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A Sustainable Blockchain Framework for the Halal Food Supply Chain: Lessons from Malaysia

Abstract

This study proposes a sustainable blockchain framework for the halal food supply chain. As is widely acknowledged, blockchain could enhance supply chain integrity, but its impacts on the halal food supply chain are unknown. Disruptive technologies for Industry 4.0 can improve transparency, which is desperately needed in the food supply chain; however, various challenges are also incurred. Based on five in-depth halal food supply chain case studies, this paper reveals a practical framework for overcoming the challenges faced by the halal food supply chain pertaining to blockchain implementation. The framework comprises five key challenges that are vital to small and medium enterprises in halal food supply chain blockchain implementation. The findings also indicate that the halal food supply chain can gain a congruent and fresh perspective in inducing or superseding blockchain technology. In addition, the roles of supply chain integration and food regulations as the key enablers on the success of blockchain technology in the halal food supply chain are also discussed in this study. Additionally, the limitations and future research directions are also discussed.

Keywords: blockchain technology, halal, food supply chain, SMEs

1.0 Introduction

Blockchain is argued to be the panacea of the current issues in multiple industries and supply chains (Hastig and Sodhi, 2019; Kamble, Gunasekaran and Gawankar, 2020). Previous studies found that a supply chain (SC) benefits from blockchain adoption because it improves the transparency (Kittipanya-ngam and Tan, 2020; Sunny, Undralla and Madhusudanan Pillai, 2020), traceability (Rejeb, 2018; Qian, Dai, *et al.*, 2020; Tan, Gligor and Ngah, 2020), firm performance (Kamble, Gunasekaran and Gawankar, 2020), and business model (Weking *et al.*, 2020). The food industry has observed the great potential of blockchain technology and considers its adoption a top priority (Edmund, 2018). Considering the advantages of blockchain, the food SC and industries have decided to adopt it for multiple aims, such as food safety, transparency, quality, and traceability (Kamilaris, Fonts and Prenafeta-Boldú, 2019; Wong *et al.*, 2020). Zwitter and Boisse-Despiaux (2018) argued that the concept of blockchain as a magic bullet in the SC is misleading. Even though a global and complex food SC intensifies the need for blockchain adoption, implementation and monitoring, Rogerson and Parry (2020) systematically reviewed studies on food SC blockchain and found that studies on the blockchain implementation challenges are scarce.

Disruptive technology has been implemented in the food SC to address the industrial problems, as depicted in Table 1. On this basis, introducing new technologies such as blockchain into the industry is a viable option. Nevertheless, blockchain technology still has unresolved issues and challenges beyond technicality that warrant more exploration and investigation (Kamilaris, Fonts and Prenafeta-Boldú, 2019). The immutable nature of blockchain (Treiblmaier, 2018; Queiroz, Telles and Bonilla, 2019; Köhler and Pizzol, 2020) may enhance SC performance and complicate fraudulent acts in the halal SC, which involve intangible values that are unable to be evaluated physically, such as slaughtering, contamination, and product purity. Halal food represents more than 17% of the total world

47 food production (Tan et al., 2017), and the absence of blockchain studies focusing on this
48 sector leaves a significant gap in the knowledge. Tan et al. (2020) highlighted that empirical
49 studies on the implementation of blockchain technology in the context of the halal food SC
50 are available. Even though some research exists in this discourse, the majority of the literature
51 on the blockchain and halal food SC nexus is theoretical in nature; for instance, regarding the
52 conceptual understanding, applicability, and opportunities, no theoretical framework has
53 been developed from a real case scenario (Tieman *et al.*, 2019; Tan, Gligor and Ngah, 2020).
54 The absence of empirical research connecting the halal food SC and blockchain is also limiting
55 (Duan *et al.*, 2020); therefore, reaping the benefits of blockchain remains difficult and
56 complex for players in the SC and policymakers.

57 The previous literature on conceptual blockchain benefits to the total SC assumed
58 application to a simplified SC. The generalizability of blockchain adoption into the food SC is
59 daunting when the firm/farm size, exporters, and business environment vary. Although
60 Kamilaris et al (2019) claimed that small players in the SC could benefit from investing in
61 blockchain adoption, the majority of the studies on blockchain adoption have scrutinized the
62 context of larger corporations and complete SCs and have generalized the findings to the
63 context of small and medium enterprises (SMEs) (e.g., Hastig and Sodhi, 2019; Kamilaris et
64 al., 2019). Especially for the halal food industry, the myriad of standards, regulations and
65 requirements increase the technicality of blockchain adoption. Thus, a novel extension to the
66 opportunities and challenges encountered by SMEs, the halal food SC and their key enablers
67 is needed to understand the debate on the blockchain adoption and implementation.
68 Specifically, the aims of this study are as follows:

- 69 1. To investigate blockchain opportunities and their potential impacts on the current
70 halal SC business model.
- 71 2. To investigate the halal food SME SC's current practices and the challenges faced in
72 embracing and adopting blockchain.
- 73 3. To propose a halal food SME blockchain challenges framework.

74 The findings of this study contribute to halal and blockchain knowledge by proposing an SME
75 challenge framework. In addition, the key enablers for leveraging blockchain technology in
76 halal food SMEs are provided. The results allow owners, managers, and policymakers to
77 understand and identify the factors and challenges that are involved in successfully deploying
78 blockchain technology in the food SC.

79 This research is presented as follows. Section 2 discusses and identifies the existing
80 theories and gaps in the blockchain knowledge base concerning the halal food SC. The
81 methodology is described in Section 3, including an explanation of the case studies involved
82 in this research. Section 4 proposes a framework for the blockchain challenges faced by the
83 SME halal food SC, followed by research and practice implications. Section 5 concludes with
84 the findings, study limitations, and suggestions for future research opportunities.

85

86 **2.0 Blockchain as Disruptive Technology in SC Management**

87 Industry 4.0 is a new era of ICT where information about real products is linked to web-based
88 applications and integrated into the production process. The technologies that provide better
89 solutions and have the ability to replace the traditional methods in the SC can be regarded as
90 disruptive (Abdel-Basset, Chang and Nabeeh, 2020). Table 1 exemplifies a list of disruptive
91 technologies that are used in addressing the issues in the food SC. The interrelatedness and
92 complexity of the food attributes in the SC (i.e., food traceability, food integrity, food safety,

93 food delivery, food quality, food security, and food recall) exacerbate the development and
94 implementation of a capstone technology that has the potential to address all of the food
95 concepts.

96 Even though a myriad of disruptive technologies has been introduced in the food SC,
97 these technologies aim to address specific food issues and work in a silo and standalone with
98 some spillover effect on the adjacent food attributes. For example, the smart-packaging that
99 can either be used as a tracking device (Shoue Chen *et al.*, 2020) or an anti-counterfeiting
100 mechanism is used as a stand-alone system (Soon and Manning, 2019). In addition, the listed
101 disruptive technology is developed for one way communication; the consumption of the user
102 with limited interaction between actors in the SC. The shortfall of the non-reciprocal
103 relationship and communication limits the interface between the actors in the SC. As food is
104 a fusion-type product, the production cannot be physically modulated once it is being
105 processed. Therefore, a disruptive technology that allows mutual development among the SC
106 stakeholders, as well as the incorporation of other existing technologies is novel. As argued
107 by Kamilaris, Fonts and Prenafeta-Boldú (2019), blockchain technology has the ability to
108 address the incorporation of the existing technologies and opening-up the horizon for more
109 SC collaborations on its platforms.

110 *****TABLE 1 to be inserted somewhere here*****

111 According to Weking et al. (2020), the application of blockchain in the production
112 process to provide better services to customers in the key part of Industry 4.0. Technically,
113 Industry 4.0 refers to the interconnected dynamic global network (Kshetri, 2018; Ben-Daya,
114 Hassini and Bahroun, 2019). In a broader scope, it is used to connect people, goods, and
115 operations through a global network and to increase global competitiveness and provides
116 network connectivity in the SC (Shankar *et al.*, no date; Chandra, Liaqat and Sharma, 2019;
117 Kamilaris). Evidence exists showing that Industry 4.0 has fostered the use of blockchain
118 technology applications in SC management (Kshetri, 2018; Zhao *et al.*, 2019; Qian, Dai, *et al.*,
119 2020). Blockchain application in SC management is forecasted to reach the value of \$3,314.6
120 million by 2023, with an increasing annual rate of 87% (Chang, Iakovou and Shi, 2020).
121 Learning from the opportunities and potential of blockchain application in the food
122 agriculture and food SC, the industry and its stakeholders aim to capitalize on the technology,
123 for example, by increasing the transparency in the SC, which is prone to fraudulent acts of
124 untrusted actors (Kamilaris, Fonts and Prenafeta-Boldú, 2019; Kittipanya-ngam and Tan,
125 2020; Rogerson and Parry, 2020). Accordingly, Kittipanya-ngam and Tan (2020) developed a
126 food SC digitalization conceptual framework, and the relationships between key
127 opportunities and challenges are posited. However, the limited studies and guidance on
128 blockchain in developing countries and firms of different sizes have been unable to address
129 the technology dynamic impact (Mavilia and Pisani, 2020; Wong *et al.*, 2020).

130 131 **2.1 Blockchain-based Halal Food SC**

132 Traditional SCs face challenges at every point of the chain, for instance, delayed delivery,
133 fraudulent acts, such as theft and spoilage, mishandling, contamination, and issues that are
134 not easily captured using visual checks (Zailani *et al.*, 2019). Concerning the halal food SC,
135 issues such as cross-contamination, halal counterfeiting, halal fraud, logistics issues and no
136 development towards a standardized halal standard that is applicable around the world have
137 always been at the forefront of the public debate (Tan *et al.*, 2017; Ali and Suleiman, 2018).
138 The halal industry encounters inaccuracy and inauthenticity issues, as control over the whole

139 system is quite difficult to achieve because not everyone has access to information, which can
140 greatly diminish the integrity of the food SC (Abidin and Perdana, 2019). All stakeholders and
141 industry players have in-house ledgers for storing information, a system that does not truly
142 embrace transparency.

143 Blockchain is expected to ensure transparency, real-time information on any product,
144 fraud circumvention, manipulation resistance, reduced operational costs, auditability,
145 enhanced product quality, safe and healthy consumption and a more structured halal
146 certification process (Hew *et al.*, 2020; Tan, Gligor and Ngah, 2020). Normally, a halal food
147 item is certified by halal certification at the country of origin by the halal authority, with some
148 relevant data having been entered into a block of the blockchain. These data are updated as
149 the food item moves along the SC, for instance, to a storage location, a warehouse or to an
150 intermediary party. The procedure is repeated until the item reaches its destination, at which
151 point it is verified by the blockchain applications before the halal authority approves its
152 receipt. These processes are captured in blockchain applications, and consumers can verify
153 all the information related to a product at any point.

154 Typically, transparency is the key to a successful halal food chain, as the presence of
155 transparency improves both the authenticity and trust regarding a halal-certified product (Ali
156 and Suleiman, 2018). Thus, blockchain itself is a technology that allows a shared database
157 equipped with an open, safe, and verifiable system that does not require the presence of a
158 central operator; therefore, the information flow cannot be easily manipulated (Rejeb, 2018).
159 The application of blockchain allows multilevel SC players to communicate effectively and
160 efficiently for better and outstanding decision-making and is believed to be an effective
161 business tool to uplift the performance of the halal SC and increase the quality of halal
162 products. In other words, leveraging blockchain technology in the halal food industry holds
163 the potential to restructure the conventional ways of managing halal food traceability,
164 promote credibility and trust, and boost the Islamic economy at large (Chandra, Liaqat and
165 Sharma, 2019).

166 As the halal industry addresses further religious needs and requirements, blockchain
167 can ensure the traceability of goods from their origin to the destination, minimizing the trust
168 invested in intermediary third parties in the halal SC for product viability and integrity
169 authentication, thus establishing the significance of this technology to the halal food market.
170 The incorporation of blockchain in the halal food SC can serve as a platform for a tangible
171 relationship between globally distributed trading partners via a transparent networking base,
172 a vital component of the Shariah screening process to ensure that the product offered is truly
173 halal. For example, each critical activity in the halal food supply chain identified in Tan et al.
174 (2017) can be recorded and the information can be transacted between players in the supply
175 chain. For halal food, these critical elements are currently represented by the halal logo. In
176 current practice, blockchain technologies are used to perform several transactions and
177 functions, such as sensing activity, motion, and temperature; actuating and collecting; and
178 processing, storing, and sharing data (Rejeb, 2018). For instance, in halal logistics, halal
179 packaging was equipped with sensors are that relay information such as temperature,
180 humidity, light levels and the movement, enabling the monitoring and tracking of the physical
181 condition of the entire shipment or an individual product. All of this information is post-
182 processed, and blockchain technology can address the intangible information that resides
183 within the halal supply chain. Devices can now even be customized and by having instant data
184 regarding a shipment's physical condition enables real-time SC visibility (Rezaei et al., 2017),

185 and the incorporation of the purity elements of the halal food supply chain is equally
186 important as added value.

187

188 **3.0 Research Methodology**

189 This research aims to determine 'how blockchain affects the halal food SC' and 'how halal
190 food SMEs view the emergence of blockchain technology'. Firms are the unit of analysis in the
191 study of the perception of the blockchain effect on the SME SC, as well as its impending
192 challenges. This research follows the methodology applied in the work of Kittipanya-ngam
193 and Tan (2020).

194 The research is designed to understand the opportunities and key challenges related
195 to blockchain technology from the nexus of halal food SMEs and the SC. Qualitative data
196 contains rich information for defining the dimensions of blockchain opportunities and halal
197 food SME challenges; hence, this research adopted an exploratory approach that enables the
198 authors to determine the important factors for further analysis (Marshall and Rossman,
199 2016). Three phases of key research activities were design to determine the main challenges
200 of blockchain technology faced by halal food SMEs. First, this research identified the factors
201 that can be used as a base for providing understanding and guidance during the exploration,
202 data collection, and analysis. The literature was scrutinized to develop a sound
203 comprehension of the blockchain opportunities and its adoption challenges in the food
204 supply, definitions and interpretations. Second, triangulation of the data obtained from the
205 cases studied, as shown in Table 2, was performed with the insights gained from phase one.
206 The second phase enables this research to contextualize relevant blockchain opportunities
207 and challenge dimensions from the angle of the SMEs in the halal industry, as shown in Figure
208 1. Finally, the data obtained from the case study was utilized to explain and consider the
209 dimensions, as stipulated in Table 3. Thematic analysis was applied to generalize the complex
210 challenges of the blockchain in the halal food SC settings.

211

212 **3.1 Case study**

213 Based on the research questions, this research opted to use case study methods following the
214 three criteria of research approaches by Yin (2009). This research aims to understand how
215 blockchain impacts the halal food SC and the rationale behind it. Since the blockchain research
216 is in the embryonic stage and limited numbers of firms are adopting the technology, survey
217 and archival analysis are deemed to be inappropriate to provide sufficient data to carry out a
218 solid and in-depth discussion. The limited number of halal food SMEs applying blockchain
219 technology impedes the experimental approach. This research focuses on blockchain, which
220 is currently a phenomenon and contemporary event; therefore, the historical research
221 approach is limited, as scarce historical information is available. Therefore, a more holistic
222 approach is needed, and close contact with the firm being investigated provides a better
223 understanding of blockchain technology in the halal food context. A multiple case study
224 design is adopted in this study to yield a better understanding of the complex halal food SC.
225 Furthermore, as highlighted by Voss, Tsikriktsis and Frohlich (2002), the multiple case study
226 approach can safeguard this research from researcher bias and enhance external validity
227 when the findings are generalized based on research findings, and more accurate conclusions
228 can be postulated.

229

230 **3.2 Data collection**

231 Due to the scarcity of literature discussing blockchain in the halal food context (Duan *et al.*,
232 2020; Tan, Gligor and Ngah, 2020), this research is designed to begin with the literature from
233 many corpuses of knowledge. The amalgamation of literature comprises the food SC, halal,
234 SMEs, blockchain technology, and adoption to identify the research gaps and existing theory
235 regarding the impact of blockchain on halal food SMEs. Then, the research questions of 'how
236 does blockchain affect the halal food SC' and 'how do halal food SMEs anticipate and embrace
237 the emergence of blockchain technology' are established to fill in this gap. Adopting the work
238 of Kittipanya-ngam and Tan (2020) on digitalization in the food SC, the following sub-
239 questions are inserted in the interview protocol and are valuable in drawing conclusions.

- 240 1. How do you see blockchain impacting the food SC, especially regarding halal food?
- 241 2. In what aspects do you think that blockchain will impact the halal food SC? How do
242 you think it is affecting it now? [Can you elaborate from the aspects of technology,
243 organization, and the environment?]
- 244 3. Could you share the opportunities/key challenges you perceive/face regarding
245 adopting or embracing the growing trend of blockchain? How does your firm address
246 these opportunities/challenges?
- 247 4. Are there any external pressures in the SC (among the stakeholders), i.e., customers,
248 competitors, or regulators, with regard to blockchain [the growing trend of
249 blockchain]? What are the pressures? How does your firm handle the pressures?
- 250 5. Is there any part of the SC or your internal business settings that can be improved to
251 prepare your firm for blockchain integration? Are there any impending challenges that
252 will cause you to continue using the traditional methods?
- 253 6. Are there any upcoming technologies that will impact your businesses?
- 254 7. What are your predictions about your business in the next five-ten years?

255 During the case study, the informants were asked and answered the key research questions
256 and sub-questions. Despite the small number of respondents or cases, the case study method
257 enriches the data collected (Eisenhardt, 1989). As per Yin (2009), the triangulation of the data
258 obtained during the case study will enhance the validity, quality, and reliability of the study.
259 Three semi-structured interviews were conducted in the case studies, as depicted in Table 2,
260 with the management of SME food manufacturers in Malaysia. The management level was
261 selected for this research to allow the researcher to have access to strategic information,
262 especially in the context of anticipating and embracing blockchain technology. All of the
263 companies were interviewed, and site visits were conducted (Case 1: between 1.5 to 2 hours;
264 Case 2: between 2 to 2.5 hours; Case 3: 1.5 to 2 hours, Case 4: 1.5 hours; Case 5: 1 hour).
265 Follow-up telephone calls were made when further clarification and explanation were
266 needed.

267

268 **3.3 Case sampling and selection**

269 To ensure research validity, case sampling is carefully conducted. This research aims to build
270 a theory that adopts theoretical sampling to enable the collection of diversified data (Glaser
271 and Strauss 1967). Variance exists in the data, allowing this research to identify different
272 categories that explain the characteristics and dimensions (Corbin and Strauss, 2014). This
273 research applies four criteria for case selection to enhance the internal validity and
274 generalizability (Mena, Humphries and Wilding, 2009; Kittipanya-ngam and Tan, 2020). This
275 research focuses on SME firms in the halal food industry that are halal certified. The reason

276 for selecting halal-certified SME firms is to facilitate comparisons between cases that fall
277 under similar parameters and contexts. All of the firms selected in this research are based in
278 Malaysia. This criterion is set because Malaysia is known as a leading country supporting halal
279 industries. The research on halal is predominantly being performed Malaysia (Mostafa, 2020);
280 therefore, a relatively new study of blockchain in this context is provided. In addition, lessons
281 learned from Malaysia's cases may represent the best understanding of halal best practices.
282 The firms that inform this research represent different mixes of product types, allowing
283 contrasting differences that are valuable for framework development. All of the companies
284 fall under the characteristic stipulated by the Malaysia governing body known as SMECorp.
285 Following these criteria, the selected cases and their details are as shown in Table 2.
286

287 *****TABLE 2 to be inserted somewhere here*****
288

289 **3.4. Data analysis**

290 Within-case and cross-case analyses are adopted in this study. First, each case is analysed
291 individually, facilitating the insights to the second phase of the analysis; then, cross-case
292 analysis is carried out to find the variance in the data. The two phases of data analysis are
293 designed in this study according to Eisenhardt (1989) to prevent a premature conclusion,
294 which can be caused by information and researcher bias. During the within-case analysis, the
295 following key dimensions are used as a base:

- 296 1. Blockchain opportunities – investigates, explains, and clarifies the rationale behind the
297 blockchain opportunities for the SME halal firm and its SC.
- 298 2. Blockchain implementation and adoption challenges – investigates, explains, and
299 clarifies the rationale behind the blockchain adoption and implementation challenges
300 for the SME halal firm and its SC.
- 301 3. Blockchain key enabler – investigates, explains, and clarifies key factors that can
302 increase blockchain technology adoption within the SME halal food SC.

303 A conceptual framework of blockchain challenges of the SME halal food SC is proposed as the
304 result of the cross-case analysis, as depicted in Figure 1. The framework is developed to
305 elucidate the relationship between blockchain opportunities and key challenges that impede
306 blockchain adoption and implementation among SMEs in the halal food SC. The theoretical
307 and practical implications are embedded in the discussion and concluded. The limitations of
308 this research design are noted, and thus, further research suggestions are provided. In
309 summary, three distinctive research activities are conducted in this case-study-based
310 research following the suggestion of Eisenhardt (1989) and Yin (2009).
311

312 *****TABLE 3 to be inserted somewhere here*****
313

314 **4.0 Results, Discussion, and Implications**

315 Figure 1 depicts the simplified blockchain that is applied in the halal food supply chain and is
316 followed by an explanation of the opportunities that emerge from using blockchain
317 technology in the halal food SC. Additionally, the key challenges of blockchain implementation
318 and adoption from the perspective of halal food SMEs are brought forward and simplified in
319 Figure 2. Furthermore, the key enablers of blockchain adoption for halal food SMEs are

320 brought forward. The theoretical and practical implications are discussed at the end of this
321 section.

322

323 **4.1 Blockchain opportunities in the halal food SC**

324 Theoretically, the parties that participate in blockchain can benefit from information sharing,
325 which is currently being practised in the halal food industry using halal certificates. In other
326 words, blockchain can simply be achieved through the digitalization of halal certificates,
327 which can assure consumers of the full-scale halal integrity (Tieman *et al.*, 2019; Keogh *et al.*,
328 2020). Blockchain may address the key aims of SC management, for instance, risk mitigation
329 flexibility, quality, and sustainability (Kshetri, 2018) and, thus, may benefit the halal food SC.
330 Specifically, the goal of the halal industry is to address the SC integrity, which is concerned
331 with issues beyond those related to food safety and quality that are commonly being
332 examined in the conventional food SC. Therefore, halal research related to food fraud,
333 traceability, and transparency is commonly investigated when considering blockchain
334 technology (e.g., Hew *et al.*, 2020; Rejeb *et al.*, 2020; Tan *et al.*, 2020). The most likely
335 explanation for this is that trends regarding the impacts of these research themes pose
336 serious impacts, such as health and religious concerns for consumers. This research and the
337 cases studied (Cases A-E) acknowledge the capability of blockchain in addressing this pressing
338 need for traceability to improve food safety, food quality and food integrity in relation to the
339 halal SC.

340 All the cases studied in this SC showed that blockchain technology is still new and that
341 its adoption and the enjoyment of its benefits are not easy to achieve, especially for SMEs.
342 The cases suggest that blockchain can be easily applied by capitalizing on the maturity of halal
343 certification and the uniformity of the data. However, a careful application of this approach
344 is needed for a few reasons. Case B highlighted some players in the SC that are considered
345 non-critical and are able to trade in the halal industry without certification. Therefore, non-
346 certified firms may be the missing link in fully integrating blockchain technology into the halal
347 SC if this measure is adhered to. Case C highlighted that the verification of halal certification
348 is currently done through manual disparity checks between halal certificates and local label
349 descriptions, which are prone to tampering. Hence, the ultimate aim of the halal food industry
350 may be defeated. This insight is visualized in Figure 1, which indicates that successful
351 implementation and adoption of the blockchain technology will enhance visibility,
352 transparency, and traceability. However, the figure also shows that when missing links exist
353 in the SC (i.e., a non-certified firm), which will further affect the blockchain system, achieving
354 halal food traceability, transparency, and integrity will become more complicated. Moreover,
355 the overreliance on halal certification in carrying out information unification and feeding
356 information to the chain yields little incentive to completely adopt blockchain technology in
357 the industry.

358

359 *****FIGURE 1 to be inserted somewhere here*****

360

361 **4.2 A blockchain framework for halal food SMEs**

362 The adoption and implementation of blockchain technology in the food SC is in the embryonic
363 phase and is suffering from many obstacles (Si Chen *et al.*, 2020). Moreover, through a
364 consolidation of the literature and case studies, this study postulates five distinct dimensions
365 of challenges faced by halal food SMEs in making blockchain viable, which are as follows:

366 complexity and capability, cost and competitive advantages, change management and
367 external pressure, halal sustainable production and consumption, and regulatory culpability,
368 as shown in Figure 2. The five dimensions reflect the challenges that reside within and beyond
369 firm control, which is important for SMEs in the halal food SC to consider before embracing
370 and adopting blockchains. It is important to note that the findings are derived from the
371 thematic analysis from the case study and are not ranked in terms of their importance. The
372 arrows in Figure 2 represent the repelling effects between the opportunities and impeding
373 challenges, where the darker downward-pointing arrows indicate more problematic issues to
374 be addressed in embracing blockchain technology.

375

376 **4.2.1 Complexity and capability**

377 Technology complexity has always been a pivotal topic in the innovation adoption literature
378 (Hew *et al.*, 2020; Maroufkhani *et al.*, 2020). The literature reveals that firms prefer
379 innovation that is simple, user-friendly, useful, and able to provide relative advantages
380 (Clohessy and Acton, 2019; Yunan, Ali and Alam, 2020). SMEs have difficulties adopting
381 blockchain technology (Kamilaris, Fonts and Prenafeta-Boldú, 2019; Wong *et al.*, 2020).
382 Sophisticated knowledge of IT and equipment is essential when adopting blockchain
383 technologies (Zhao *et al.*, 2019), which is not common among SMEs in the halal food industry.
384 Moreover, digital devices must be available to all SC actors involved for data entry into the
385 network chain (Kamble, Gunasekaran and Gawankar, 2020). However, for SMEs, this practice
386 is not common, as data are still recorded using pen and paper. As an example, in Case C, all
387 incoming stocks are checked manually. Another common practice is the reliance of firms on
388 the halal labelling and certification of a product. Moreover, the materials used for production
389 are standard with little variability; therefore, replacing traditional paper and pen with digital
390 devices can be costly (Si Chen *et al.*, 2020). In all cases, homemade monitoring and control
391 systems are used. As observed, all three systems are unique and different, which has made
392 transferring information to a blockchain a serious problem (Nash, 2018). Consequently, the
393 readiness of halal food SME firms regarding the complete adoption and implementation of
394 blockchain technology in the food SC is questionable.

395 The halal food SC comprises firms of many sizes. Without a uniform standard of
396 information, these firms are unable to share data and cannot share data that will result in
397 information gaps, and technical compatibility between firms in the SC is almost impossible to
398 achieve (Zhao *et al.*, 2019; Dutta *et al.*, 2020). All cases also highlighted the absence of a
399 standard information format shared with suppliers, except for the information available
400 regarding halal certification. Negotiations with the actors in the SC to unify the data formats
401 can be conducted as a solution (Si Chen *et al.*, 2020); however, the economic scales of SMEs
402 are too limited, thus influencing the negotiations. This limitation significantly hinders a firm's
403 ability to adopt the blockchain strategy. The offshoring of difficult and costly SC activities by
404 a firm is a sound strategy. Complex blockchain adoption can be overcome through the
405 appointment of blockchain-based service providers. In the halal food context, many emerging
406 blockchain service providers exist, such as Halal Digital Chain in Malaysia and HalalChain in
407 the United Arab Emirates (Hew *et al.*, 2020). However, the imminent risk of non-ethical issues,
408 such as Halachic vague data ownership and information leakage, arises when shared with a
409 compromised third party in the blockchain (Chang, 2021; Kamilaris, Fonts and Prenafeta-
410 Boldú, 2019). Consequently, the capability of halal food SMEs to control their blockchain
411 adoption is limited.

412

413 4.2.2 Cost and competitive advantages

414 While halal food is produced to fulfil the expanding Islamic religious dietary market, one
415 notable risk is that the food may be fraudulently produced. Islam is one of the fastest-growing
416 religions, and a higher demand for halal food is anticipated (Ali and Suleiman, 2018).
417 Furthermore, halal food is also consumable by other religions; this increase in the number of
418 consumers will also impact the production of halal food. By contrast, food production is still
419 catching up with the demand, a challenge that halal food is not exempt from. Furthermore,
420 the literature has found that the usefulness of blockchain technology among SMEs in the halal
421 food industry has yielded mixed findings. Although promising opportunities have been
422 mentioned, the extensiveness of the application of blockchain is still limited.

423 For SMEs, which are commonly limited in their resources, the return on investment in
424 technology adoption is critical. As highlighted by Ji *et al.* (2020), the uncertainty circling the
425 return of the investment in blockchain technology casts more doubts about its
426 implementation and adoption. For instance, developing a blockchain-based halal traceability
427 system requires significant investment in multi-resources that are expensive for the firm and
428 ultimately stop the stakeholders from participating (Hew *et al.*, 2020). Instead, blockchain
429 adoption for food traceability has slim profit margins, especially for grocers and restaurants
430 (Kim and Laskowski, 2018; Nash, 2018). This issue was present in all cases studied in this
431 research. For example, Case B raises the following questions: Halal requires wholesomeness
432 in its SC. Can blockchain fulfil this? Can it offer a better control mechanism than the existing
433 one? The firms spent more than 7 years establishing their current control mechanisms in their
434 SCs by aligning all the processes and activities suitable for halal standards and requirements
435 laid out by the halal regulatory body. Another example is Case A, which is a member of the
436 restaurant chain and produces OEM food products; it developed a closed-loop system
437 business model that required more than 15 years to accomplish. All of the material supplies
438 are produced either by the central kitchen or by the OEM factory, and the distribution is done
439 in house. The control measures that ensure that the halal requirement is met with strict
440 supplier selection have been a competitive weapon for the firm. Hence, the competitive
441 advantages provided by blockchain require establishing its cost-effectiveness and a higher
442 return on investment for the firm.

443 The halal food industry depends on halal certification, which has been tested for
444 blockchain applicability (Tieman *et al.*, 2019; Keogh *et al.*, 2020). Each of the case study firms
445 are aware of this effort and monitors it closely. However, they noted that the blockchain
446 application will take much time to implement in the halal food industry because more than
447 70% of the total halal food market is composed of SMEs. For example, in Case C, their main
448 raw materials are sourced from key suppliers that are distributors, and the information is
449 passed along through halal certificates. They indicate that due to the small sizes of orders, an
450 agreement with the main supplier is not achievable where data integration beyond halal
451 certification is impossible, impeding blockchain viability. Similarly, Case A highlighted that
452 suppliers are not keen to share any data other than that stipulated in the halal certificates.
453 Limited data sharing may lead to missing information (Dutta *et al.*, 2020); therefore, the
454 application value proposition of blockchain in the halal food context will be limited to the
455 digitalization of halal certification. SME SCs are commonly shorter, and the number of
456 products is small, making them less complex and manageable, therefore hindering SMEs from
457 jumping on the blockchain bandwagon. In addition, the blockchain advantage of eliminating
458 intermediaries (Saurabh and Dey, no date; Hastig and Sodhi, 2019) is not that appealing for
459 the SME halal food SC.

460 Digitalization has improved transparency in the SC (Kittipanya-ngam and Tan, 2020).
461 Conceptually, when all players in the SC put information up on the chain, the members of the
462 chain can develop a strategic alliance and choose their business partners freely (Treiblmaier,
463 2018; Kamble, Gunasekaran and Gawankar, 2020). Relative to conventional digital
464 technologies, blockchain technology enables all of the SC actors to have full access to the
465 transactions (Ølnes, Ubacht and Janssen, 2017). Tracing this concept back to the period
466 before the existence of blockchain, transparency was previously achieved through SC
467 integration. SC integration argues that a firm with more extensive integration of its SC
468 members is better off in terms of its performance (Frohlich and Westbrook, 2001; Tan *et al.*,
469 2017). Correspondingly, a myriad of research has provided empirical evidence of the impact
470 of SC integration on firm performance. However, from the context of the food SC, the findings
471 on SC integration yield mixed results in terms of the performance achieved. The dominant
472 explanation for this inconsistent result is that players in the SME food SC reluctantly share
473 information (Tan *et al.*, 2017). This reluctance is due to the nature of the SME food business,
474 which allows the easy replication of information. As noted in Case B, a few occasions of larger
475 firms trying to emulate their product due to some information leakage during a transaction
476 can be observed. A substantial number of resources are required to mitigate the issue.
477 Although blockchain may establish a trusted source of information for all transactions, making
478 digitalized information available to anyone in the system may cause uneasiness for the SMEs
479 in the halal food industry (Kaur *et al.*, 2018). Similarly, in Case C, the supplier information was
480 mishandled, resulting in the creation of a few competitors in the marketplace. Since the
481 number of credible suppliers with halal certification is scarce in the industry, each firm has to
482 redevelop its products to obtain a greener marketplace. Hence, until blockchain technology
483 sets some parameters to ensure the privacy and security of sensitive information (Kaur *et al.*,
484 2018), the SME halal food SC will lag in its adoption.

485

486 **4.2.3 Change management and external pressure**

487 Generally, the awareness of and skills related to blockchain are limited in the food SC (Zhao
488 *et al.*, 2019). However, blockchain professionals and experts who can provide training
489 platforms for the food SC are still scarce and are actually still gaining new knowledge
490 themselves (Chang *et al.*, 2020; Dutta *et al.*, 2020; Mavilia and Pisani, 2020). All cases in this
491 research showed that they are aware of blockchain technology. However, the understanding
492 of blockchain technology in the food SC is still at the conceptual level due to the limited
493 references and guidance regarding blockchain implementation in practice (Tan, Gligor and
494 Ngah, 2020). SMEs commonly implement flatter organizations and have centralized decision-
495 making processes. The adoption of blockchain depends on the knowledge and skills of upper
496 management. Case C shows that the decision regarding technological inducement and
497 automation within firms belongs to upper management, typically the owner of the firm. Halal
498 food SMEs commonly see halal certification as a market qualifier; hence, additional changes
499 to the existing system, i.e., to accommodate blockchain, are deemed not timely or
500 appropriate. This situation is exemplified in Case A, where the restaurant chain and OEM food
501 products were impacted by online viral cases that show the production of food products
502 containing swine, which is not permissible for Muslim consumption. After a quick and careful
503 investigation by the halal regulatory body, the viral cases were rebutted later that same day.
504 The efficiency of the current halal mechanism may outweigh the benefits of blockchain
505 application in terms of traceability because the cost of the technology is higher than the value
506 of the food itself. Investment in blockchain-based systems, i.e., enhancing traceability in food

507 SC, incurs raised costs without necessarily increasing revenue (Kim and Laskowski, 2018; Erol
508 *et al.*, 2020; Ji *et al.*, 2020).

509 Blockchain technology adoption and implementation require firms to have a holistic
510 understanding of the related infrastructure and setup necessary to support the technology
511 within each firm. Most likely, the existing infrastructure and support systems of firms will be
512 outdated and thus not aligned with blockchain technology. In addition, a new business model
513 may also be needed, and business models and operations may suffer from incompatibility
514 with blockchain technology (Hastig and Sodhi, 2019; Urbano *et al.*, 2020; Weking *et al.*, 2020).
515 Blockchain adoption by a firm may require a major overhaul, which will impact change
516 management. The greatest challenge in change management is commonly related to human
517 resource management; firms are expected to encourage employees to accept blockchain
518 technology (Shankar *et al.*, no date). For instance, Case B presented the difficulty faced in
519 managing employees and operations during efforts to achieve Hazard Analysis and Critical
520 Control Point (HACCP) certification, with major changes being required within the firm.
521 Moreover, the food industry is flooded with meta-systems and certifications (Ali and
522 Suleiman, 2018). These meta-systems are overlapping, conflicting and demanding, bringing
523 about more challenges for blockchain-related regulations and laws that will require daunting
524 changes within firms to make them ready to adopt the technology (Galvez, Mejuto and Simal-
525 Gandara, 2018).

526

527 **4.2.4 Halal sustainable production**

528 Firms are now more inclined towards being sustainable and socially responsible (Kittipanya-
529 ngam and Tan, 2020). Halal production is regarded as sustainable because of its specific
530 processes (Ali and Suleiman, 2016; Tan *et al.*, 2017). Because the goal of halal production is
531 to produce products that are safe, high quality, and with intact integrity for consumers,
532 incorporating the dynamism of the food concept into blockchain application implementation
533 should be considered. In addition, not all of the food parameters can be monitored using
534 analytical methods (Kamilaris, Fonts and Prenafeta-Boldú, 2019). Some of the food concepts
535 and parameters, such as safety, quality, integrity, and purity, are very difficult to measure and
536 establish analytically, as they encompass and involve many aspects of production at every
537 echelon of the SC (Ali and Suleiman, 2018).

538 Zhao *et al.* (2019) argued blockchain technology to be beneficial in reducing food
539 safety risks, which relates to social impact. Case B and Case C provide important examples
540 that refute this argument. Both cases imply that limited information regarding, e.g., the
541 pesticides and fertilizers used to grow plants is made available. They further argue that
542 farmers cannot update information regarding, e.g., the type, amount, frequency, and potency
543 of pesticides and fertilizers used over the typically long periods of cultivation. Some available
544 information is commonly given as blanket information for the whole process, such as
545 sustainability certificates (Köhler and Pizzol, 2020). Even if proper information input is
546 available when blockchain technology is adopted, the process is tedious, exhaustive, and
547 costly for SMEs in the halal food SC (Wong *et al.*, 2020). Economically, Case D indicated a
548 similar concern regarding the unwillingness of employees who are established, experienced
549 and knowledgeable to embrace the blockchain into their business practices. They presume
550 that the current operations are sustainable enough and are yet to observe a success story
551 from blockchain adoption into the business. Similarly, Case E hinted that including blockchain
552 as part of sustainable efforts is confusing and unrelatable. They further highlighted that their
553 supply chain members still relate the blockchain with transaction and communication that

554 has minimal impact on sustaining the firms. Commonly, halal food SMEs, unlike other
555 premium food producers, cannot transfer these costs to the end customer by setting higher
556 prices and therefore satisfy the existing mechanisms that are argued to be highly related to
557 sustainable efforts.

558

559 **4.2.5 Regulatory culpability**

560 Blockchain will eventually benefit the SC; however, it is highly dependent upon the regulatory
561 bodies that govern the industry. Common legal requirements and standardization of the
562 blockchain technology have yet to be agreed upon and established (Duan *et al.*, 2020; Keogh
563 *et al.*, 2020), requiring a substantial amount of policy underwriting by the regulatory bodies
564 that play a significant role in the halal food industry, such as JAKIM and the Ministry of Health.
565 Blockchain policy and regulation are necessary for determining the feasibility of adoption.
566 Furthermore, voluntary-based and underutilized international halal standards complicate the
567 smart contracts between two parties in the halal SC. As mentioned, halal food relies upon
568 governmental/certification bodies that have their own interpretations of Islamic divine
569 sources, i.e., the Quran and practices of the prophet Muhammad, which may slightly differ
570 from one another.

571 Nonuniformity and voluntary-based certification leave some uncritical players in the
572 SC, i.e., vegetable farmers, distributors, and logistic providers, without halal certification,
573 which may further complicate data sharing on the blockchain. The transition to wider
574 adoption of the blockchain technology should be led and governed by a higher industry
575 authority (Ølnes, Ubacht and Janssen, 2017; Hew *et al.*, 2020). However, efforts are being
576 made to realize and trace physical data using blockchain through hazard and critical control
577 point systems, which may apply to the halal food industry (Tian, 2017; Creydt and Fischer,
578 2019). However, the risk to halal food products exists at all levels, which is beyond the reach
579 of the critical point. For the halal concept, the blockchain policy and regulations are
580 anticipated to be tied with the current panacea for the halal industry and halal certification.
581 Following this logic, to ensure the successfulness of blockchain implementation, uncritical
582 players should also be certified, which will impact the small farmers residing within the SME
583 SC. This scenario is exemplified by Case B regarding the difficulties in finding a halal-certified
584 farmer as a supplier. Extending halal certification to uncritical players will impose a stricter
585 requirement within the existing halal SC and further hinder the absolute application of
586 blockchain technology. For SMEs that belong to uncritical points, blockchain technology can
587 be viewed as another voluntary certification that they will not implement when the benefits
588 are not obvious. This issue has been highlighted by Case C and E, who state that involving a
589 third-party halal logistic provider is challenging and does not provide additional value to their
590 finished product. Further, halal logistic providers are not largely available and are used on a
591 voluntary basis, which complicates the blockchain implementation of the complete halal SME
592 supply chain.

593

594 **4.3 Key enablers for halal blockchain in the SME SC**

595 Informed by dynamic capabilities theory, to adapt with the changing environments, the firms
596 should be able to integrate, build and reconfigure internal and external competencies (Teece
597 *et al.* 1997). Correspondingly, to obtain success in blockchain adoption in halal food SMEs,
598 integrating internal and external competencies is crucial. Following Teece's (2018)
599 operationalization of the dynamic capabilities (i.e., sensing, seizing, and transform), the cases

600 studied have indicated that blockchain is regarded as a disruptive technology with great
601 potential if it is adopted and applied in the halal food SC. However, the adoption and
602 implementation of blockchain technology in the halal food industry, particularly in SMEs in
603 this industry, is low. The perplexing situation of the mismatch between opportunities and the
604 adoption of blockchain has been identified in this research and suggests that internal and
605 external factors are needed to reduce the impact and seize blockchain opportunities in the
606 halal food SME SC. From the findings, this research postulates extensive SC integration and
607 regulatory intervention (internal and external competencies respectively) as universal
608 enablers, as shown in Figure 3.

609 The fostering of SC integration between firms is mandatory. Blockchain remains a
610 technology that aims to simplify and enhance the collaboration between two parties in the
611 SC. Without more extensive SC integration, regardless of the form, how advanced, and how
612 simple the implementation and application are, the potential and benefits of blockchain can
613 never be achieved. The component of trust in the halal industry should extend beyond halal
614 certification. As exemplified in Case A, a closed system was established within the firms that
615 successfully safeguarded the halal issues in the firm and regarded them as competitive
616 advantages. This system was developed with strategic SC partners by sharing data even more
617 sensitive than halal certificates. Being able to take risks through information sharing with
618 suppliers, for instance, is a daunting task, as it demands the utmost trust between parties.
619 Furthermore, as blockchain does not allow the 'Control Z' options, the information is
620 permanently available in the chain. Several uncontrollable factors also exist, such as foul play
621 by some players of the SC, and strategic and trusted alliances can never be discovered if a
622 firm does not gradually become more welcoming in terms of data sharing and being digitally
623 connected. Hence, the readiness of a halal SME firm for blockchain integration strongly affects
624 the implementation of blockchain in the overall SC.

625

626 *****FIGURE 3 to be inserted somewhere here*****

627

628 Regulations, halal standards, and halal regulatory bodies have been the backbone of
629 the halal industry. Stricter regulations, revised halal standards, and proactive regulatory
630 bodies in the halal industry can play a large role in blockchain adoption. Case B, for example,
631 values halal integrity and calls for non-critical players in its SC to be halal certified. Blockchain
632 cannot work at the optimum level when missing links/information occur in the SC. The halal
633 industry/product values wholesomeness and integrity; therefore, a formative approach
634 should adhere to blockchain implementation and adoption. Therefore, the halal industry
635 requires a body that not only governs but also champions any innovation that contributes to
636 the betterment of the industry. Moreover, halal governing bodies could play an important
637 role in improving the ethical issues surrounding issues that have been of concern by the case
638 firms studied, hence ensuring privacy, fairness and regulation for SMEs who are willing to
639 commit to blockchain technology (Chang, 2021). In particular, SMEs in the halal food SC face
640 challenges that limit the ability to adopt blockchain technology and are the largest segment
641 in the halal food industry. In summary, the governmental and regulatory role are important
642 in assisting SMEs (Øines, Ubacht and Janssen, 2017; Veronica *et al.*, 2020), especially in the
643 case of the adoption non- eminent benefits technology such as blockchain.

644 These two enablers are interrelated, and the synergetic value between these enablers
645 can address some of the challenges. For example, extensive SC integration is needed for
646 system customization if halal regulations/standards are revisited and a decision is made to

647 incorporate blockchain technology. In another example raised by Cases C and D, the lack of
648 significant value attached to blockchain technology in the SME SC may be due to a lack of
649 knowledge and awareness. This issue could be mitigated by halal governance body
650 intervention through training or self-experience regarding the benefits of more extensive SC
651 integration.

652

653 **4.4 Theoretical Contribution and Practical Implications**

654 This research has contributed to theory in many different ways. First, the proposed
655 framework addresses the gap highlighted in the halal food SC literature regarding the scarce
656 amount of research investigating blockchain, as argued by Tieman et al. (2019). The proposed
657 conceptual framework offers five key dimensions for practitioners to revisit the challenges
658 and opportunities that can be achieved after adopting blockchain technology. Second, the
659 adoption of the case study method in this research for framework development addresses
660 the lack of empirical blockchain studies, especially concerning the halal food SC (Tan, Gligor
661 and Ngah, 2020). Three SME firms participated in this research, enabling an in-depth
662 explanation of and reasoning regarding the diffusion of blockchain technology. Third, this
663 research responds to the call of Duan et al. (2020) for a real-life investigation of blockchain
664 adoption and its application in the halal industry. Fourth, this study focuses on unresolved
665 non-technical issues surrounding blockchain, as suggested by Kamilaris et al. (2019). Fifth,
666 SMEs constitute the main discussion topic of this research, which extends the research by
667 Wong et al., (2020) by investigating blockchain within the halal food context.

668 In practice, this research sheds light on the different players in the halal food SC. First,
669 practising managers can use this research as a guideline to understand the relationship
670 between the opportunities and challenges for blockchain adoption through the conceptual
671 framework developed. Moreover, firms that have characteristics similar to those of the cases
672 studied in this research can become aware of similar challenges that lie within their SC on
673 blockchain adoption. Thus, firms should be more ready and proactive when preparing for
674 blockchain adoption in the future. In addition, this research unravels the challenges that halal
675 food SMEs face in reality. Through a detailed discussion and examination of the blockchain
676 opportunities and challenges provided, this research offers important information pertinent
677 to governmental policy underwriting.

678

679 **5.0 Conclusion**

680 In summary, our findings indicated that blockchain, as disruptive technology, can help halal
681 food SMEs achieve food SC transparency. However, some challenges may hinder its adoption.
682 An investigation of blockchain in the context of halal SCs that is supported by empirical
683 evidence is urgently needed. Hence, the objective of this research is to address the research
684 gap through the development of a conceptual framework using a case-based approach as
685 guidance for determining the blockchain challenges among SMEs in the halal food SC.
686 Extending the research on blockchain from the context of the halal food SC, SMEs and non-
687 technical aspects using empirical case studies, a framework is proposed regarding halal food
688 SME blockchain challenges that comprise five main dimensions (complexity and capability,
689 cost and competitive advantages, change management and external pressure, halal
690 sustainable production, and regulatory culpability) underpinning the challenges of halal food
691 SMEs in terms of blockchain opportunities. In light of the key enablers, this research provides
692 blanket solutions for overcoming the challenges of blockchain adoption.

693 Some limitations are associated with this research. The impacts of blockchain on the
694 SME halal food SC are postulated in a framework that collapses into five dimensions.
695 However, the dimensions are equally important in the context of the halal food SC.
696 Corroborating the literature indicating that the halal food SC is a formative concept, these
697 dimensions are interrelated. In other words, the absence of one dimension will shatter the
698 absolute meaning of halal. However, the interrelations between the dimensions have yet to
699 be explored in the context of blockchain. In addition, blockchain technology is highly
700 associated with the contemporary decrease in halal traceability of other important food
701 aspects, such as food quality, safety, and integrity. Future research on the blockchain that
702 encompasses more food aspects under a single study would yield a more in-depth
703 understanding of the applicability of the framework. Furthermore, a detailed practical guide
704 for explaining the framework is needed, as SMEs are bound not only to traceability as their
705 SCs become shorter and less complex.

706 As this research is limited to identifying the challenges of blockchain technology
707 adoptions and probable solutions based on the dynamic capability's perspective, there are
708 many others ways of seizing the opportunities from blockchain technology. It is important to
709 ensure that the technology adopted by the halal SMEs are reflected and aligned with the
710 current and future needs. Therefore, sustainability notions, such as green supply chain
711 management, are argued to be important future research avenues. Following this research
712 highlights the overlapping challenges, practices, perspectives and enablers, which are
713 important gaps that warrant investigation. For example, future research can strategically
714 identify the priority and ranks of the challenges/practices of blockchain technology faced by
715 the halal food supply chain that need to be addressed (e.g., Abdel-Baset et al., 2019), hence,
716 providing important insights to the food industry, SMEs, and the complex SC discourse.

717 SC complexity differs from one firm/product to another; thus, validation of the
718 generalizability and universality of the framework should be attempted in future research.
719 This research is exploratory in nature, and further research with more cases involving firms
720 of similar/different sizes (i.e., micro-firms and multi-national corporations) or more food
721 product types can result in theoretical validation and replication of this study (Yin, 2009).
722 Further research may consider expanding the interviewee list to other roles in the SC, such as
723 the government, food regulators, customers, suppliers, farmers, distributors and retailers,
724 which may enrich the data and provide new insights into the blockchain technology. This will
725 become more necessary in the future, as at the time this article was written, blockchain
726 technology had yet to be implemented in the halal food SME context. Halal-related research
727 is predominantly conducted in Malaysia (Mostafa, 2020). The findings of the halal food
728 research in Malaysia could be argued to be advanced, and this research may suffer from bias
729 because the understanding and awareness of halal food production in Malaysia are high. Halal
730 food is a global dietary phenomenon, and similar industries in other parts of the world may
731 differ significantly in regard to their technological and environmental readiness for blockchain
732 adoption. Different nations and industrial settings may provide different contexts for halal SC
733 industrial and governance structures that could influence blockchain implementation and
734 adoption.

735
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742

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993 3(16), pp. 1–7. doi: 10.1186/s41018-018-0044-5.
- 994 Table 1: Examples of disruptive technologies in food SC management

	Technologies	Description	Authors
Food traceability	Quick Response (QR) Code	QR Code is a cheap and effective way of providing the consumers with needed information (i.e., country of origins) beyond conventional pre-packaged food labelling complexity.	(Kim and Woo, 2016; Spence <i>et al.</i> , 2018; Tan and Ngan, 2020).
	Radio Frequency Identification (RFID)	An RFID tag is attached to the pre-packaged food packaging, which contains a certain amount of information to identify leaks in the distribution network.	(Kelepouris, Pramadari and Doukidis, 2007; Alfian <i>et al.</i> , 2020; Urbano <i>et al.</i> , 2020)
	Smart packaging	Smart-packaging is integrated with wireless communication and cloud service, which enables food product real-time monitoring, thus providing transparency regarding the product movement in the SC.	(Shoue Chen <i>et al.</i> , 2020).
	Big data	Big data analysis services could be used for competitiveness advantage maximization through transparency.	Navickas & Gruzauskas (2016)
	Internet of Things (IoT)	IoT-based business solutions enabled tracking and tracing platform through real-time visibility.	(Zhao <i>et al.</i> , 2015)
	GPS tracking system	A GPS track and trace system can be utilized in the logistic process to, e.g., detect delays in the transportation system, which may prevent food counterfeiting.	(Kandel, Klumpp and Keusgen, 2011)
	Blockchain	The shared data in blockchain technology enhances the efficiencies of data extraction of essential data in tracing the information of a food product.	(Hackett, 2017; Bumblauskas <i>et al.</i> , 2020).
Food integrity	Anti-counterfeiting	The overt and covert approach in anti-counterfeiting technology can enhance food integrity. Overt allows the users to verify the product authenticity visually (e.g., barcodes, holograms, watermarks, RFID, tamper-proof). Covert requires more advanced applications, such as intaglio printing, invisible ink, and mobile applications, that have higher technological interference and are more difficult to replicate.	(Soon and Manning, 2019)
	Internet of Things	Internet of Things allows controlling and food fraud mitigation in the SC. IoT can	(Bouzembrak <i>et al.</i> , 2019)

		ensure food adulteration, contamination, and degradation.	
	Blockchain	Blockchain is able to assure business integrity, for instance, sustainably sourced, organic or faith-based, and certification. Blockchain data is immutable and unchangeable, thus reducing the risk of food fraud in the SC.	(Köhler and Pizzol, 2020; Rejeb <i>et al.</i> , 2020).
Food safety	Smart packaging	Smart packaging enhances the traceability and its effects spill over on the overall quality and safety of the food supply.	(Shoue Chen <i>et al.</i> , 2020)
	Drone technology	Drones can help to provide information about individual animals, such as temperature and location of lost stock.	(Haji <i>et al.</i> , 2020)
	Internet of Things	IoT enables collaboration among SC actors, including food producers, transportation and hospitality/retail companies, ensuring efficient delivery and food safety.	(Zhao <i>et al.</i> , 2015)
	Blockchain	Blockchain enables the firm to identify products suffering from food-borne illnesses in seconds instead of weeks. Blockchain enhances food safety and provides consumers with the nutritional information of all edible items through digitized information.	(Hackett, 2017; Tian, 2017; Creydt and Fischer, 2019)
Food delivery	Robotic	Speeds up the most repetitive tasks in agriculture, food processing, and packaging.	(Rejeb <i>et al.</i> , 2020)
	Drone technology	Drones will operate along one predetermined delivery route, connecting a distribution center with a single delivery point. Drones are expected to replace current delivery methods, which suffer from traffic congestion, and reduce the use of multimodal transportation.	(Haji <i>et al.</i> , 2020; Hwang, Kim and Lee, 2020)
	Internet of Things	IoT-based fleet management enhances the continuous visibility of intermodal transportation and provides transportation alternatives and on-time delivery.	(Zhao <i>et al.</i> , 2015)
Food security	Artificial Intelligence	Artificial intelligence enables food resilience through early identification of disease, maximizing agriculture inputs and return based on supply and demand.	(How, Chan and Cheah, 2020)
	Big Data	Data-driven systems will be the future for more sustainable food production and consumption.	(Zhong, Xu and Wang, 2017)

	Internet of Things	IoT integrates the food SC ecosystems and reproduces the production flows from the market demand.	(Zhao <i>et al.</i> , 2015)
	Blockchain	Blockchain can enhance the visibility of food and commodities and its related environmental footprint. Blockchain might also be used to identify food surplus for distribution to beneficiary bodies.	(Ahmed and Broek, 2017)
Food Quality	3D food printing	With 3D printing technology, firms can personalize food based on customer demand, for instance, allowing them to choose the ingredients and nutrition, flavours, and shapes.	(Sun <i>et al.</i> , 2015; Mantihal, Kobun and Lee, 2020)
	Artificial intelligence	Artificial intelligence can be used in food quality prediction and control.	(Qian, Ruiz-Garcia, <i>et al.</i> , 2020)
	Internet of Things	IoT-based testing equipment can be used to confirm the food quality when it leaves the factory or warehouse, for instance, a mobile application could be used to test the freshness of food.	(Zhao <i>et al.</i> , 2015)
	Temperature and Moisture Sensor	For perishable goods that are temperature-sensitive in transit can be controlled through sensor-enabled refrigeration systems.	(Mercier <i>et al.</i> , 2017)
	Smart packaging	Smart packaging solutions are beneficial to the overall quality and safety of the food supply by enhancing product traceability and reducing the amount of food loss and waste.	(Shoue Chen <i>et al.</i> , 2020)
	Blockchain	Blockchain impacted extrinsic product quality characteristic (associated with food but not part of the food product).	(Tian, 2017; Stranieri <i>et al.</i> , 2021)
Food sustainability	Artificial Intelligence	Artificial intelligence capable of providing alternatives to complex problems, saving valuable resources and reducing environmental damage	(Di Vaio <i>et al.</i> , 2020)
	Smart packaging	Smart-packaging provides accurate data regarding the product condition, reduces food loss and waste, prevents theft and provides brand protection. Recyclable and bio-based packaging is environmentally friendly and reduces material waste, elongates the shelf life and enhances the food quality.	(Adeyeye, 2019; Li <i>et al.</i> , 2020; Shoue Chen <i>et al.</i> , 2020)

	Blockchain	This technology allows farmers to reduce the use of chemical inputs, machinery, and water by using the information on soil, temperature, humidity, agricultural equipment, livestock, fertilizers, soil, and sown crops.	(Rejeb <i>et al.</i> , 2020)
Food recall	Blockchain	Blockchain enables efficient and effective product recall through more detailed transaction data, hence preventing economical, reputational, and social loss.	(Zhang, Brown and Li, 2019; Duan <i>et al.</i> , 2020; Rejeb <i>et al.</i> , 2020)

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Table 2: Summary of the cases studied in this research

Case	Type of Business	Turnover in 2018 (USD)	Employees	Informant	Interview Duration
A	Restaurant Chain and OEM Food Product	800,000	70	Managing Director	Between 1.5 to 2 hours
B	Beverages	250,000	20	Owner	Between 2 to 2.5 hours
C	Confectionary	200,000	30	Owner	Between 1.5 to 2 hours
D	Livestock and food processing	1,000,000	30	Chief Executive Officer	Between 1.5 to 2 hours
E	Snacks	500,000	50	Operation Manager	1 hour

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Table 3: Summary of cross-case analysis of the key challenges of blockchain adoption in the SME halal food SC

	Key Challenges of Blockchain Adoption among Halal Food SMEs				
	Complexity and Capability	Cost and Competitive Advantages	Change Management and External Pressure	Halal Sustainable Production	Regulatory Culpability
Case A	///	///	//	//	///
Case B	//	///	//	///	/
Case C	//	///	/	/	//
Case D	//	//	//	///	//
Case E	///	//	//	//	///

Notes: ///: heavy impact; //: moderate impact; /: light impact

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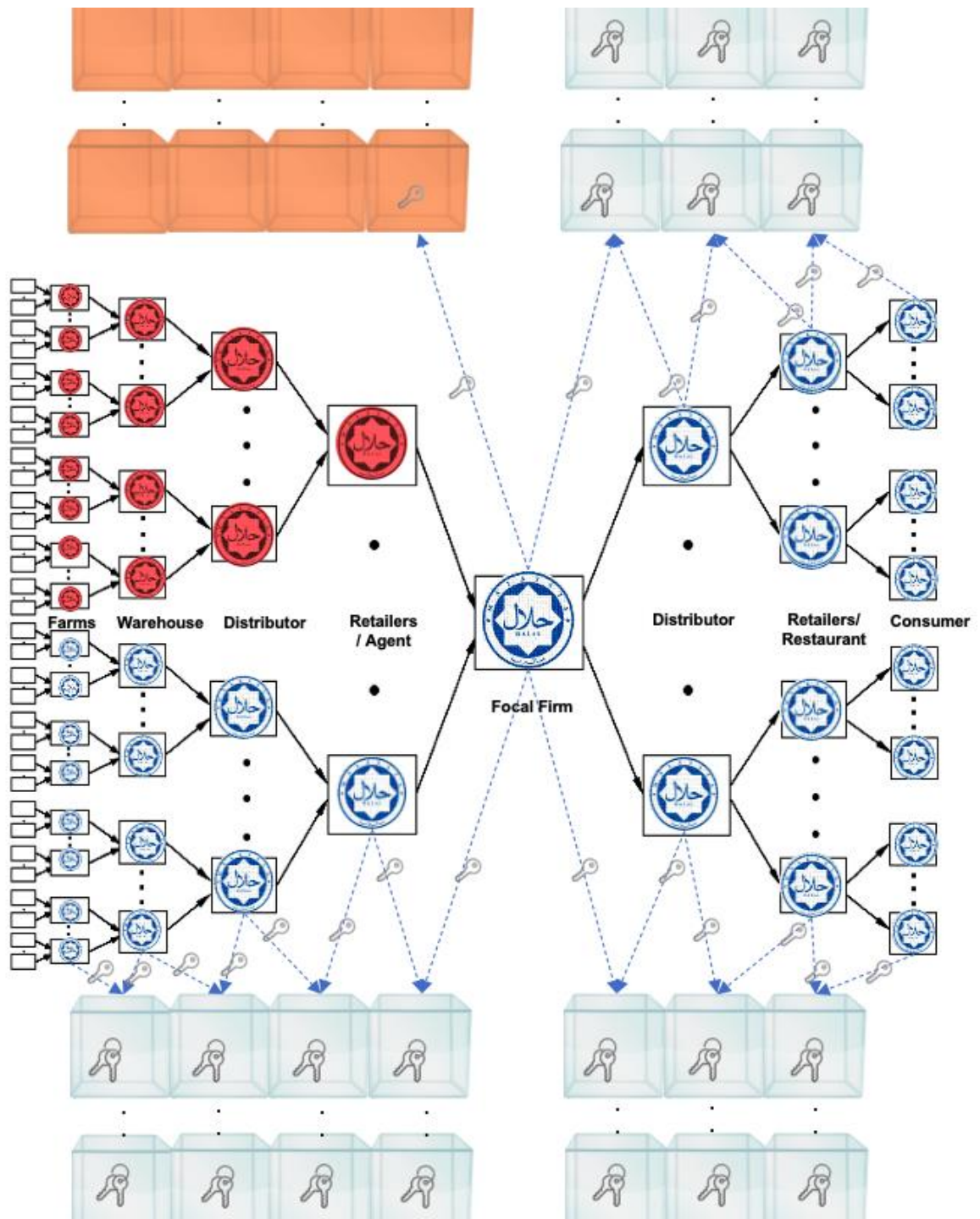


Figure 1: Simplified blockchain-based halal SC

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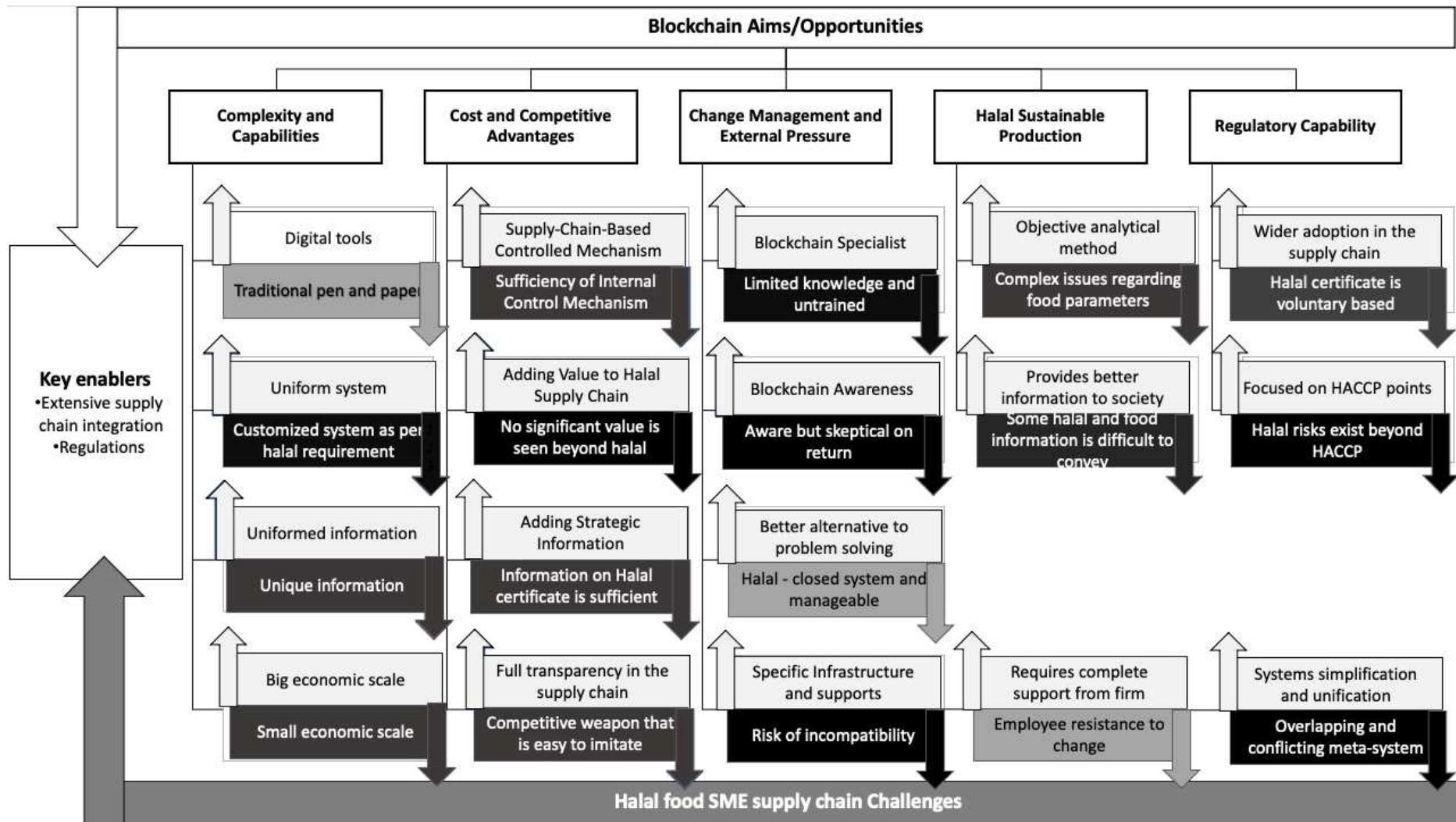
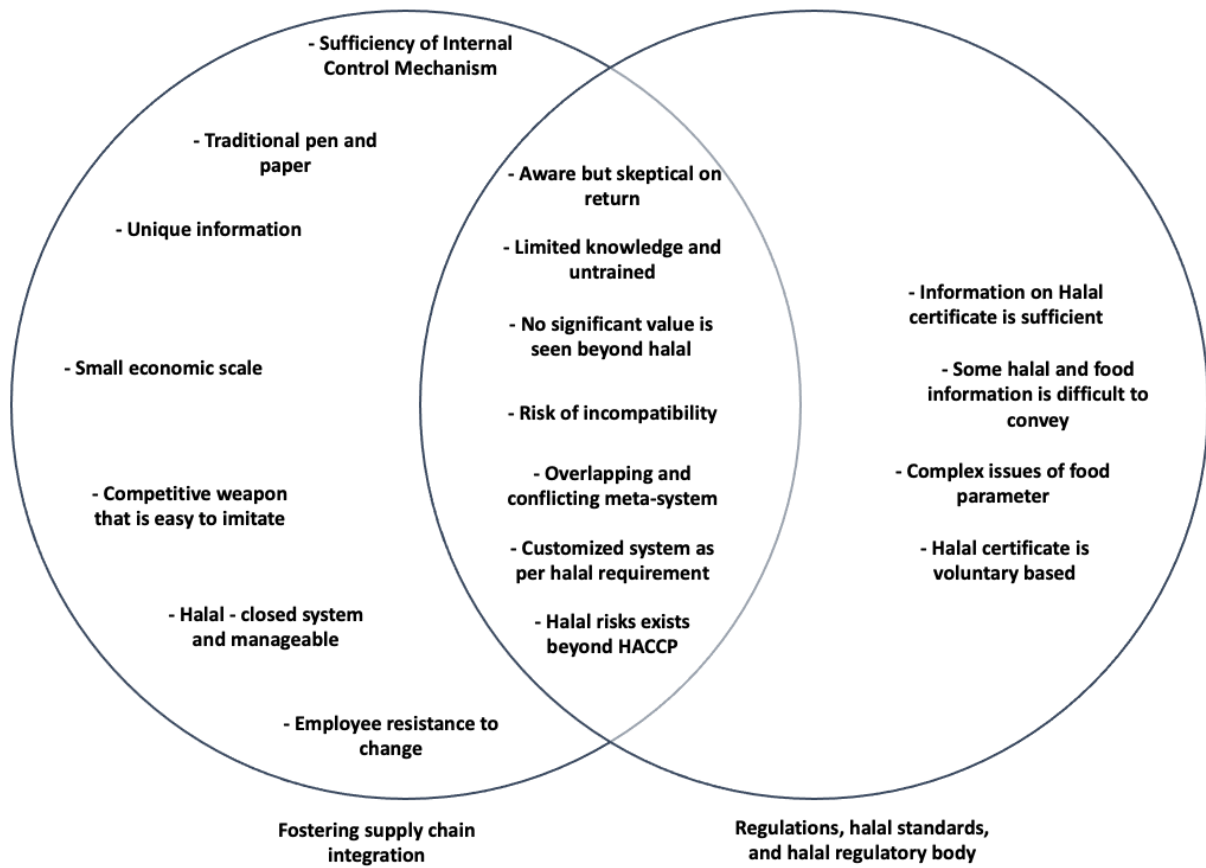


Figure 2: Proposed halal food SME blockchain challenge framework embedded with the within-case analysis



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Figure 3: Key enablers for halal SME food SC blockchain challenges