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ORIGINAL PAPER

Do online agri-food sellers contribute to food security in Indonesia? A PCA-based composite index and a Tobit approach

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Abstract
Despite a widely accepted view of the increasing role of e-commerce in providing food access, conceptual frameworks, measures, and factors affecting the contribution of e-commerce participants to food security still need to be improved. This study develops a conceptual framework using data from an online survey of 198 online agri-food sellers in the East Java province recruited through a local small business platform. Then, it conducts a quantitative analysis to assess the contribution of online agri-food sellers to food security and the factors affecting their contribution. Specifically, the study develops a novel principal component analysis-based E-Commerce Food Security Contribution Index (EFSCI) using 26 food availability, access, utilisation, and stability indicators. It applies a Tobit model to identify factors affecting the EFSCI. This is the first study to associate food security issues with e-commerce selling behaviours of small online businesses using empirical data and a newly constructed index. The Tobit model reveals that sellers with more experience in e-commerce and selling processed meat contribute more to food security. To a lesser extent, being a male seller and marketing on social media are negatively associated with the EFSCI. The results highlights the necessity to support new entrants and those selling on social media to better understand food security aspects in their e-commerce operations, the importance of food safety, and the significant role of women in promoting food security.

Keywords Agri-food · E-commerce · Indonesia · Food security · Composite Index · Principal Component Analysis · Tobit

JEL Classification L81 · O12 · O13 · Q13 · Q18

1 Introduction

In recent years, consumers have witnessed rapid growth in e-commerce across the globe. Globally, the e-commerce market sales reached $5.2 trillion in 2021 and will grow by more than half the subsequent years, amounting to over $8 trillion by 2026, making up nearly a quarter of all retail sales (Statista, 2022c). Reports from major developing countries such as China, India, and Indonesia document substantial figures of e-commerce development even before the pandemic. In China alone, the largest e-commerce market in the world, rural online retail sales reached 1.7 trillion yuan in 2019 (or approximately US$242.9 billion), comprising 16.1% of the country's total retail sales (Li et al., 2021). According to GlobalData's E-Commerce Analytics, the Chinese e-commerce market will reach US$3 trillion in 2024. The Indian e-commerce market is expected to expand to US$111 billion by 2025, up from US$46 billion in 2020 (IBEF, 2021). In Indonesia, at the start of the pandemic, in March 2020, the Indonesian Central Bank (BI) reported a significant increase in e-commerce transactions by 18.1% to 98.3 million. In 2022, *Tokopedia*, a leading e-commerce platform in the country, amounted to nearly 150 million monthly web visits showing an even further spike in e-commerce sales. The value of sales of goods through a customer-to-customer marketplace is expected to reach $95 billion by 2025 (Statista, 2022a).

Agri-food e-commerce also experienced significant growth in recent years. Globally, the food segment of e-commerce markets is set to reach $244 billion in revenue in 2022 and a projected market volume of over $600 billion by 2027 (Statista, 2022b). During the COVID-19 pandemic,

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retailers "pivoted" to e-commerce to reach consumers and apply e-procurement to reach producers. However, the degree of offline-to-online transformation varies between countries, supply chains and firms. This increased importance of e-commerce during the pandemic has stimulated many studies looking at the growing role of e-commerce in ensuring consumers' continued access to food (Bakalis et al., 2020; Béné et al., 2021; Gao et al., 2020). In addition, e-commerce provides a shorter supply chain and serves as an additional mechanism to cope with the food resilience issue (Bakalis et al., 2020; Reardon et al., 2021; Swinnen & McDermott, 2020).

Despite the increased policy and research interests in the link between food security and e-commerce, several knowledge gaps are identified in the literature. Firstly, a framework and measures to assess the contribution of e-commerce participants to food security still need to be developed. The current claims on the contribution of e-commerce to food security during the pandemic are primarily based on global statistics and observational data. At the time of writing, only one study that develops a conceptual framework and uses micro-level empirical data to assess the impacts of online food purchasing on households' food security is found (Liang et al., 2022). Using Chinese household data, Liang et al. (2022) find that while e-commerce minimises the declining food intake due to the closure of wet markets and mobility restrictions, it only provides a "partial fix" to food insecurity issues with issues ranging from a limited variety of food, high food prices and delivery issues.

Nevertheless, studies still need to present a conceptual framework and empirical data to assess the link between food security and e-commerce from the perspective of online sellers. This different perspective is necessary given that other food system actors are likely to have different priorities in food systems (Dengerink et al., 2021). In addition, little is found in assessing the rapid development of 'informal e-commerce' and delivery services through non-dedicated platforms such as WhatsApp and Facebook (Béné et al., 2021). This sub-sector of the economy is particularly important for developing countries and small and medium enterprises (SMEs). Furthermore, the current discourse on e-commerce tends to be about food access, while food security covers other dimensions such as food utilisation, availability, and stability.

Against this backdrop, this study investigates agri-food e-commerce participants' contribution to food security using Indonesia as a case study. While this study focuses on Indonesia, the framework and methods used in this study are relevant to other developing countries. More specifically, this study uses data from an online survey of 198 online agri-food sellers in the East Java province in Indonesia recruited through a partnership with a local SME platform. The study addresses the following three research questions:

1. What are the agri-food e-commerce aspects related to the four food security dimensions (availability, accessibility, affordability, and stability)?
2. How should e-commerce sellers' contribution to food security be measured? and
3. What are the factors affecting e-commerce sellers' contribution to food security?

To address the first research question, leveraging on previous studies (Béné et al., 2021; Brouwer et al., 2020; Liang et al., 2022), this study develops a conceptual framework for assessing the four food security dimensions (availability, accessibility, affordability, and stability) of e-commerce operations. The second research question is addressed by developing a novel E-Commerce Food Security Contribution Index (EFSCI) using the Principal Component Analysis. Then, the Ordinary Least Square (OLS) and Tobit approaches are employed to assess the third research question on factors affecting the EFSCI.[1]

As the first study that associates food security and e-commerce selling behaviours by presenting a conceptual framework and a newly constructed index supported by empirical data, this study contributes to the following scholarly work. First, it complements existing studies, including Liang et al. (2022), that focus on the e-commerce impacts on household food security by capturing the different nuances of online agri-food sellers. Secondly, it also complements numerous studies that provide valuable insights into e-commerce contribution to food security during the pandemic but yet to provide supporting evidence at the micro-level (Bakalis et al., 2020; Béné et al., 2021; Swinnen & McDermott, 2020). Thirdly, its novel index, derived based on micro-level data, contributes to the literature on food security indices that mostly use aggregate data (Izraelov & Silber, 2019; Odhiambo et al., 2021; van Berkum & Ruben, 2021). Lastly, the study also contributes to the literature by presenting evidence from a developing world context adding to a growing body of literature on e-commerce that primarily focus on China (Jin et al., 2020; Liu et al., 2021; Zeng et al., 2017b).

The Indonesian agri-food sector presents a fitting case study. Global online marketplaces such as Amazon, Alibaba and eBay often dominate policy discourse and research focus on e-commerce. However, in developing worlds such as Indonesia, agri-food e-commerce takes many forms, affecting how products are sourced, processed, handled, marketed, and distributed, hence the availability, access, utilisation, and stability of agri-food products. "Social commerce", for instance, represents 40% of all e-commerce sales

[1] This study focuses on online sellers' contribution to society's food security instead of their food security status, although there is a good possibility that these two are correlated.

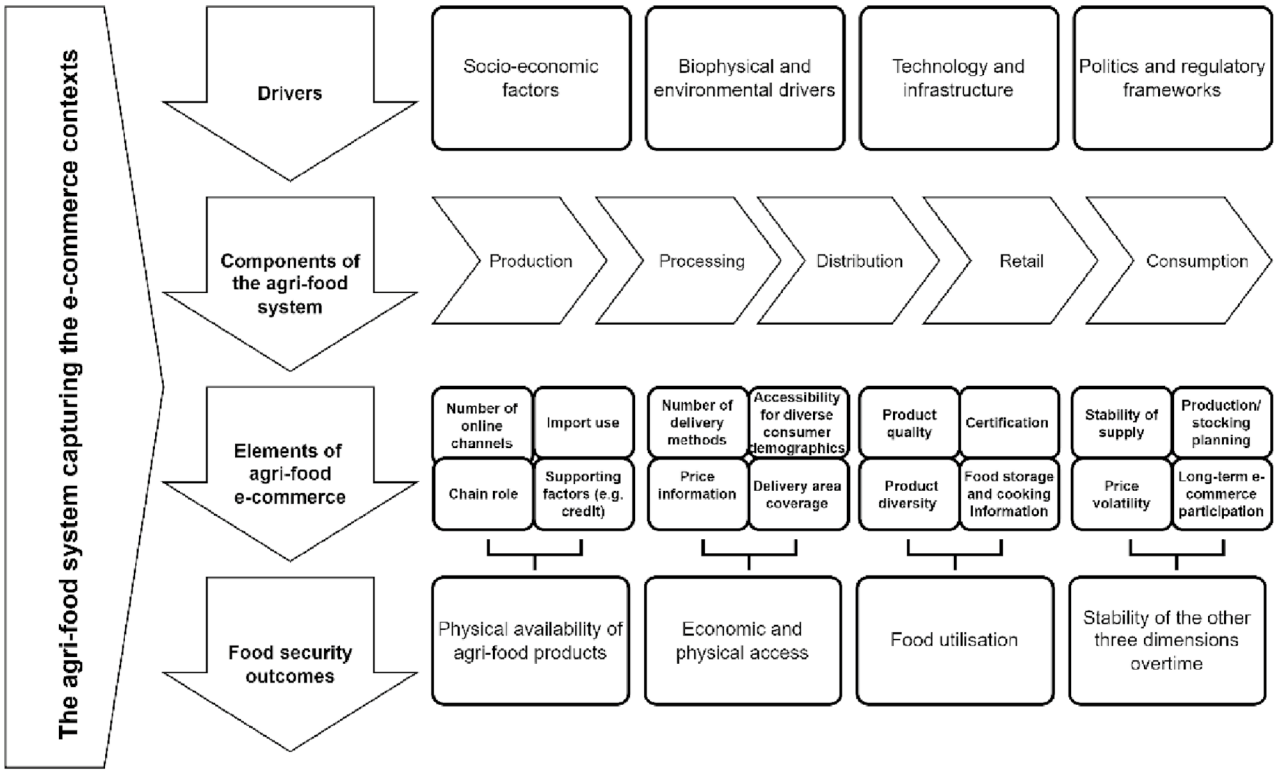

Fig. 1 The agri-food system capturing the e-commerce contexts. Source: Author's illustration adapted from Béné et al. (2021), Brouwer et al. (2020), HLPE (2017), and Lu et al. (2022)

in Indonesia (JP Morgan, 2019) and provides 'an accessible entry point' for small businesses wanting to enter the online markets using social media and networking applications such as WhatsApp, Facebook, and Instagram. Indonesian consumers also enjoy the convenience of the website or smartphone application-based e-commerce platforms, including food delivery service applications (such as GRAB, GoFood, GoShop), the general marketplace (such as Tokopedia, Shopee, Blibli), the agri-food-specific marketplaces (such as Etanee, Sayurbox, Tanihub), and food/meat processors, butchers, or supermarkets with online services (such as Lottemart, KIBIF, Indoguna). Furthermore, in the pre-pandemic era, the country was already Southeast Asia's biggest e-commerce market in 2019. The COVID-19 pandemic further accelerated this growth. In 2020 at the onset of the pandemic, the food and beverages category experienced a substantial increase in the share of product mix in the Indonesian e-commerce market from 17% in the pre-COVID period to 20% (SIRCLO, 2020).

The remainder of this article is structured as follows. Section 2 presents a conceptual framework for assessing the role of agri-food e-commerce in food security. Section 3 describes the data source and methodology used in this study, including the PCA to derive the EFSCI and the empirical specification to assess the determinants of the EFSCI. Results and discussion are presented in Section 4, while Section 5 provides conclusions and recommendations.

2 A conceptual framework for assessing the role of agri-food e-commerce for food security

To address the first research question on identifying the aspects of e-commerce operations related to food security, this study considers food system frameworks developed by earlier studies (Béné et al., 2021; Brouwer et al., 2020; Lu et al., 2022). Like earlier studies, it focuses on the widely-cited definition of food security as achieved at the World Food Summit in 1996: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006). In this study, the food system refers to a broader concept, defined as "all elements and activities related to the production, processing, distribution, preparation and consumption of food, the market and institutional networks for their governance, and socio-economic and environmental outcomes of these activities" (Brouwer et al., 2020; HLPE, 2017).

Figure 1 shows a framework to assess the food security aspects of e-commerce operations developed in this study. The different components of the food systems (from production to consumption) have led to four streams of food system analyses, as defined by Brouwer et al. (2020). These include supply-oriented analyses (focusing on long-term food availability), midstream-oriented analyses (the link between food production and consumption), demand-oriented analyses (food access and ensuring appropriate diets) and system-oriented analyses (governance). This study relates to the midstream-oriented and demand-oriented analysis types. While it acknowledges the importance of investigating the supply and consumption segments of the supply chains from a systemic approach, given the data coverage and study scope, it focuses on understanding how the e-commerce market facilitates food supply, food access, food quality and diversity and their stability.

Like the HLPE (2017), the framework distinguishes the three components of food systems, namely drivers, components, and outcomes:

- *External drivers* - The agri-food system is influenced by external drivers, including socio-economic (such as economic growth, population and urbanisation), political, technology and infrastructure and environmental (such as weather, water, energy and climate) factors (Béné et al., 2019; Brouwer et al., 2020; Ruben et al., 2021; van Berkum & Ruben, 2021).
- *Components* - These drivers affect various activities in the supply chains, which are considered the food systems' components, from production to retail and consumption. In the retail segment, technological changes and urbanisation have driven the growing e-commerce sales (Zeng et al., 2017a).
- *Outcomes* - Food security is seen as one of the food system outcomes. Other outcomes considered by previous studies include inclusiveness, a sustainable environment, and resilience to climate change (Ruben et al., 2021; van Berkum & Ruben, 2021).

Figure 1 also includes *elements of agri-food e-commerce* that can affect the four food security outcomes. Appendix Table 5 shows indicators of these various elements using survey data, while the explanation of how these elements can be correlated with food security outcomes is presented. The basic idea of the new *EFSCI* is to capture the multi-dimensionality of these agri-food e-commerce elements into a composite indicator as adopted by previous studies in agriculture (Gómez-Limón & Riesgo, 2009; Izraelov & Silber, 2019; Manyong et al., 2006; Odhiambo et al., 2021). The proposed framework captures not only the food access benefit of agri-food e-commerce that has been widely cited by previous studies during the COVID-19 pandemic (Bakalis et al., 2020; Béné et al., 2021; Gao et al., 2020) but also the other three food security outcomes that are yet to be investigated by existing studies.

2.1 Availability

Availability is about food supply and trade. Improving availability, therefore, involves strategies to increase the performance and resilience of production and distribution segments of the chain. Within e-commerce operations, factors such as the diversity of online marketing channels, the supply chain structure, the role of online sellers, and supporting factors such as access to credit determine how e-commerce improves food security. Regarding the diversity of online marketing channels, considering the potential digital divide among customers, social commerce using WhatsApp, Facebook, and Instagram, for instance, caters for customers with limited experience of using the web or app-based e-commerce platforms, hence improved availability to these group of population. Likewise, the e-commerce seller's position in the food supply chain affects their contribution to food security. A farmer seller, for instance, has more control over their supply than sellers who are intermediaries (e.g., collectors, wholesalers, etc.). Moreover, in addition to the supply of products to be marketed at the e-commerce platforms, access to credit is critical for ensuring continued operation, hence the availability of agri-food products in the e-commerce market. Appendix Table 6 presents data from the survey related to the availability dimension.

The number of online channels WhatsApp is used by about 80% of online agri-food sellers surveyed, while Facebook and Instagram are used by over 40% and 50% of the respondents, respectively. Despite the growing number of marketplaces focusing on agri-food products, many online sellers prefer food delivery apps and general marketplaces.

Chain role and import use The survey data suggest that over 60% of the respondents are food processors. This indicates that the emergence of e-commerce growth in Indonesia does not necessarily imply direct selling from farmers to end-consumers. While the chain might be shortened, e-commerce operations, including those of food processors, would still be susceptible to typical supply chain risks, such as the inconsistent supply of farm produce in terms of quality and quantity. However, risks facing agri-food e-commerce operations are relatively confined to domestic food systems. Only 2.5% of the respondents reported using imported ingredients, inputs, and raw materials.

Access to credit In the survey, respondents were asked how effective access to credit has been in helping them improve supply (in terms of quality, quantity, and consistency). The

results suggest that 31% of the respondent never had access to credit, while 49% supported the effectiveness of access to credit to improve their supply. Meanwhile, 18% of the respondents viewed that access to credit is either ineffective or very ineffective in helping them improve their supply. Overall, this finding highlights that access to credit should be something other than a silver bullet to ensure improvement in e-commerce supply. Other factors should also be considered, such as training and improving access to market and regulatory information.

2.2 Access

The claim that e-commerce helps alleviate food insecurity during the pandemic is based on the premise that e-commerce provides alternative access for customers to purchase food and the convenience of home delivery when human mobility is severely constrained. However, e-commerce customers often need help with limited delivery options and waiting lists (O'Meara et al., 2022). In addition, the digital divide also exists, and studies find that the elderly tend to be under-served by e-commerce (Gao et al., 2020). Therefore, in this study, the access dimension of food security is focused on delivery aspects and understanding the types of customers currently served by e-commerce services to understand physical access. Additionally, the study incorporates price information to capture economic access, as shown in Appendix Table 7.

The number of delivery methods The different roles of online sellers in the e-commerce supply chains mean different ways to deliver their products to customers. For example, farmer sellers send deliveries to e-commerce platform procurement officers who act like 'collectors' getting farm produce from many farmers and farmer groups. The survey data, however, suggest that nearly 80% of the respondents deliver their products directly to buyers. This finding is expected given that many respondents are food processors, with final products being consumables. However, it is essential to note that other players, such as kiosks, warehouse managers, and resellers, also play a part in the distribution. Once again, this highlights the continued important role of intermediaries in e-commerce supply chains.

Price information Access to food is also about economic access. One important feature is whether price information is readily available for customers before their online purchases. While this might sound very trivial, it is interesting to note that only 82% of the respondents provide price information on their online channels. Further looking at the data, this study finds that 83% of those respondents who do not provide price information use individual WhatsApp accounts as their online marketing channel. It is not unheard of in Indonesia that sellers using social media such as Instagram posts and WhatsApp communication often impose price discrimination between customers. This observation, therefore, raises concerns over the access implications of social commerce for access to food.

Accessibility for diverse consumer demographics To understand who enjoys access to agri-food products offered by e-commerce markets, the survey asked respondents to describe their customer demographics in the online survey platform using the percentage slider between 0 and 100%. The survey finds that from the perspectives of online agri-food sellers, typical customers are mainly females (65% of their customers); about half are under 30 years old and middle-income class; about 63% live in urban areas. Respondents, the majority of whom are small businesses, also reported that most of their customers are household or individual customers, with only 23% serving food services. The findings, therefore, suggest that e-commerce is relatively accessible to a wide range of customers.

Delivery area coverage The online sellers' contribution to food access also depends on their delivery area coverage. Two-thirds of the respondents deliver to other cities, and only 44% provide to other provinces.

2.3 Utilisation

Utilisation involves improving nutrition and food safety and increasing diversity in diets. If e-commerce is set to be the main agri-food marketing channel in the future, a careful assessment of how product quality is tested, the diversity of products sold online, and certification issues become essential. E-commerce also has a potential role in becoming a source of information for potential buyers. Information such as recommendations on storage and cooking methods can help customers ensure food safety and diversify meals. Appendix Table 8 presents insights from the survey data regarding these utilisation aspects.

Product quality Major e-commerce companies typically have minimum product quality requirements, while 'informal commerce', such as those selling through WhatsApp, is usually not a subject of close regulatory supervision. Appendix Table 8 shows different strategies to ensure product quality in agri-food e-commerce markets. Technical advice from e-commerce is the most common strategy to ensure product quality, as reported by 37% of the respondents. Meanwhile, other mechanisms, such as product testing or specifying product requirements in the contract, are reported by about 21–27% of the respondents. To a lesser extent, certification is also used in e-commerce markets, as reported by 19% of the respondents. However, it is essential to note that this figure

does not represent the adoption of those quality-checking measures but the respondents' knowledge of whether the e-commerce platforms they supply impose such standards.

Product diversity The diversity of Indonesian demographics necessitates a wide range of food options. The survey finds that online sellers specialise in one or two food categories. In line with their roles in the agri-food supply chain, only a tiny proportion of the respondents sell fresh food product categories such as fruit and vegetables, eggs, and unprocessed meat. Nearly half of the respondents sell ready-to-eat meals.

Certification Various certificates apply to agri-food products in Indonesia. The survey finds that 43% of the respondents adopt the Halal certificate. While the main objective of the Halal certificate is to cater to Muslim's religious dietary requirements, the Halal concept also concerns food safety (Booz-Allen & Hamilton, 2000). In Indonesia, managed by the Halal Products Certification Agency (BPJPH), the Halal certificate is mandatory for food and beverages (with some exceptions, such as alcohol and pork). However, some products have until 2022 to comply. Meanwhile, the National Agency of Drug and Food Control (BPOM) governs product registration in Indonesia, including agri-food products. In short, certification mechanisms can be seen as a potential way to improve food safety standards in agri-food e-commerce markets. However, only 17% of respondents have the BPOM certificate.

Food storage and cooking information Customers' food handling also influences food safety as a critical component of the utilisation dimension. One potential avenue to educate customers is through providing information about a recommended storage option and cooking method, which 51% and 40% of the respondents have displayed on their online platforms.

2.4 Stability

In addition to the access dimension, the COVID-19 pandemic has raised particular concerns over the stability of our food systems. Globally, in terms of price volatility, for instance, supply chain disruptions and trade issues during the pandemic, on top of adverse weather events in some parts of the world, led to a significant increase in the FAO Food Price Index in November 2021, averaging 134.4 points which is the highest level since June 2011 and 27.3% higher than its level in November 2020 (FAO, 2021). Furthermore, in 2022, the rising living costs and the Russia-Ukraine war continued to pose concerns about food insecurity issues.

Within the context of e-commerce, many argue that digital technology and improved access to information allow online sellers to manage better and stabilise the food supply. Appendix Table 9 presents a summary of the survey data on these aspects. Since many online sellers are not primary producers, the role of e-commerce in achieving food security largely depends on its sellers' ability to secure supply, monitor price fluctuations, and plan for production or stocking management. Additionally, the survey captures future projections on whether they plan to continue their online market presence and how they perceive prospects in the post-COVID era. This information can provide micro-level insights into whether e-commerce markets will continue to thrive as much as global statistics and reports have projected.

Stability of supply, price stability and production/stock planning The survey asks respondents to compare their experience of e-commerce participation to selling to other marketing channels. About half of the respondents find that supplying to e-commerce platforms is less or much less difficult. Around 32% of respondents think it is about the same, while 18% perceive it somewhat or much more difficult to supply to e-commerce than providing to other marketing channels. In addition, the survey finds that e-commerce marketing channels make it easier for online sellers to monitor price fluctuations. About 63% of respondents find monitoring price fluctuations much less difficult or difficult to do via e-commerce platforms.

The survey also finds that 63% of respondents perceive planning for production and stocking management on e-commerce platforms as more straightforward. About 23–24% of respondents are indifferent about differences in price monitoring and production or stocking planning between e-commerce and other marketing channels. In short, there is evidence that e-commerce helps nearly two-quarters of the surveyed online sellers monitor prices and plan production and stock management. Attention should be given to assisting about 13% of online sellers who find price monitoring and production planning via e-commerce more complicated.

Long-term e-commerce participation The survey examines future participation, prospect, and e-commerce development factors. The hypothesis is that those with a more optimistic view of e-commerce and a good understanding of e-commerce development drivers would have long-term e-commerce participation and contribute to food stability. The survey shows the optimism of online sellers towards the future of the Indonesian e-commerce market. Only 3% of respondents do not plan to continue their e-commerce participation after the pandemic. Moreover, about 84% of respondents think that opportunities for marketing agri-food products through online channels will increase after the pandemic. Only 3% of respondents see decreased opportunities. Most respondents (86%) highlighted the importance of technological advancement for driving future e-commerce

development. Other essential factors include changing lifestyles and government support, as reported by over half of the respondents.

3 Data and methods

3.1 Data

The study uses data collected from an online survey of online agri-food[2] sellers conducted in June-July 2021 in East Java province, Indonesia. According to the Indonesian Statistics Agency (BPS), the East Java province was ranked 4th in 2019 in terms of the percentage of e-commerce business, after the Special Region of Yogyakarta, North Sulawesi, and West Java.

The survey has two criteria for selecting respondents: i) the respondent is currently selling agri-food products online, and ii) the respondent must be above 18. The questionnaire was developed using the RedCap survey and consisted of the following main sections: the individual and business characteristics; e-commerce operations; perceptions of market trends and regulatory frameworks; and the role of youth and COVID-19 implications. Ethical approval was obtained accordingly before the survey.

Invitations to participate in an online survey were sent to several SME platforms and community groups in East Java through a partnership with a local SME platform. This approach was deemed more effective in increasing the response rate and ensuring respondents' compliance with selection criteria than making a publicly accessible invitation to the online survey. The partner platform has a significant presence in the province. The platform is well connected to local small business groups and has experience in SME training and managing a survey of SMEs. No sampling frame with a complete list of small businesses in the agri-food sector existed in the East Java province, hence the need to collaborate with this SME platform to reach suitable respondents. Working with this SME platform, a list of more than three hundred small businesses selling agri-food products in East Java was gathered. An electronic invitation was then sent out to those small businesses. Responses from 228 respondents were received, suggesting a more than 60% response rate. After data cleaning, the study adopted information from 198 respondents out of the 228 surveyed.

[2] In this survey, agri-food products include but are not limited to fruits, vegetables, chicken, beef, lamb, fish, seafood, processed meat products, dairy products, rice, coffee, spices and herbs, and ready-to-eat food.

3.2 Methods

This study develops a novel online seller-specific EFSCI using the PCA and estimates the determinants of the index using the OLS and Tobit models. The PCA is a common multivariate technique to reduce the dimensionality of a dataset consisting of interrelated variables while retaining data variation as much as possible. The method has been used by many existing studies, for example, to derive the crop-livestock integration index (Manyong et al., 2006), a social-ecological index for measuring flood resilience (Kotzee & Reyers, 2016), a composite indicator of agricultural sustainability (Gómez-Limón & Riesgo, 2009), an energy sustainability index (Doukas et al., 2012) and to revisit the global food security index (Izraelov & Silber, 2019; Odhiambo et al., 2021). Furthermore, recognising that there are various methods to develop composite indices (Greco et al., 2019), the data-driven nature of the PCA-based composite indicators provides a more objective alternative to indicators developed using weights assigned through subjective procedures such as expert survey and a more favourable option compared to an equal weights approach.

This study uses 26 indicators, as shown in Column (5) of Appendix Table 5. Some variable transformation is done to ensure that the variable used is food-security enhancing, e.g., a higher variable value should be positively associated with food security contribution. For instance, while we are unsure whether selling to a marketplace or conducting social commerce is positively associated with higher food security contribution, it is assumed that those selling through more online marketing channels make agri-food products more accessible, hence higher food security contribution. Therefore, the number of online marketing channels is used instead of multiple dummy variables. Before the application of PCA, given the various units that the 26 selected variables have, the normalisation of the chosen indicators is performed using the following equation, which transforms all the selected variables to the 0–1 scale:

$$x_i = \frac{X_i - Min(X_i)}{Max(X_i) - Min(X_i)} \tag{1}$$

where x_i is the normalised value of the indicator, X_i is the actual value, and $Min(X_i)$ and $Max(x_i)$ are the lowest and highest values of the indicator observed in the sample.

In the PCA, Q variables $x_1, x_2, \ldots, X_q$ into principal components $Z_1, Z_2, \ldots, Z_q$. Each component is a linear combination of variables with the strongest correlation. To conduct PCA, first, the correlation matrix is obtained. The second step is to decide the number of principal components (PCs) to be extracted using a scree test showing j components with eigenvalues more than one are retained. The first PC accounts for the largest proportion of total variation. Thirdly,

factor loadings, which are the correlations between the original variables and the components ($Corr(x,)$) Z, are calculated for each of the variables on the components. A varimax rotation minimises the number of variables with high loading on a specific component.

After obtaining principal component scores ($F_1, F_2, \ldots, F_j$), the fourth step is to derive the e-commerce food security contribution index for online agri-food seller i ($EFSCI_i$), which is a composite indicator derived by applying the weight to F_{ji}:

$$EFSCI_i = \sum_{j=1}^{j} \left(\frac{eigenvalue_j}{\sum_{j=1}^{j} eigenvalue_j} \right) F_{ji} \quad (2)$$

The weights, therefore, show the relative importance of the respective indicators for determining the final composite index score.

To address the third research question on the determinants of e-commerce food security contribution, this study uses the *EFSCI* as a dependent variable in a Tobit model. First, it uses a one-limit Tobit with the dependent variable *EFSCI* censored at zero after normalising figures of *EFSI* for all online agri-food sellers. Then, the following empirical model is estimated:

$$\begin{aligned} EFSCI_{ir} = {} & \beta_0 + \beta_1 MALE_{ir} + \beta_2 AGE_{ir} + \beta_3 EDUC_{ir} \\ & + \beta_4 EXP_{ir} + \beta_5 CONTRACT_{ir} + \beta_5 EXP_{ir} \\ & \times CONTRACT_{ir} + \beta_6 STAFF_i + \beta_7 SOCECOMM_{ir} \\ & + \beta_8 MARKETPLACE_{ir} + \beta_9 MEAT_{ir} \\ & + \beta_{10} PROCMEAT_{ir} + \beta_{11} DAIRY_{ir} + \gamma_r + \epsilon_{ir} \end{aligned} \quad (3)$$

$EFSCI_{ir}$ is the normalised PCA-derived EFSCI index for the online agri-food seller i residing in district r. A higher index shows a higher seller's contribution to food security. As a robustness check, the analysis also uses $TOTALEFSCI_{ir}$ as an alternative dependent variable, the sum of the 26 (normalised) e-commerce food security contribution indicators used to derive *EFSCI*: $TOTALEFSCI_{ir} = \sum_{q=1}^{25} x_{irq}$.

To assess the determinants of *EFSCI*, the analysis includes three categories of variables: individual characteristics, e-commerce participation and product types:

- *Individual characteristics:* A dummy variable on gender $MALE_{ir}$ (1 if male); years of schooling $EDUC_{ir}$; ordinal variables of years of experience selling online EXP_{ir} (1 if less than 1 year; 2 if $> 1- \leq 2$ years; 3 if $> 2- \leq 5$ years; and 4 if > 5 years are included.
- *E-commerce participation:* A dummy on contract $CONTRACT_{ir}$ (1 if the online seller has a contract with e-commerce platforms being supplied) and its interactions withEXP_{ir}[3]; the number of staff (including the seller) ($STAFF_{ir}$) to proxy the size of the business; two main types of e-commerce *MARKETPLACE* (1 if the seller supplies to the general marketplace, agri-food marketplace or supermarkets with online services); and $SOCECOMM_{ir}$ (1 if the seller uses social media such as WhatsApp (both individual and business accounts), Facebook (both individual and marketplace), and Instagram to sell agri-food products).
- *The types of products:* $MEAT_{ir}$ (1 if the seller sells chicken meat, beef, lamb, or seafood); $PROCMEAT_{ir}$ (1 if the seller sells processed meat products such as sausages, chicken nuggets, meatballs, etc.); and $DAIRY_{ir}$ (1 if the seller sells dairy products).[4]

Table 1 shows descriptive statistics and the expected sign for each variable. Nearly three-quarters of our respondents are female. The average online seller in the sample is 32 years old and has completed about 14 years of education, which suggests that most online sellers in the data have received some secondary education. Regarding their e-commerce participation, social commerce is the most frequently used online channel among our respondents, with 91% currently selling through social media such as WhatsApp, Instagram, and Facebook. Meanwhile, about 30% of respondents use the marketplace to sell agri-food products.

Furthermore, only 13% have a contract with e-commerce companies. The survey data also suggest that the average online seller employs between 1 and 2 staff members. Regarding types of products, 12% and 22% of the sample sell meat and processed meat products, respectively. Only 7% sell dairy products.

4 Results and discussion

4.1 The e-commerce food security contribution index (EFSCI)

This study uses the first nine components showing eigenvalues greater than one. Figure 2 shows the scree plot from PCA. Table 2 shows that these nine components account for 60.9% of the variances cumulatively. Meanwhile, PCA scoring coefficients are shown in Appendix Table 10. After calculating

[3] Online sellers engaging in a contract typically need to follow food safety requirements that can increase their food security contribution. Additional years of experience might magnify this contract effect as sellers become more familiar with the food safety requirements over the years, hence the inclusion of the interaction terms between EXP_{ir} and $CONTRACT_{ir}$.

[4] Among other types of agri-food products included in the survey, these three categories represent those requiring more proper handling, given their perishable nature.

Table 1 Descriptive statistics and expected sign

Variable name	Expected sign	Mean	Min	Max	Standard deviation
MALE	+/-	0.253	0.000	1.000	0.436
AGE	+/-	31.692	18.000	60.000	9.351
EDUC	+	13.985	9.000	18.000	2.157
EXP_1 (<1 year)		0.333	0.000	1.000	0.473
EXP_2 (> 1− ≤ 2 years)	+ (relative to EXP_1)	0.268	0.000	1.000	0.444
EXP_3 (> 2− ≤ 5 years)	+ (relative to EXP_1)	0.253	0.000	1.000	0.436
EXP_4 (> 5 years)	+ (relative to EXP_1)	0.146	0.000	1.000	0.354
CONTRACT	+	0.131	0.000	1.000	0.339
STAFF	+	2.495	1.000	13.000	2.207
SOCECOMM	-	0.919	0.000	1.000	0.273
MARKETPLACE	+	0.298	0.000	1.000	0.459
MEAT	+	0.116	0.000	1.000	0.321
PROCMEAT	+	0.217	0.000	1.000	0.413
DAIRY	+	0.066	0.000	1.000	0.248

Source: Author's calculation using survey data

PC scores for each respondent, a weighted index is derived using the formula in Eq. (2) and weights in Column (5) of Table 2, which is the ratio of the eigenvalue of each PC to the total eigenvalues across the nine selected PCs.

The Kaiser-Meyer-Olkin (KMO) measure can be performed to assess sampling adequacy. The measure takes values between 0 and 1, with small values indicating that overall, the variables have little in common to warrant a principal components analysis. Values above 0.5 are considered satisfactory for a PCA to be conducted. This study finds an overall KMO measure of 0.6. While this might be regarded as 'mediocre', the Bartlett test of sphericity with the null hypothesis that the variables are not intercorrelated (i.e., the correlation matrix is an identity matrix) finds p-value = 0.000 suggesting that there is a substantial correlation in the data.

The study finds that the PCA-based *EFSCI* scaled between 0 and 1 follows a normal distribution with a mean of 0.531.

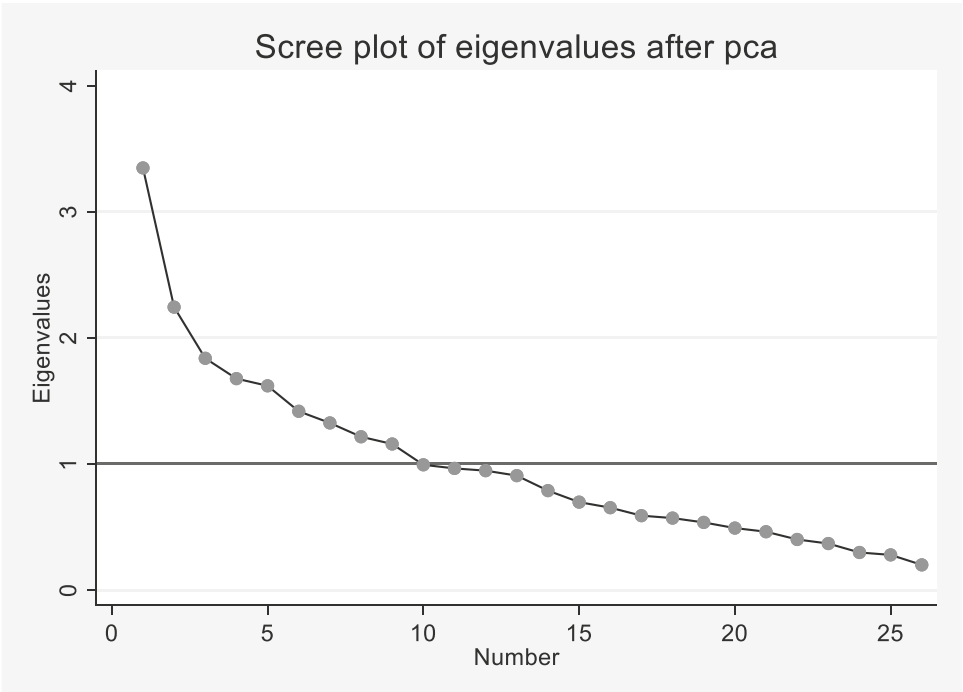

Fig. 2 Scree plot. Source: Author's calculation using survey data

Table 2 Principal components, eigenvalues and proportion of variance explained

Component	Eigenvalue (1)	Difference (2)	Proportion (3)	Cumulative (4)	Weights (5)
Comp1	2.378	0.170	0.092	0.092	0.150
Comp2	2.208	0.219	0.085	0.176	0.139
Comp3	1.989	0.202	0.077	0.253	0.126
Comp4	1.787	0.131	0.069	0.322	0.113
Comp5	1.657	0.033	0.064	0.385	0.105
Comp6	1.623	0.079	0.062	0.448	0.102
Comp7	1.544	0.144	0.059	0.507	0.097
Comp8	1.399	0.143	0.054	0.561	0.088
Comp9	1.257		0.048	0.609	0.079

Only components with eigenvalues above one are included. Weights in Column (5) are the ratio of each component's eigenvalue in Column (1) to the sum of eigenvalues from the nine components. Varimax rotation is applied

Source: Author's calculation using survey data

Figure 3 shows the kernel probability distributions of the *EFSCI* by dummy variables included in the analysis: *MALE*, *CONTRACT*, *SOCECOMM*, *MARKETPLACE*, *MEAT*, *PROCMEAT* and *DAIRY*. It provides a non-parametric visual illustration of the probability density function of a random variable, in this case *EFSCI*. Most respondents' indices are around the mid-point, i.e., between 0.4 and 0.6, with the distributions showing a single peak across different categorical groups.

Regarding gender (plot (i)), the *EFSCI* distribution for females has a higher density at the right end of the distribution. Meanwhile, the *EFSCI* distribution does not differ by contract status (plot (ii)). Regarding the types of marketing channels, the *EFSCI* distribution for respondents selling through the marketplace peaks at a higher point than their counterparts (plot (iii)). This is in contrast with social commerce which peaks at a lower point (plot (iv)). Finally, in terms of the types of agri-food products, while

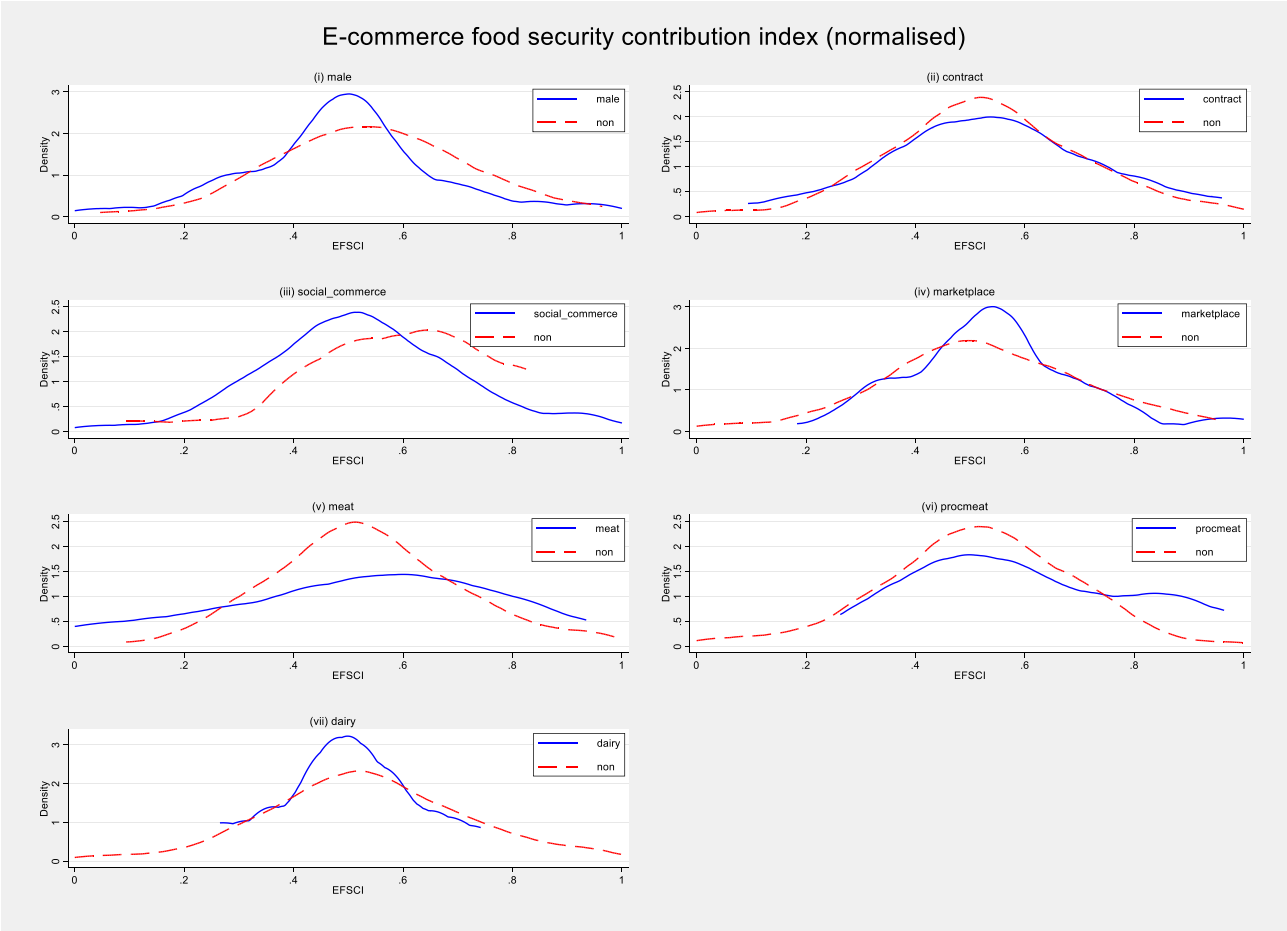

Fig. 3 Kernel Density for the E-Commerce Food Security Contribution Index

the inclusion of *MEAT*, *PROCMEAT*, and *DAIRY* in plots v-vii are to capture products that usually require cold chains, hence a higher contribution to food safety aspects, the last three plots in Fig. 3 do not show a clear indication of such relationship. The following section is to apply the Tobit analysis to control for other variables.

4.2 Factors affecting the EFSCI

Table 3 shows the results of the analysis. Columns (1) and (2) apply the OLS model to assess factors affecting *EFSCI* and *TOTALEFSCI*, respectively. Meanwhile, Column (3) shows the preferred model using the Tobit approach to

Table 3 Tobit model: Determinants of EFSCI

Dependent variable:	*EFSCI*	*TOTALEFSCI*	*EFSCI*
Method:	OLS	OLS	Tobit (one-limit)
	(1)	(2)	(3)
MALE	-0.059*	-0.804*	-0.060**
	(0.030)	(0.425)	(0.029)
AGE	-0.002	0.005	-0.002
	(0.002)	(0.022)	(0.001)
EDUC	-0.006	0.014	-0.006
	(0.006)	(0.084)	(0.006)
EXP_2 (> 1− ≤ 2 years)	0.107***	1.612***	0.108***
	(0.035)	(0.480)	(0.033)
EXP_3 (> 2− ≤ 5 years)	0.079**	1.100**	0.080**
	(0.036)	(0.537)	(0.033)
EXP_4 (> 5 years)	0.112**	1.601**	0.113***
	(0.044)	(0.634)	(0.041)
CONTRACT	0.094	1.459*	0.094
	(0.067)	(0.795)	(0.062)
$EXP_2 \times CONTRACT$	-0.097	-0.402	-0.098
	(0.128)	(1.129)	(0.120)
$EXP_3 \times CONTRACT$	-0.157	-1.395	-0.158
	(0.126)	(1.469)	(0.117)
$EXP_4 \times CONTRACT$	-0.097	-0.819	-0.096
	(0.100)	(1.222)	(0.093)
STAFF	0.011	0.237***	0.011
	(0.009)	(0.085)	(0.008)
SOCECOMM	-0.092*	-0.188	-0.093*
	(0.052)	(0.638)	(0.049)
MARKETPLACE	0.021	1.539***	0.022
	(0.027)	(0.351)	(0.025)
MEAT	-0.015	-1.118	-0.018
	(0.055)	(0.709)	(0.053)
PROCMEAT	0.088**	1.384***	0.088***
	(0.034)	(0.410)	(0.032)
DAIRY	-0.081	-1.329**	-0.080*
	(0.049)	(0.670)	(0.046)
Constant	0.726***	11.387***	0.724***
	(0.117)	(1.501)	(0.109)
District fixed effects	YES	YES	YES
The F-test joint of significance	F (26, 171) = 2.36	F (26, 171) = 2.92	F (26, 172) = 2.70
Prob > F	0.000	0.000	0.000
R^2/Pseudo-R^2	0.209	0.319	-0.448

Robust standard errors are in parentheses. EXP_1(< 1 year) is the reference category. OLS stands for ordinary least squares. Sample size = 198. Significance levels: *p < 0.1; **p < 0.05; ***p < 0.01

Table 4 Robustness check

Dependent variable:	$EFSCI_2$ Excluding availability	$EFSCI_3$ Excluding access	$EFSCI_4$ Excluding utilisation	$EFSCI_5$ Excluding stability
MALE	-0.078***	-0.032	-0.057**	-0.049*
	(0.029)	(0.024)	(0.029)	(0.027)
AGE	-0.001	-0.001	-0.003**	-0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
EDUC	0.007	-0.002	-0.007	-0.006
	(0.006)	(0.004)	(0.006)	(0.005)
EXP_2 (> 1− ≤ 2 years)	0.074**	0.100***	0.115***	0.101***
	(0.031)	(0.027)	(0.033)	(0.031)
EXP_3 (> 2− ≤ 5 years)	0.067**	0.066**	0.055*	0.049*
	(0.033)	(0.029)	(0.031)	(0.029)
EXP_4 (> 5 years)	0.117**	0.071**	0.070*	0.059
	(0.046)	(0.035)	(0.038)	(0.036)
CONTRACT	0.128**	-0.045	0.104	0.097
	(0.053)	(0.052)	(0.065)	(0.060)
$EXP_2 \times CONTRACT$	-0.115	0.041	-0.205**	-0.198**
	(0.106)	(0.070)	(0.086)	(0.079)
$EXP_3 \times CONTRACT$	-0.157	0.096	-0.15	-0.148
	(0.107)	(0.071)	(0.116)	(0.105)
$EXP_4 \times CONTRACT$	-0.065	0.124*	0.039	0.048
	(0.100)	(0.072)	(0.102)	(0.097)
STAFF	0.003	0.010**	0.011	0.008
	(0.008)	(0.005)	(0.007)	(0.007)
SOCECOMM	-0.038	0.01	-0.029	-0.025
	(0.047)	(0.037)	(0.046)	(0.044)
MARKETPLACE	0.041	0.082***	0.035	0.03
	(0.025)	(0.021)	(0.024)	(0.023)
MEAT	-0.065	-0.027	0.079*	0.077*
	(0.046)	(0.047)	(0.048)	(0.045)
PROCMEAT	0.084***	0.076***	0.185***	0.178***
	(0.030)	(0.022)	(0.028)	(0.026)
DAIRY	-0.071*	-0.048	-0.008	0.003
	(0.040)	(0.035)	(0.041)	(0.040)
Constant	0.515***	0.651***	0.540***	0.510***
	(0.107)	(0.086)	(0.107)	(0.101)
District fixed effects	YES	YES	YES	YES
Number of principal components used to derive *EFSCI*	8	7	8	8

Robust standard errors are in parentheses. EXP_1(< 1 year) is the reference category. OLS stands for ordinary least squares. Sample size = 198. Significance levels: *p < 0.1; **p < 0.05; ***p < 0.01

investigate factors influencing *EFSCI*. The limitation of the OLS regressions is that it provides inconsistent estimates of the parameters when the variable is censored.

Across two dependent variables and modelling techniques, Table 3 shows that the years of e-commerce experience variable (*EXP*) and a dummy on selling processed meat (*PROCMEAT*) are positively associated with the e-commerce food security contribution index at a 5% level of significance. The predicted *EFSCI* of a seller with more than five years of e-commerce experience would be 0.1 higher than that of sellers with less than one year of experience. Selling processed meat is associated with an 0.9 increase in *EFSCI*.

Additionally, the results suggest that being a male online agri-food seller is negatively associated with *EFSCI* at a 5% significance level, as shown in Column (3) of Table 3, and at a 10% significance level, with *TOTALEFSCI*. Column (3) shows that for males, the predicted *EFSCI* would be 0.06 points lower than for females. In terms of types of e-commerce, there is an indication that selling on social media has lower *EFSCI*. However, the *SOCECOMM* coefficients are only significant at a 10% significance level in Columns (1) and (3).

The above results are likely sensitive to the selection of indicators. Therefore, the *EFSCI* is recalculated as a robustness check by excluding one of the four food security dimensions to address this. Column (1) of Table 4 shows the determinants of the index when the availability indicators are excluded; Columns (2), (3), and (4) are when the access, utilisation and stability indicators are excluded, respectively. From a food security point of view, these indices are obviously 'incomplete'. However, this exercise helps investigate how variable selection affects earlier interpretations. Table 4 shows that the coefficients of EXP_2 ($> 1- \leq 2$ years) and *PROCMEAT* are positive and significant in all columns, consistent with the previous interpretation.

4.3 Discussion

Overall, the results consistently show the higher contribution of those with more years of experience in e-commerce and selling processed meat to food security. However, the robustness check shown in Table 4 suggests that the significance of other variables, such as the gender variable and marketing channels (e.g. through social commerce), is sensitive to the *EFSCI* index construction.

The significance of years of e-commerce experience is not surprising. Businesses with more years of experience generally have better management capabilities to adopt strategies to improve aspects related to food security, including food safety and certification, than less experienced ones. For instance, a study suggests that senior management's awareness of food safety is essential in implementing a food safety strategy (Bolat, 2002). Likewise, older firms are more likely to adopt international standards in agriculture (Gebreeyesus, 2015). It is argued that the firm's experience represents accumulated resources, market knowledge and developed networks (Gebreeyesus, 2015; Hadjimanolis, 2000). The significance of years of e-commerce experience suggests knowledge-sharing activities among online agri-food sellers. Those with experience selling perishable products such as processed meat using cold chains should also be encouraged to share their experience with other online sellers.

The significance of a dummy variable on selling processed meat is also as expected. A study in China, for example, finds that meat sold online has potential hazards, with endpoint temperature control being the most critical factor in ensuring meat safety (Liu et al., 2019). These potential hazards may lead to a more careful procedure conducted by sellers to ensure the quality and freshness of meat products when being delivered to customers, hence a higher food utilisation aspect. In Indonesia, popular processed meats sold in e-commerce markets include meatballs and sausages (Permani et al., 2021). Sellers typically store these products in a refrigerator or freezer before being distributed to customers. Looking at the descriptive statistics of the survey data,[5] processed meat sellers sell more product varieties, have a higher BPPOM food safety certificate adoption rate and provide more cooking instructions to customers than non-processed meat sellers. This shows processed meat sellers' better awareness of food safety issues, hence a higher food utilisation aspect.

The Tobit model in Column (3) of Table 3 suggests the negative and significant coefficients of variables on being a male (at a 5% significance level) and selling through social media (at a 10% significance level). The negative coefficient of a dummy variable on being male is in line with the extensive literature on the role of women in achieving food security. Most studies focus on either production (e.g., female farmers) or consumption (e.g., female roles in the household) side (Agarwal, 2018; Ibnouf, 2011; Larson et al., 2019). Women with more control over income and access to credit are argued to have more dietary diversity and less food insecurity (Larson et al., 2019).

The negative coefficient of selling through social media is interesting to note. While informal e-commerce, such as marketing through WhatsApp and Instagram, can be seen as "a path to financial inclusion and economic independence", particularly among women (Shah, 2020), social media has more limited features than dedicated e-commerce platforms and is typically used by smaller businesses and new entrants. This lack of knowledge and experience may limit their contribution to food security.

[5] Results are not shown here to preserve space.

5 Conclusions and recommendations

This study investigates the agri-food online sellers' contribution to food security. It is motivated by the increasing role of e-commerce observed in recent years and a literature review that suggests the lack of conceptual frameworks and measures to assess the contribution of e-commerce participants, such as online sellers, to food security and the lack of understanding of factors affecting their food security contribution. To the author's knowledge, this is the first study that uses empirical data to examine this issue. The conceptual framework developed in this study describes the different elements of agri-food e-commerce potentially linked to food security outcomes as proxied by 26 indicators related to food availability, access, utilisation, and stability, which can be replicated in other developing countries. The study highlights a wide range of potential roles in food security that an online agri-food seller can play, from ensuring affordable prices and a stable supply of agri-food products, increasing customers' knowledge of proper cooking and food storage methods, diversifying food options to quality control mechanisms including the use of cold chain, certification, and product testing.

Using data from an online survey of 198 online agri-food sellers in Indonesia, results from the Tobit model suggest that years of experience in e-commerce and selling processed meat are positively associated with a higher contribution to food security, as proxied by *EFSCI* at a 5% significance level. In contrast, being a male seller and marketing on social media are negatively associated with the *EFSCI* at a 10% significance level. The results show the necessity to support new entrants and those selling on social media to better understand food security aspects in their e-commerce operations, the importance of food safety as demonstrated by processed meat sellers, and the significant role of women in promoting food security.

Some caveats should be considered when interpreting the results of this study. First, despite the extensive range of aspects captured by the 26 selected indicators, the multidimensionality of food security means a possibility of important indicators being excluded from the analysis. For example, while this study captures the stability aspects using perception-type questions that compare the seller's experience of online selling to traditional marketing, understanding the extent to which the sellers manage the stability of supply is important. Second, this study has yet to capture the broader food environment aspects, including footprint. For instance, the study finds that selling processed meat is associated with a higher food security contribution without considering greenhouse gas emissions from livestock production. The footprint topics are critical, given a strong push towards more sustainable consumption and production (Chueamuangphan et al., 2020). Finally, the sample size included in the analysis is modest. However, it should still capture the varieties of online agri-food sellers' characteristics and their contribution to food security. These drawbacks, therefore, highlight the need for further research to investigate this critical issue.

Appendix

Table 5 Typology of food security aspects in the context of agri-food e-commerce

(1)	(2)	(3)	(4)	(5)	
E-commerce aspect	Survey questions to online sellers	Answer options	Variable name	Inclusion in the E-Commerce Food Security Contribution Index	#
AVAILABILITY					
Number of online channels	Do you currently sell agri-food products using the following marketing channels?	A food delivery service app (GRAB, GoFood, GoShop); an online marketplace selling both food and non-food products (Tokopedia, Shopee, Blibli); an online marketplace specialising in food products (Etanee, Sayurbox, Tanihub); supermarkets/ hypermarkets with online services (e.g., Lottemart); butchery with online services; Personal Whatsapp; Whatsapp for business; Personal Facebook; Facebook marketplace; Instagram	food_delivery general_marketplace agrifood_online supermarket_online butchery_online whatsapp_indiv whatsapp_business facebook_indiv facebook_marketplace Instagram	Number of online marketing channels (n_channel)	1
Chain role	What is your main occupation?	Individual farmers; food processor owner/staff; Supermarket owner/ staff; Cooperative member/committee; Importer; Collector; Wholesaler; Other	farmer foodproc supermarket coop importer collector wholesaler other_role	farmer (dummy), foodproc (dummy)	2 3
Import use	Do you use any imported ingredients, inputs or raw materials? What are they?	Yes/No; followed by an open-ended question	import_use	import_use (dummy)	4
Access to credit	How effective has the following supporting factor to help you improve supply (in terms of quality, quantity and consistency)? Financing/access to credit	Never access, very ineffective, ineffective, effective, very effective	access_credit	access_credit (dummy)	5
ACCESS					
Number of delivery methods	How are your products being transferred to your buyers?	delivered to/collected by e-commerce platform procurement officers; delivered to e-commerce platform warehouse; delivered to/collected by agents/resellers as part of the e-commerce platform; delivered to food services; delivered to kiosks; delivered to households/end-consumers; other	deliver_procurement deliver_warehouse deliver_reseller deliver_foodservice deliver_kiosk deliver_household	Number of delivery methods (n_delivery)	6
Price information	Do your online channels have the following product information: **price**?	Available; Not available; Don't know	info_price	info_price (dummy)	7

Table 5 (continued)

(1)	(2)	(3)	(4)	(5)	
Accessibility for consumer demographics	Respondents were asked to use the slider (0–100%) to describe the characteristics of customers buying their products online	% Female customers, % customers aged under 30, % customers from middle-upper income class, % customers from urban areas, % individual/household customers, % customers from food services	customer_female customer_under30 customer_midinc customer_urban customer_foodservice	customer_female customer_under30 customer_midinc customer_urban customer_foodservice	8 9 10 11 12
Delivery area: other cities	Do you deliver your products to customers in other cities	Yes/No	deliver_othercity	deliver_othercity	13
Delivery area: other provinces	Do you deliver your products to customers in other provinces?	Yes/No	deliver_otherprovince	deliver_otherprovince	14
UTILISATION					
Product quality	Does the e-commerce platform conduct any of the following activities to ensure the quality of your products?	Product testing; Specifying product requirements in the contract; Providing technical advice to suppliers; Certification, Other	quality_testing quality_contract quality_techadvice quality_certification quality_other	Number of product quality testing methods (n_quality)	15
Product diversity	Which of the following products do you market through online channels?	Fruits and vegetables; Chicken; Eggs; Beef; Lamb; Fish; Seafood; Processed meat products (e.g., meatballs, sausages, nuggets, etc.); Dairy products; Rice; Coffee; Seasoning and spices; Ready-to-eat meals; Other	fruitveg chicken eggs beef lamb fish seafood procmeat dairy rice coffee herbs cookedfood other	Number of products marketed through online channels (n_product)	16
Certification	Do your agri-food products marketed through online channels have any of the following certifications?	SNI (Indonesian National Standard certification); Halal certification, BPPOM (Food and drugs agency) certification; Veterinary control number for animal products; HACCP; Organic certification; Other	certificate_halal certificate_bppom certificate_nkv certificate_haccp	halal (dummy) bppom (dummy)	17 18
Information for customers: recommended storage	Do your online channels have the following product information: **recommended storage**?	Available; Not available; Don't know	info_storage	info_storage	19
Information for customers: recommended cooking	Do your online channels have the following product information: **recommended cooking**?	Available; Not available; Don't know	info_cooking	info_cooking	20

Table 5 (continued)

(1)	(2)	(3)	(4)	(5)	
STABILITY					
Stability of supply	Compared to selling your products to other markets (such as wet markets, supermarkets, etc.), how much more or less difficult do you think it would be for you to do the following when supplying to an e-commerce platform: **supply consistent product season to season**	Much more difficult; Somewhat more difficult; About the same; Less difficult; Much less difficult	supply_stability	supply_stability (Likert; 1–5)	21
Price stability	Compared to selling your products to other markets (such as wet markets, supermarkets, etc.), how much more or less difficult do you think it would be for you to do the following when supplying to an e-commerce platform: **monitor price fluctuations**	Much more difficult; Somewhat more difficult; About the same; Less difficult; Much less difficult	price_volatility	price_volatility (Likert; 1–5)	22
Production/stocking planning	Compared to selling your products to other markets (such as wet markets, supermarkets, etc.), how much more or less difficult do you think it would be for you to do the following when supplying to an e-commerce platform: **plan for production/stocking**	Much more difficult; Somewhat more difficult; About the same; Less difficult; Much less difficult	planning_prodstocking	planning_prodstocking (Likert;1–5)	23
Future participation	When the COVID-19 pandemic is over, will you continue to market your agri-food products through online channels?	Yes/No	future_participation	future_participation (dummy)	24
Prospect	When the COVID-19 pandemic is over, what do you think about opportunities for marketing agri-food products through online channels?	Strongly Decrease; Decrease; Neutral; Strongly increase; Increase	prospect	prospect (dummy)	25
E-commerce development factors	In your opinion, what factors would drive future e-commerce development?	Technological advancements; Government support; Growing middle-income class; Changing lifestyle; Changing dietary preference; the role of Millenials; Further opening of the economy, e.g. as a result of free trade agreements; Other	factor_tech factor_govsupport factor_midinc factor_lifestyle factor_diet factor_millenial factor_openecon factor_other	factor_tech (dummy)	26

Source: Author's compilation

Table 6 Availability dimension of agri-food e-commerce

	mean	st.dev	min	max
Online channels*				
food_delivery	0.247	0.433	0.000	1.000
general_marketplace	0.268	0.444	0.000	1.000
agrifood_online	0.020	0.141	0.000	1.000
supermarket_online	0.030	0.172	0.000	1.000
butchery_online	0.010	0.100	0.000	1.000
whatsapp_indiv	0.798	0.403	0.000	1.000
whatsapp_business	0.258	0.438	0.000	1.000
facebook_indiv	0.404	0.492	0.000	1.000
facebook_marketplace	0.263	0.441	0.000	1.000
Instagram	0.576	0.495	0.000	1.000
Chain role				
farmer	0.076	0.265	0.000	1.000
foodproc	0.616	0.488	0.000	1.000
supermarket	0.010	0.100	0.000	1.000
coop	0.015	0.122	0.000	1.000
importer	0.005	0.071	0.000	1.000
collector	0.000	0.000	0.000	0.000
wholesaler	0.035	0.185	0.000	1.000
other_role	0.242	0.430	0.000	1.000
Import use				
import_use	0.025	0.158	0.000	1.000
Access to credit				
access_credit	2.955	1.485	1.000	5.000

Source: Author's calculation using survey data

*Respondents can answer more than one

Table 7 Access dimension of agrifood e-commerce

	mean	st.dev	min	max
Delivery to customers*				
deliver_procurement	0.268	0.444	0.000	1.000
deliver_warehouse	0.061	0.239	0.000	1.000
deliver_reseller	0.237	0.427	0.000	1.000
deliver_foodservice	0.116	0.321	0.000	1.000
deliver_kiosk	0.187	0.391	0.000	1.000
deliver_household	0.788	0.410	0.000	1.000
Price information				
info_price	0.818	0.387	0.000	1.000
Customer demographics				
customer_female	65.237	21.874	0.000	100.000
customer_under30	52.337	23.612	0.000	100.000
customer_midinc	54.884	21.317	0.000	95.000
customer_urban	62.612	23.247	0.000	100.000
customer_foodservice	22.472	23.820	0.000	99.000

Source: Author's calculation using survey data

*Respondents can answer more than one

Table 8 Utilisation dimension of agrifood e-commerce

	mean	sd	min	max
Product quality*				
quality_testing	0.278	0.449	0.000	1.000
quality_contract	0.217	0.413	0.000	1.000
quality_techadvice	0.374	0.485	0.000	1.000
quality_certification	0.192	0.395	0.000	1.000
quality_other	0.162	0.369	0.000	1.000
Product diversity*				
fruitveg	0.162	0.369	0.000	1.000
chicken	0.056	0.230	0.000	1.000
eggs	0.025	0.157	0.000	1.000
beef	0.010	0.100	0.000	1.000
lamb	0.000	0.000	0.000	0.000
fish	0.051	0.220	0.000	1.000
seafood	0.045	0.209	0.000	1.000
procmeat	0.217	0.413	0.000	1.000
dairy	0.066	0.248	0.000	1.000
rice	0.051	0.220	0.000	1.000
coffee	0.157	0.364	0.000	1.000
herbs	0.111	0.315	0.000	1.000
cookedfood	0.480	0.501	0.000	1.000
other	0.172	0.378	0.000	1.000
Certification*				
certificate_halal	0.434	0.497	0.000	1.000
certificate_bppom	0.167	0.374	0.000	1.000
certificate_nkv	0.005	0.071	0.000	1.000
certificate_haccp	0.005	0.071	0.000	1.000
certificate_organic	0.045	0.209	0.000	1.000
certificate_other	0.439	0.498	0.000	1.000
Information for customers				
info_storage	0.510	0.501	0.000	1.000
info_cooking	0.399	0.491	0.000	1.000

Source: Author's calculation using survey data

*Respondents can answer more than one

Table 9 Stability dimension of agri-food e-commerce

	mean	min	max	sd
Stability of supply, price monitoring and production/stocking planning				
supply_stability[b]	3.566	1.000	5.000	1.177
price_volatility[b]	3.744	1.000	5.000	1.084
planning_prodstocking[b]	3.758	1.000	5.000	1.039
Future participation and prospect				
future_participation	0.969	0.000	1.000	0.173
prospect	1.914	1.000	4.000	0.727
E-commerce development factors[a]				
factor_tech	0.864	0.000	1.000	0.344
factor_govsupport	0.551	0.000	1.000	0.499
factor_midinc	0.374	0.000	1.000	0.485
factor_lifestyle	0.561	0.000	1.000	0.498
factor_diet	0.157	0.000	1.000	0.364
factor_millenial	0.475	0.000	1.000	0.501
factor_openecon	0.394	0.000	1.000	0.490
factor_other	0.020	0.000	1.000	0.141

Source: Author's calculation using survey data

[a]Respondents can answer more than one

[b]'Don't know' responses are excluded

Table 10 PCA scoring coefficients

Variable	Comp1	Comp2	Comp3	Comp4	Comp5	Comp6	Comp7	Comp8	Comp9
n_channel	0.298	0.046	-0.138	-0.235	-0.115	-0.142	0.056	-0.064	-0.263
farmer	-0.028	-0.159	0.107	0.182	-0.162	0.462	0.189	-0.251	0.101
foodproc	0.144	0.198	-0.130	-0.301	0.077	-0.212	-0.369	0.197	0.098
import_use	0.098	0.038	-0.016	-0.129	-0.192	-0.203	0.110	0.387	0.007
access_credit	0.154	0.016	0.030	0.039	0.267	0.339	-0.292	-0.041	-0.103
n_delivery	0.278	-0.083	-0.288	-0.142	0.013	0.117	0.055	0.059	-0.139
info_price	0.080	0.182	0.254	0.054	-0.133	-0.229	-0.198	-0.204	-0.221
customer_female	0.146	0.225	0.231	-0.174	-0.069	0.043	0.259	0.026	-0.294
customer_under30	-0.058	0.180	0.357	-0.112	0.116	0.122	-0.148	0.131	-0.118
customer_midinc	0.239	0.238	0.215	-0.175	-0.090	0.359	0.101	0.200	0.069
customer_urban	0.205	0.194	0.290	-0.191	-0.132	0.244	0.192	0.008	0.109
customer_foodservice	0.094	-0.023	-0.207	0.144	0.118	0.259	0.075	0.467	0.170
deliver_othercity	0.303	0.040	-0.233	0.198	-0.340	-0.006	0.045	-0.211	-0.043
deliver_otherprovince	0.265	0.069	-0.254	0.115	-0.384	0.023	0.043	-0.135	0.069
n_quality	0.241	-0.012	-0.287	-0.016	0.326	0.193	-0.064	-0.006	-0.086
n_product	0.104	0.016	0.010	0.016	0.273	-0.080	0.206	-0.276	-0.437
certificate_halal	0.167	0.117	-0.188	-0.067	0.303	-0.187	0.357	0.013	0.192
certificate_bppom	0.087	0.163	0.106	0.118	0.415	-0.118	0.335	-0.227	0.287
info_storage	0.153	0.296	0.114	0.476	-0.018	-0.110	-0.106	0.178	-0.029
info_cooking	0.153	0.263	0.072	0.519	0.078	-0.141	-0.010	0.155	-0.026
supply_stability	0.238	-0.405	0.195	0.091	-0.029	-0.104	-0.043	0.171	-0.016
price_volatility	0.290	-0.394	0.269	0.057	0.083	-0.102	0.052	0.082	-0.040
planning_prodstocking	0.268	-0.434	0.220	0.039	0.050	-0.116	-0.005	0.069	0.024
future_participation	0.202	0.047	0.089	0.004	-0.090	-0.018	-0.245	-0.233	0.472
prospect	-0.171	-0.013	0.064	-0.065	-0.176	-0.214	0.401	0.149	0.149
factor_tech	0.211	0.027	0.116	-0.254	0.082	-0.147	-0.132	-0.243	0.338

Only components with eigenvalues above one are included. Varimax rotation is applied

Source: Author's calculation using survey data

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