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Analysis of Key Factors Influencing Spice Traceability Systems: The Example of Black Pepper (Piper nigrum L.)

Analiza kluczowych czynników wpływających na systemy identyfikowalności przypraw na przykładzie pieprzu czarnego (Piper nigrum L.)

Joanna Newerli-Guz[1], **Marcin Rybowski**[2]

[1] Gdynia Maritime University, Department of Quality Management, Morska 81-87, 81-225 Gdynia, e-mail: j.newerli-guz@wznj.umg.edu.pl, ORCID: https://orcid.org/0000-0002-4309-9966

[2] Gdynia Maritime University, Department of Transport and Logistics, Morska 81-87, 81-225 Gdynia, e-mail: m.rybowski@wn.umg.edu.pl, ORCID: https://orcid.org/0000-0003-1380-2275

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ABSTRACT

Objective: To analyse key issues related to the pepper market, the transport of pepper and requirements during transport; to examine issues related to supply chain management of peppers (and, by extension, other spices and related products) with a particular emphasis on their traceability.

Research Design & Methods: Statistical data was collected and analysed along with the literature on the traceability systems of black pepper.

Findings: The study identified the main problems related to product identification, transparency and security of the data used in traceability systems.

Implications/Recommendations: Product traceability changes the perception of products on the market and increases confidence in supply chains. For the black pepper supply chain

(BPSC), solutions that ensure process transparency and continuity of the information stream are paramount to reduce the possibility of product adulteration and other forms of fraud. Black pepper traceability should facilitate the detection of dangerous products and their withdrawal from the market. The ease with which traceability systems can control and reduce the costs associated with product aging and spoilage is less important for the trade of black pepper, but is nonetheless a factor.
Contribution: Recommendations are put forward for future studies on ensuring food safety and customer satisfaction as well as product reliability.

Article type: original article.

Keywords: black pepper, quality, transport, supply chains, traceability.

JEL Classification: R410, Q170.

STRESZCZENIE

Cel: Analiza kluczowych zagadnień związanych z rynkiem pieprzu, jego transportem i wymaganiami stawianymi podczas przewozu oraz zbadanie zagadnień związanych z zarządzaniem łańcuchem dostaw tego rodzaju produktów ze szczególnym uwzględnieniem ich identyfikowalności.
Metodyka badań: Gromadzenie i analiza danych statystycznych oraz literatury dotyczącej systemu identyfikowalności pieprzu czarnego.
Wyniki badań: Badanie pozwoliło na rozpoznanie głównych problemów związanych z identyfikacją produktu, transparentnością i bezpieczeństwem otrzymanych danych w systemach identyfikowalności.
Wnioski: Identyfikowalność produktów zmienia ich postrzeganie na rynku i zwiększa zaufanie do łańcuchów dostaw. W przypadku łańcucha dostaw pieprzu czarnego (BPSC) najważniejsze są rozwiązania zapewniające przejrzystość procesów i zachowanie ciągłości strumienia informacji o nich, aby ograniczyć możliwość zafałszowania produktu i innych oszustw. Identyfikowalność w przypadku pieprzu czarnego powinna również ułatwić wykrywanie produktów niebezpiecznych i wycofanie ich z rynku. Łatwość, z jaką systemy identyfikowalności mogą kontrolować i zmniejszać koszty związane ze starzeniem się i psuciem produktów, jest zdecydowanie mniej ważna w przypadku handlu pieprzem czarnym.
Wkład w rozwój dyscypliny: Wskazanie rekomendacji co do przyszłych badań dotyczących zapewnienia bezpieczeństwa żywności i satysfakcji klientów z wiarygodnej identyfikacji zakupionych produktów.

Typ artykułu: oryginalny artykuł naukowy.

Słowa kluczowe: pieprz czarny, jakość, transport, łańcuchy dostaw, identyfikowalność.

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1. Introduction

Spices are an important sector of food production. The global value of this market in 2018 was 15.9 billion US$, and its value is estimated to grow to 22.8 billion US$

by 2026, with an annual growth rate of 4.7% (Prophecy Market Insights 2022). Globally, the most widely used and widely traded spice is black pepper (*Piper nigrum* L.), a Fast-Moving Consumer Good (FMCG). Factors that affect the quality of black pepper include transport conditions, supply chain transparency and traceability information sharing and tracking. There are also different technological solutions intended to ensure certainty, transparency and the security of data obtained in traceability systems, including those used for black pepper.

This study focused on the analysis of key issues related to the market, transport and its requirements for pepper with particular emphasis on black pepper (*Piper nigrum* L.). The methodological approach employed for the research was to search the subject literature, identify the main problems, discuss the results and make further recommendations for future studies. Black pepper traceability systems are also specified, as the quality and safety of product are mostly affected by critical events that can be affected by such systems. The aim of this study was to identify the key issues related to the pepper market, the transport of the spice and the requirements involved with them (with a particular emphasis on black pepper *Piper nigrum* L.). It is based on a reading of the relevant literature and analysis of black pepper traceability systems described therein. The study also looks at the main problems with product identification as well as the transparency and security of data received by traceability systems.

2. Product Characteristics

Black pepper, called black gold, the king of spices, is one of the oldest cultivated plants, and is probably native to the northern part of India (Assam) or northern Burma. The homeland of pepper is considered to be the Malabar Coast. Black pepper is the fruit of an evergreen shrub of the pepper family. The ripe fruit should be hard, with a diameter from 3 to 6 mm and a strongly wrinkled pericarp. It is brown-black or dark grey to grey-brown in colour, with an aromatic, spicy, strong smell (PN-A-86965:1997). Harvested from fruits at the initial stage of ripening, the peppercorns are then dried, most often in the sun, until the skin acquires a dark, nearly black, colour.

Black pepper intended for sale is standardised and different quality classes are used. There are classes in India, five in Malaysia, and two in Brazil. The class of the product is most influenced by its purity and residual humidity. Attention is focused mainly on the presence of "light berries" and foreign components, including dust, stems, parts of leaves and other parts of plants. The most elaborate system of division for black pepper is found in India, where it is divided into 14 types, based on the size and shape of black pepper berries. Here are ten of its constituents:

– Malabar garbled black pepper (MG) – grades 1, 2,
– Malabar ungarbled black pepper (MUG) – grades 1, 2,

– Tellicherry garbled special extra bold black pepper (TGSEB),
– Tellicherry garbled extra bold black pepper (TGEB),
– Tellicherry garbled black pepper (TG),
– garbled light black pepper (GL) – special grades 1, 2,
– ungarbled light black pepper (UGL) – grades 1, 2,
– pin heads (PH) – special and grade 1,
– black pepper (non-specified),
– black pepper not listed elsewhere (NS).

Very small and underdeveloped pepper berries are classified as "pinheads". Most types of black pepper listed above are Malabar pepper, which has medium-sized fruits. Larger-sized berries fall under the Tellicherry categories. Pepper has been traded in Tellicherry since ancient times (Parathasarathy, Chempakam & Zachariah 2008). Good black pepper should have a density of 500–600 g per litre and the content of light berries should be less than 10%, and pin heads less than 4%. Low density indicates a greater proportion of bright berries and pin heads, lowering product quality. Quality black pepper should have a good smell and a biting, pungent taste. It should contain at least 1.5% essential oil and 3% piperine (Ravindran 2001, Ravindran & Kallupurackal 2012). But multiple factors affect the quality of black pepper. The variety of the plant is the most important factor, especially as there are more than 2,000 varieties, at least in The Indian Spice Research Institute's collection (Krishnamoorthy & Parthasarathy 2010). Other important factors include growing and harvesting conditions, and post-harvest procedures including drying, cleaning, standardisation, and the transport and storage procedures used by exporters.

3. Production, Trade and Terms of Transport

In OECD Economic complexity rankings, black pepper falls in the coffee, tea, mate and spices group. The pepper group includes pepper of the genus *Piper*, whole and crushed or ground, but also *Capsicum* or *Pimenta*, dried and crushed or ground.

In 2020, the pepper group was the world's 536th most traded product, with a total trade of $4.1B. Between 2019 and 2020, exports of the pepper group grew by 5.38%, from $3.89B to $4.1B. Trade in the pepper group represent 0.025% of total world trade. In 2020, whole pepper of the genus *Piper* was the world's 1678th most traded product, with a total trade of $1.25B, while crushed or ground pepper of the genus *Piper* was the world's 2952nd most traded product, at $382M. Between 2019 and 2020 the exports of whole pepper of the genus *Piper* decreased by 6.62%, from $1.34B to $1.25B, while exports of crushed or ground equivalent grew by 0.11%, from US$381M to US$382M (OECD 2022).

Table 1 lists the main exporters and importers of the pepper group, pepper *Piper* whole and pepper crushed or ground in 2020. It contains the value of imports and exports in US dollars and the percentage of the share of individual countries in the total export/ imports of these goods.

Table 1. The Main Exporters and Importers of the Pepper Group, Pepper of the Genus *Piper* Whole, and Crushed or Ground in 2020

Specification	Pepper Group			Pepper Whole			Pepper Crushed or Ground		
	Country	US$	%	Country	US$	%	Country	US$	%
Export	India	1.16B	28.0	Vietnam	532M	42.5	Vietnam	134M	35.1
	Vietnam	695M	16.9	Brazil	188M	15.1	India	34M	8.9
	China	587M	14.3	Indonesia	155M	12.4	Germany	31M	8.0
	Spain	227M	5.5	Sri Lanka	51M	4.1	US	24M	8.9
	Brazil	200M	4.9	India	39M	3.3	Netherlands	20M	5.3
Import	US	611M	14.9	US	172M	13.8	US	78M	20.5
	China	575M	14.0	China	130M	10.4	UK	33M	8.8
	Thailand	203M	4.9	India	106M	8.4	Canada	29M	7.6
	Germany	192M	4.7	Germany	90M	7.2	Netherlands	19M	4.9
	Spain	159M	3.9	Vietnam	83M	6.6	Japan	16M	4.2

Source: based on (OECD 2022).

The volumes (in tonnes) of production, export and import between 2013 and 2020 are shown in Figures 1, 2 and 3.

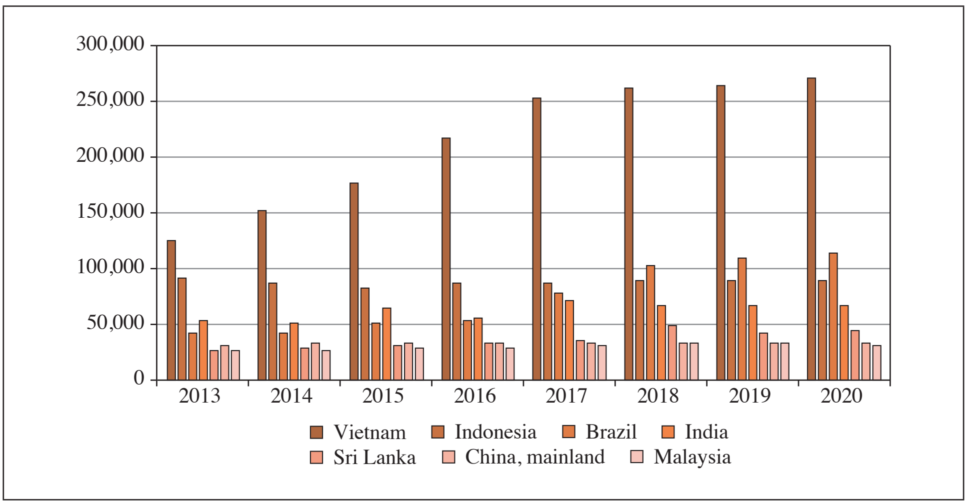

Fig. 1. The Volume of Black Pepper Produced in 2013–2020 (in Tonnes)

Source: (Food and Agriculture Organization of the United Nations (FAO) 2022).

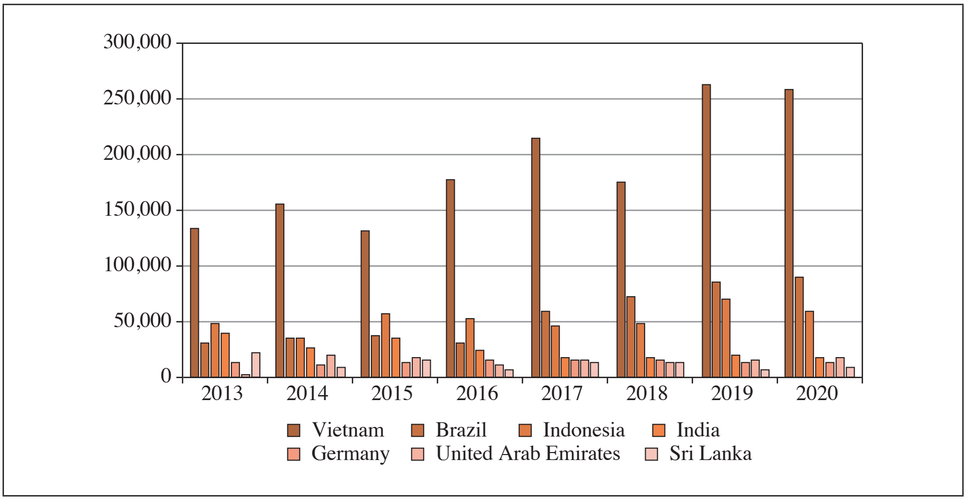

Fig. 2. The Volume of Black Pepper Exported in 2013–2020 (in Tonnes)
Source: (Food and Agriculture Organization of the United Nations (FAO) 2022).

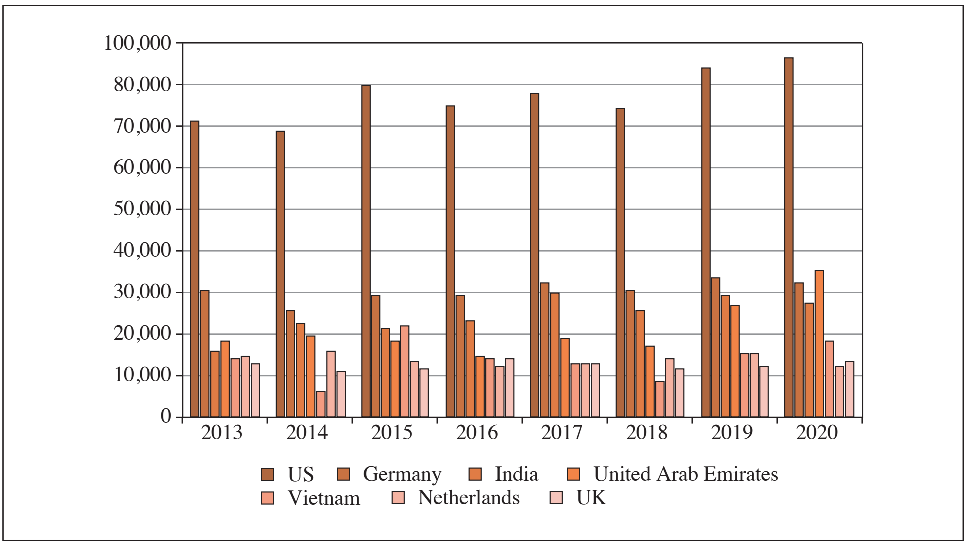

Fig. 3. The Volume of Black Pepper Imported in 2013–2020 (in Tonnes)
Source: (Food and Agriculture Organization of the United Nations (FAO) 2022).

According to the Code of Practice for the Packaging and Transport of Fresh Fruit and Vegetables (CXC 44-1995), the bulk transport of spices and dried culinary herbs, by ship or rail, should be well ventilated with dry air to prevent moisture condensation. Prior to bulk transport, the products must be dried to a safe moisture level to prevent the growth of moulds and pathogenic bacteria (Codex Alimentarius 2018).

Table 2. Transport Conditions of Black Pepper *Piper Nigrum* L.

Conditions	Favourable	Possible Consequences
Temperature	5–25°C	temperatures > 25°C, loss of essential oils, risk of self-heating; temperatures > 40°C, the product dries out by > 0.5%; when container exposed to direct solar radiation, product may dry out by > 2%
Humidity Moisture / water content	50–60% 10–15% very moisture-sensitive; strongly hygroscopic	rotting, product spoilage, formation of mold
Ventilation conditions	air exchange rate 10 changes / hour; the stowage space should be cool, dry and easy to ventilate	product spoilage
Biotic activity	pepper has 3rd order biotic activity, the respiration processes of which are suspended	biochemical, microbial and other decomposition processes occur and must be taken into consideration
Gases	should be ventilated	continuing fermentation processes in the hold, increased CO_2 concentration and a consequent O_2 shortage may occur
Self-heating / spontaneous combustion	inadequate ventilation, high water content, and high temperature cause the pepper to spoil due to self-heating	pepper becomes completely wet, swells and heats up so much that it begins to steam; as a result, the product may become worthless in a very short time
Odour The strong, pleasant odour of pepper comes from its essential oils – piperine and piperidine – and the resin chavicine	increased odour in the container or hold indicates self-heating, increased release of water vapour and the loss of essential oils	pepper should be stowed separately and away from foodstuffs which readily absorb foreign odours (e.g. coffee, tea or copra); pepper is extremely odour--sensitive and should not be stowed with strong-smelling products (extracts or essential oils)
Contamination	not present	active behaviour; pepper does not cause contamination; passive behaviour; pepper is sensitive to contamination by dust, dirt, fats and oils

Table 2 cnt’d

Conditions	Favourable	Possible Consequences
Insect infestation/diseases	pepper is very rarely affected by insects	damage is mainly caused by small rodents or insects (e.g. beetles, moths or mites)
Shrinkage/shortage	normal values are 2–4%	weight losses of up to 7% may occur by evaporation of residual intrinsic moisture content

Source: (German Insurance Association (GDV e.V.) 2022, Newerli-Guz 2018).

Non-porous bags/containers are used to protect the spices and dried culinary herbs from contamination and the introduction of moisture, insects and rodents. The reabsorption of ambient moisture must also be prevented. Contamination can be avoided with the use of liners where appropriate. It is recommended that new bags or containers be used for food contact packaging. If reusable bags/containers are used, they should be properly cleaned and disinfected before use. All bags/containers should be in good condition and particular attention should be paid to the possibility of potential contamination in the form of loose sac fibers. Secondary containment bags/containers providing additional protection can be reused but should not have been used previously to hold non-food materials such as chemicals or animal feed. Spices and dried culinary herbs should not be sprayed with water to prevent breakage during packing. The presence of water can result in the growth of moulds and microbial pathogens (Codex Alimentarius 2018, p. 20). The preferred conditions for transport of pepper are shown in Table 2.

4. Food Supply Chains

Food supply chains (FSC) are complex, large-scale, global systems which involve many entities, from small farmers and processors, medium-sized traders to large multinational corporations. While some of these FSCs are limited local solutions, most have a complicated, expanded form with high-end elements. The majority of FSC products and commodities are manufactured in bulk. The relationships between products and between entities in FSCs are many-to-many, and create a structure that is difficult to understand and manage.

The foremost problem in FSC turns out to be one that characterises the spice trade: ascertaining information about the product, original producers or suppliers and production processes. But collecting such information is essential for black pepper (*Piper nigrum* L.), a plant product that is not only cultivated in a specific geography, and climatic and soil conditions, but is sold throughout the world as the single most popular spice (Parathasarathy, Chempakam & Zachariah 2008). The multiplicity of the cultivation locations, followed by the processing, sorting and packaging of the product, create a complicated system on the supply side of FSC in the exporting countries. In importing countries, the product undergoes subsequent operations, mainly logistical and commercial, including repackaging and distribution, as well as re-export.

The complexity of FSC can result in multi-aspect bottlenecks that pose a challenge for chain management. Such bottlenecks are critical to address in FSCs, which need to be transparent to ensure food safety and authenticity in particular. Some of the problematic issues result from deliberate measures, such as product mixing or physical contamination, which enable adulteration and food fraud. They can also be caused by a lack of control over product processing, reloading and repackaging from bulk to unit packages. During these operations, food product may lose its quality features, specific properties, or regional, national and certificate ("Fair Trade," for example) affiliation. Most of these changes can be detected at the initial and final stages of the supply chain using fingerprint analysis (Wilde *et al*. 2019), chemometrics (Rivera-Perez, Romero-Gonzalez & Garrido Frenich 2021), and spectroscopy (Hu *et al*. 2018) or DNA tests (Parvathy *et al*. 2014).

Time is of the essence in every FSC and is crucial for fresh food, if less important for processed food. Proper preparation, mainly the drying of spices, ensures a longer period of time, in which they can be transported, stored, sold and consumed without losing its quality. FSCs are particularly vulnerable to time-related risks, making planning and implementation methods and techniques for the flow of goods and information of great importance.

5. Transparency and Traceability

As a food product, and like most FMCG (Fast Moving Consumer Goods), black pepper is sold based on an intensive distribution model (selling a product in as many outlets as possible), although some consumers do look for product of a specific origin, type, color, appearance, taste, pungency, texture, shape and volatile oil contents. FSC managers must supervise and control all processes, to maintain the key quality features for a given product across the supply chain. Product flow in FSC is always accompanied by the flow of information, with integrity as its main, necessary feature, contributing to the improvement of food safety. The health implications of food products were behind the push to create concepts of transparency and traceability in FSC, based on a full, uninterrupted, high-quality information stream.

As a critical organisational function, supply chain transparency enables the construction of information links between the organisation and its internal (supply chain partners, employees) and external (customers, governments, local communities, NGOs) stakeholders. Striving to increase transparency improves process visibility in FSC, leads to greater accountability and improves control over supply chain operations. Thus, transparency strategies reduce operational risk, improving FSC resilience in the face of uncertain environments.

From the perspective of FSC external partners', transparency strategy guarantees product origin, authenticity and integrity. This is the effect of reducing information asymmetry between buyers and sellers, limiting the risk associated with transactions and increasing confidence. Supply chain transparency is achieved thanks to a traceability system which, may lead to the achievement of sustainable goals, mainly social and environmental ones. Such goals may include ensuring decent work conditions, fighting slavery and human trafficking, reducing carbon footprint, and connecting with local communities (Montecchi, Plangger & West 2021). FSC transparency is mainly based on quality, availability, accuracy, accessibility and updatedness of data, which creates information for supply chain players, both in vertical and horizontal dimensions (Bastian & Zentes 2013). The relevance of that information is highlighted by the extent to which all of a network's stakeholders have a shared understanding of, and access to, product- and process-related information that they request, without loss, noise, delay or distortion (Beulens *et al*. 2005).

Transparency in FSC is particularly important for maintaining the quality and guaranteeing the safety of food products. According to the European Parliament and the Council of the European Union (Regulation (EC) No 178/2002), a key instrument for transparency in food safety system is traceability, understood as the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into food or feed, through all stages of production, processing and distribution (Salampasis, Tektonidis & Kalogianni 2012).

There are three main components of many definitions of traceability: tracing as a backward follow-up on products, tracking as a forward follow-up and the product history information associated with the product movement in the supply chain (Bosona & Gebresenbet 2013). In their extensive analysis of these elements, Bosona and Gebresenbet concluded that even the international standardisation of the definition of traceability as an ISO standard (ISO 8402) does not guarantee a complete and comprehensive description of the phenomenon. Furthermore, a systematic literature review shows that even in scientific papers there is considerable confusion and inconsistency (Karlsen *et al*. 2013, Olsen & Borit 2013). Food traceability is defined as a part of logistics management that captures, stores, and transmits appropriate information about a food, feed, food-producing animal or substance at all stages in the food supply chain so that the product can be checked for safety and quality control, traced upward or downward at any time required (Bosona & Gebresenbet 2013). Figure 4 illustrates the concept.

Using traceability in FSC, a system is created where each processor should be able to ensure that foodstuffs entering its premises are traceable to the supplier and foodstuffs leaving the control of the business are traceable to the immediate consumer (European Spice Association 2018).

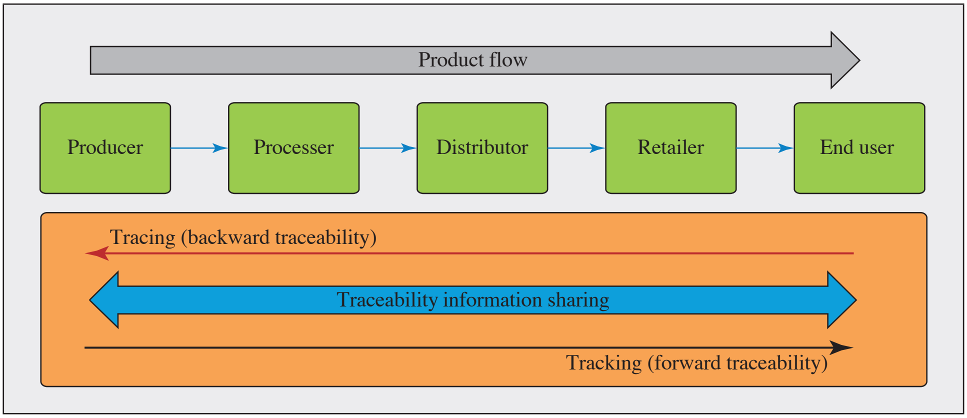

Fig. 4. Scheme of Traceability Information Sharing and Tracking
Source: (Bosona & Gebresenbet 2013).

Due to the multiplicity of approaches to traceability, there is a lack of uniform requirements and standards for different industries, including FSC. Food products have many particular features that are reflected in the design and management of FSC processes. Important elements of an effective traceability system include information on trading partners, product and processing locations, and the types of products used and created within the supply chain. All this in combination with logistic data on loading units, shipments, packaging, dates and places where they appear. In this system, the most important factor is to identify individual events and the related data elements. The stages of the processed food supply chain and spices including black pepper are: cultivation, harvesting (crop), processing (drying), packaging, transport, repackaging and distribution and storage processes (technological or commercial). Critical Tracking Events (CTEs) and Key Data Elements (KDEs) for each of these steps have been described in detail by Zhang and Bhatt (2014). They indicated the need to use a uniform system in which each flow element can be uniquely identified globally, and for all FSC participants to use an internal and external traceability system that ensures full visibility.

The Codex Alimentarius Commission recommends that traceability records for culinary herbs and spices identify the source (or lot number) of incoming raw materials and link it to the lots of outgoing products (Codex Alimentarius 2014). Such an internal traceability system that links incoming and outgoing product or that traces the splitting up and combining of batches would contribute to more targeted and accurate withdrawals or recalls, and could be used to confirm compliance with standards or agreement conditions (Schaarschmidt *et al*. 2016).

The initial stages of BPSCs (black pepper supply chains) are of essential importance, as it is mostly here that product quality and safety are affected by critical events. These stages involve, among other things, capturing and recording the type and number of contaminants that occur naturally, that come from the same plant species but a different, unwanted part of it or from other external sources. It is also here that preventive measures are used, particularly ones seeking to stop the deliberate adulteration of product resulting from the use of undesirable additives or the mixing of products with different characteristics (Lafeuille *et al*. 2019). Other bottlenecks in BPSC may relate to the repackaging of product from bulk to unit packaging, when the properties of the processed product are altered, intentionally or otherwise. Further problems may arise during transport, storage and trans-shipment operations, and all of them can be a potential source of threats to product quality.

A traceability system cannot exist without the use of technological innovations related to three areas: data acquisition, ensuring the certainty, transparency and security of the data, and managing the information acquired.

The first group of these solutions make it possible to effectively and efficiently acquire data about a product's provenance and ingredients, facilitate full insight into the product history, and record supply chain events which are important from the point of view of food safety and consumer protection (Wallace & Manning 2020). These technologies, intended for product and other resources identification, include older solutions such as bar codes, RFID (Radio Frequency Identification) tags (Badia-Melis, Mishra & Ruiz-Garcia 2015), electronic identification (eID), as well as newer ones like the Internet of Things (IoT). The entire IoT ecosystem includes the objects that can communicate as well as the infrastructure that mediates communication, IT solutions that allow information to be transmitted, collected and processed and all standards for such exchanges. IoT creates four types of functionality: autonomy, optimisation, control and monitoring. Each functionality can be used in transport and supply chains. IoT uses well-known data acquisition technologies, but also supports newer ones, such as smart tags, sensors, and geospatial data capturing. These technology applications are not only limited to obtaining data, but sending, processing and sharing it as well.

Friha *et al*. (2021) presented a comprehensive description of the roll IoT is playing in agriculture. FSC management is one of the many IoT applications they described. Others concerned the monitoring of food production processes, irrigation and fertilisation of crops, disease management and smart harvesting. In FSC, IoT technologies support traceability systems by creating commonly accepted and internationally standardised solutions. An example of such a solution is the smart container (Becha *et al*. 2021), which is based on IoT technology as a data source and supports enhanced decision-making. A wide range of sensors capture various information about the current status of both the container and its content (e.g.: temperature, GPS position, shock events) and can remotely change their parameter settings. An ISO container is a collective and transport packaging and as such is an external environment in which individual cargo items are transported. At the lower level of packaging, a useful source of data in FSC comes from intelligent packages, which monitor product quality and safety in the environment, tracing product movements across the supply chain, sensing, detecting, recording and communicating essential information about the product (Kalpana *et al*. 2019). Thanks to the IoT, these functions can be realised in real time and include critical or time indicators and sensors of temperature, freshness, leakage, pH, humidity (Firouz, Mohi-Alden & Omid 2021).

The second group of technological solutions is intended to ensure the certainty, transparency and security of the previously obtained traceability system data. Blockchain, which can facilitate the recording of transactions and monitoring resources in business networks like FSC, is a key technology here. Blockchain deprives these transactions of centralisation features and the influence of the human factor in favour of a model based on sharing and trust (a shared algorithm-based trust model). All activities occurring in this model are transferred to the digital domain and a new category of smart contracts is created. In addition to the basic blockchain functionality of smart contracts, the next most attractive solution in supply chains is the guarantee of object traceability, which is possible in conjunction with IoT technology.

Blockchain allows an organisation to receive documents with full information about creation dates and source of each entry made in their registers. This information cannot be deleted and the complete history of changes is always available. Blockchain allows access to data contained in documents for various participants in the supply chain, though that access depends on the right to view being granted. It may be possible to update the data, extending it or making it fully or partially read-only. Blockchain ascertains the provenance and the authenticity of goods, their stated value, maintaining the assumed condition during logistics processes and the integrity of all other data appearing in supply chains. This leads to the risk reduction of the entire process and its acceleration by eliminating or shortening the duration of control, customs and insurance operations. This technology boosts the transparency of business processes in industries particularly exposed to disruptions, such as FSC (Champion *et al*. 2018, David, Kumar & Paul 2022).

The last group of technological solutions concerns the management of data that has been obtained with IoT and had its integrity confirmed by blockchain. The ability to use data depends on the needs and perception of users. The data needed by those confirming the origin of goods differ from the data required by customs or phytosanitary officers allowing the goods to be imported, logistics managers, the owners of the goods or final consumers. Data Pipeline and Single Window are tailored to solving the problem of data multiplicity, variety and accessibility (Tijan *et al*. 2019). Data pipelines allow data to be provided once and used multiple times, from source and on throughout the supply chain, regardless of the mode of transport, party or border agency accessing the data (UNECE 2018). A Single Window facilitates trade by allowing parties involved in trade and transport to lodge standardised information and documents with a single entry point to fulfil all import, export, and transit-related regulatory requirements. Individual data elements are submitted once, electronically (UNECE 2017). Using Single Window and Data Pipeline proposals, users must be sure that data is entered and captured by the right person, at the right place and at the right time. Here too blockchain technology creates opportunities to maintain full knowledge of all activities, participants and execution times, and may also provide secure solutions for recording responsibility range.

6. Conclusions

Given the global nature of modern trade, product traceability systems are of particular importance for the smooth operation of supply chains. In the case of food products, such systems are used to ensure food safety, increase consumer satisfaction (acquiring a product with known origin and characteristics), and support the management of supply chains, especially in crisis situations. A product's traceability changes how it is perceived on the market and, more generally, increases trust in supply chains, thanks to which producers gain useful feedback and the potential to invest in new solutions on new markets. For BPSC, solutions ensuring process transparency and the continuity of information about them are most important, not least to reduce counterfeiting, product adulteration and other frauds (e.g. documentation). As for any food product, traceability should facilitate the detection of hazardous products, which can be withdrawn from the market via recalls and thus reduce social costs. Of less importance for black pepper is the ease of traceability systems to control and reduce the costs associated with the aging of the product and its spoilage.

From these considerations, the social factors behind the development of traceability systems for BPSC come to the fore, with an emphasis in particular on safety and quality. Economic factors, including ones related to the increased competitiveness of BPSC based on product traceability systems, increased the reputability of traceability and better conditions for further expansion into new international markets are crucial. Regulatory factors affecting the unification of legislation (documentation, quality concept), communication (ontology, semantics) and technological issues (in physical, network, application layers), also play an important role.

The multiplicity of solutions in this field can lead to confusion and be a barrier to the implementation of traceability systems. Other barriers limiting the creation and functioning of traceability systems for BPSC are the cost of implementing and developing such sytems, limited access to data (a lack or low quality of data at some stages of the supply chain), lack of awareness and/or belief of BPSC participants in the positive effects of such systems. The latter barriers are particularly visible in developing countries (where the majority of black pepper originates) and everywhere where small economic entities are involved (at the initial stages of production). This can lead to difficulties in identifying products, their origin and quality characteristics, and it may also upset the entire system from the outset. Nevertheless, the surest path to success with traceability systems seems to involve implementing domain solutions that consider the specificity of the industry and are based on proven universal standards. A similar traceability system for black pepper based on the considerations in this article could be the focus of more detailed future research.

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