169 (Manning et al. 2019). These limitations mean that, whilst still a major element of assuring
170 provenance, verification of management systems via third party audits is not a complete
171 solution and needs to be used in tandem with other approaches. The use of triangulation i.e.

172 determining veracity by comparison of data from different sources of evidence counterbalances
173 the strengths and weaknesses of different verification methodologies and approaches and in
174 doing so increases the credibility and depth of provenance verification processes (Yeasmin and
175 Rahman, 2012; Carugi, 2016; Jespersen and Wallace, 2017; Manning, 2018; De Boeck et al.
176 2019; Manning et al. 2019). One case study example that demonstrates this ability to triangulate
177 is considering provenance in terms of geographic origin.

178 A geographic information system (GIS) is a system developed to store, index and
179 archive data, and allow its retrieval, and manipulation based on the geographic coordinates of
180 its elements. GIS based approaches can be used to determine geographic origin when
181 combined with stable isotope analysis to provide a food isotope map or isoscape. Stable
182 isotopes of elements such as carbon (C), hydrogen (H), nitrogen (N), oxygen (O) or Strontium
183 (Sr) vary in their concentration in different land substrates, and so an understanding of their
184 geographic and spatial location can allow an isoscape to be developed (Bowen et al. 2009) that
185 links the isotopes in a given food to a location (Kelly et al. 2011). GIS driven isotope maps and
186 isotope footprints have been developed for beer, cereal crops, cheese, fruit juices, tea, coffee,
187 must, olive oil, peppers, soft fruit, tiger prawns, tomato based products, vinegar, wine and
188 asparagus (West et al. 2007; Flores et al. 2013; Carter et al. 2015; Stevenson et al. 2015; Bong
189 et al. 2016; Chiocchini et al. 2016; Camin et al. 2017; Fragni et al. 2018; Perini et al. 2018;
190 Eftimov et al. 2019; Gopi et al. 2019a, 2019b; Richter et al. 2019) so that provenance and thus
191 authenticity can be clearly demonstrated through isotope analysis testing and then comparison
192 of the results with pre-defined isotope maps (Danezis et al. 2016). In terms of extrinsic
193 attributes isotope analysis can distinguish between farmed and caught from the wild fish
194 products (Gopi et al. 2019a); and whether artificial nitrogen fertiliser has been used or organic
195 fertiliser (Inácio et al. 2015; Stevenson et al. 2015; Perini et al. 2018; Manning & Monaghan,
196 2019). This would seem to offer an effective solution to verify provenance claims, at least for

197 these product groups. Other studies have proposed the use of X-ray fluorescence (XRF)
198 through Itrax to examine elemental profiles (Gopi et al. 2019a; 2019b) and also the use of
199 inductively coupled plasma mass spectrometry (ICP-MS) to develop distinct fingerprints by
200 geographic location for blue mussels (Bennion et al. 2019) and ground water (Voerkelius et al.
201 2010).

202 However to be effective, isotope analysis must be based on an authentic set of samples
203 with irrefutable origin (Kelly et al. 2005; Eftimov et al. 2019). Camin et al. (2017) state that
204 whilst some stable isotope ratio standard methods have been accepted for over 20 years, there
205 is an argument that laboratories should be accredited to ISO17025 so that there can be
206 confidence in the validity and repeatability of the results via proficiency testing approaches.
207 As databanks are created for isotope ratio methods then there needs to be demonstrable
208 assurance as to the representativeness of the dataset. The fusion of such dataset information
209 with data from other sources to provide a view on the degree of adulteration of a foodstuff is
210 gaining more widespread recognition as a quality control tool and in this context validation
211 protocols and ongoing verification activity is key. (Callao & Ruisánchez, 2018).

212 4. Technology and Provenance

213 Distributed Ledger Technology (DLT), one example of which is Blockchain, can “provide
214 a cryptographically secure and immutable record of transactions and associated metadata
215 (origin, contracts, process steps, environmental variations, microbial records, etc.) linked
216 across whole supply chains” (Pearson et al. 2019, p.145). Galvez et al. (2018) report that
217 Blockchain first appeared in 2008 as a technology to provide transactional ledger functionality
218 for Bitcoin. The technology was designed to overcome issues of trust that arise in trading
219 networks when transactions rely on one ‘trusted intermediary’ (e.g. a bank), where giving
220 power and trust to that intermediary is needed to mitigate the potential for fraud. In Blockchain,

221 transactions between network members are recorded in the ‘blocks’ and all members have
222 copies of all the data such that all members agree the information in each transaction and
223 following agreement records cannot be altered (Galvez et al. 2018). Blockchain can afford the
224 ability for “high fidelity tracking and tracing” across supply chains (Pearson et al. 2019). The
225 potential for Blockchain technology to deliver traceability systems and provenance assurance
226 in the food supply chain is considerable (Figure 2). Linking and data sharing/agreement among
227 all the groups of actors in the food supply chain provides not only trust between suppliers and
228 customers forming individual links, but also simultaneously transmitting trustworthy data
229 through the entire supply chain.

230 **Take in Figure 2**

231 Applications of Blockchain in food supply are being examined by researchers across
232 multiple scientific disciplines such as computing science, supply chain and food science
233 perspectives and a variety of Blockchain based platform providers exist. This is a rapidly
234 developing field in terms of research and business perspectives such that many specific food
235 chain applications have been proposed and/or tested in practice. Some reported application
236 models are general such as across agriculture or agri-food supply chains, large enterprises and
237 fresh food (Casado-Vara et al. 2018, Galvez et al. 2018); other applications are more specific
238 (Table 1). Stated objectives in Blockchain trials and applications include traceability and
239 transparency, brand protection, financial and performance improvement (e.g. speed of
240 transactions), animal welfare, waste reduction, environmental impact, having an auditable
241 system, trusted information, (improved) supervision and management and support for small
242 farmers and growers (Kamilaris et al. 2019; Galvez et al. 2018). Various technologies could be
243 used in combination with a Blockchain system including radio-frequency ID (RFID) based
244 systems (Musa et al. 2014; Shin & Eksioglu, 2015) to reduce the risk of fraudulent behaviour
245 (Yan et al. 2020). Several large retail and manufacturing chains have been active in Blockchain

246 developments for the supply chain, notably Walmart, Unilever, Nestle, Cargill, Kroger and
247 Coca Cola (Kamilaris et al. 2019).

248 **Take in Table 1**

249 Theoretically Blockchain offers advantages of assuring trust, transparency and
250 traceability in food supply chains. Specific food provenance issues such as identity and
251 integrity of supply can be verified through a Blockchain network, and the immutability of the
252 data, i.e. any alteration of data by one user is transparent to all users (Pearson et al. 2019), has
253 obvious benefits in the prevention of food fraud as well as supply chain control of specific food
254 safety hazards such as allergens. Linking consumers to supply chain information through
255 scannable elements on food packaging and menus enables trust aspects and provision of
256 necessary information. However, challenges remain in the application of Blockchain
257 technology in the food supply chain to assure provenance, not least because all stakeholders in
258 the chain must hold their data in digital form and then collaborate to adopt and implement the
259 technology for it to work effectively (Galvez et al. 2018) and this will have inherent set-up
260 costs that could be a barrier to market entry for some businesses. Zhao et al. (2019) report six
261 main practical challenges for applying Blockchain technology in the agri-food chain: 1. Storage
262 capacity and scalability issues, relating to the large amounts of information that may need to
263 be stored and size of network (and hence numbers of transactions); 2. Potential for privacy
264 leakage, since all members of the network have copies of all of the data and this could cause
265 problems where some members may be in competition; 3. Regulatory problems, since there
266 are no global regulatory requirements for food chains or for Blockchain technology; 4.
267 Problems of high cost, relating to money and resources such as time and computing power
268 needed to be part of a blockchain network; 5. Throughput and latency issues, such as
269 transaction capacity and limits on numbers of transactions possible per second or time to create
270 blocks and validate transactions; and 6. Lack of skills and knowledge of how Blockchain can

271 be used in the agri-food chain. From a food safety and quality perspective, a further challenge
272 relates to quality of data (Creydt and Fischer, 2019). Although data cannot be changed once it
273 is timestamped and accepted into the Blockchain, the potential for poor quality, and possibly
274 fraudulent, data at the beginning of the chain may still be possible, e.g. if a raw material
275 produced using pesticides was falsely certified and declared as ‘organic’ (Creydt and Fischer,
276 2019). Thus, additional verification methods are still required for assuring data security and
277 measures such as auditing and analytical tests should continue to be used with results then fed
278 into the Blockchain data system by reputable service providers. Nevertheless, Blockchain and
279 other DTL technologies offer potential for developing trust through transparent and traceable
280 supply chains where product and ingredient identity information is securely maintained such
281 that full history of information is accessible to retailers and foodservice businesses and could
282 be passed on to consumers via scanning technology.

283 **5. Conclusion/Summary**

284 Recent advances in developing transparent data systems to demonstrate food provenance
285 have been considered in this review including Blockchain, and the use of GIS and stable isotope
286 analysis to provide provenance mapping and identification methods. Three perspectives have
287 been used: consumers and provenance, management systems and assurance, and the role of
288 technology in enabling trust. Whilst there are limitations in application of these and other
289 technologies they offer the potential for greater transparency in supply chains and the ability
290 to verify provenance claims more effectively. Trust will be a major component of
291 organisational value creation in the future. Assuring product integrity and identity underpins
292 trust building and brand allegiance for consumers and at food supply chain and individual
293 business level demonstrating provenance will be key to developing sustainable and resilient
294 food businesses.

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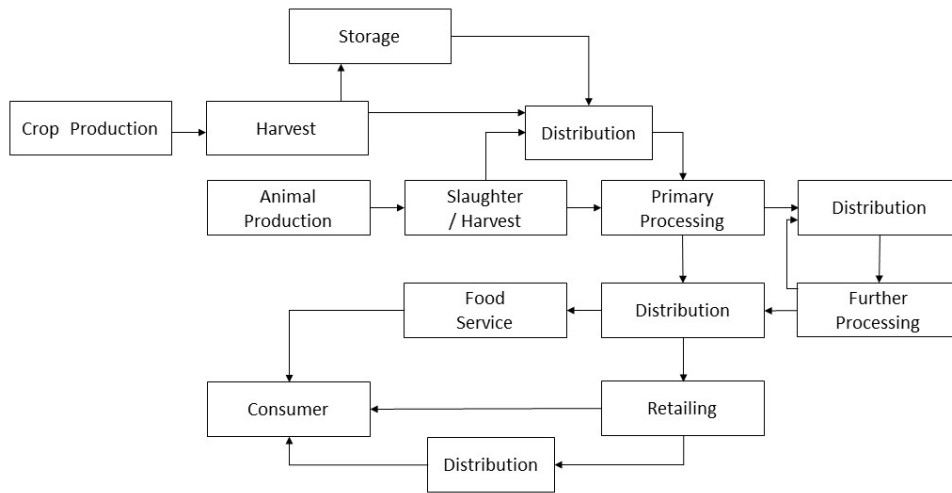
466 **Table 1. Selected food supply chain applications of Blockchain**

Sector	Specific foods	Reference
Agricultural Crops	<ul style="list-style-type: none"> • Soy beans¹ • Grains¹ • Mangoes¹ • Sugar cane¹ • Grapes¹ • Rice¹ • Fruits² 	¹ Kamilaris et al. (2019) ² Galvez et al. (2018) ³ Creydt and Fischer, (2019) *Model of potential application only; All other foods listed were part of actual blockchains
Meat and Fish	<ul style="list-style-type: none"> • Turkeys¹ • Pork^{1,2} • Beef¹ • Chicken¹ • Seafood¹ • Fish² 	
Processed Foods	<ul style="list-style-type: none"> • Canned Pumpkin¹ • Chocolate³ * • Wine² 	

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Figure 1 Simplified Supply Chain Model (Adapted from Wallace, Sperber and Mortimore, 2018)



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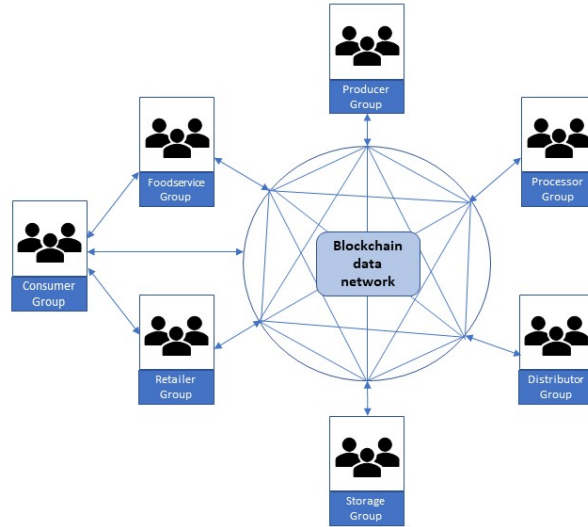
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479 Figure 2 Blockchain Supply Chain Model (Adapted from Casadora-Vara et al, 2018; Galvez et al,
2018)

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