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SUPPLY CHAIN AND TRACEABILITY IN THE PROCESSING OF COCOA BEANS

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Summary. Cocoa originates from beans of the cocoa tree (*Theobroma cacao* L.) and it is a main ingredient in chocolate manufacture. Cocao is a very important commodity in the international trade. The journey from cocoa tree to chocolate bar is not complex, but it requires several steps, each of which requires special treatment in order to get the best from the finished product. Cocoa is a product with a relatively constant growth in demand. On the supply side, extraordinary market developments caused for example by weather patterns, diseases, or environmental or political forces may significantly change the amount of cocoa harvested. The following review outlines the sustainable development, origin of cocoa (traceability) and the supply chain in the processing of cocoa beans. It depicts a method of identifying cocoa in a supply chain, as well as some new technologies, for example radio frequency identification and mapping of supply chain systems.

Key words: cocoa, supply chain, traceability, food safety, sustainable development, chocolate

INTRODUCTION

Cocoa as a main ingredient of choclate is an important commodity in the world. Cocoa and chocolate products appear to be one of the most promising foods due to their high polyphenol content, which evidently highlights the link with health-promoting properties [Alañón et al. 2016]. Chocolate and cocoa-containing products are a good source of non-nutrient bioactive polyphenols with potential health benefits including reduced risk of cardiovascular disease and prebiotic activity [Hu et al. 2016, Beg et al. 2017].

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A health claim on cocoa flavanols referring to their properties beneficial to cardiovascular health was granted by EFSA in 2012 [Commission Regulation (EU) 432/2012, D'Souza 2017]. Cocoa beans are the seeds of the tropical *Theobroma cacao* L. tree. There are four types of cocoa: Forastero, which comprises 95% of the world production of cocoa and is the most widely used; Criollo, which is rarely grown because of disease susceptibility; Trinitario, which is a more disease-resistant hybrid of Criollo and Forastero; and Nacional, which is grown only in Ecuador [Beckett 2000, Afoakwa et al. 2013]. Interestingly, cocoa is cultivated on lands covering over 70,000 km^2 worldwide [Kim et al. 2011] between 20° north and south of the equator, where there are optimal conditions for their development. About 70% of the world's cocoa production takes place in the equatorial region of West Africa, and the rest in the equatorial regions of Central and South America, the West Indies, and tropical areas of Asia [Mahazar et al. 2015]. According to the World Cocoa Foundation, there are 5–6 million farmers in developing countries across tropical Africa, Asia and Latin America who produce around 90% of cocoa worldwide, and the number of people who depend upon cocoa for their livelihoods world-wide is 40––50 million [WCF 2012, Beg et al. 2017, Wickramasuriya and Dunwell 2018]. In West and Central Africa, cocoa continues to be an important source of export earnings contributing significantly to the gross domestic product of these producing countries. Cocoa exports generate over USD 8 billion for the region's national economies [IFDC 2014] and support about two million smallholder farm households in West and Central Africa. In Ghana, the industry employs about 70% of the national agricultural labour force in the country [COCOBOD 2013]. For these farmers, cocoa contributes about 70–100% of their annual household incomes [Anang et al. 2013, Nunoo et al. 2014]. Most of the cocoa beans are produced in small or medium-sized farms; only 30% of the raw cocoa production originates from high-end farming [Bernaert et al. 2012]. The global demand for cocoa grew steeply over the last 15 years. This increase was primarily due to the population and economic growth of the Asian and African countries [ICCO 2014, Squicciarini and Swinnen 2016]. The primary aim of food traceability is to increase food safety and also bring other benefits to production systems and supply chains [Saltini and Akkerman 2012].

Cocoa farmers in west Africa tend to be older, have small areas of farmland, produce low yields, and in some cases struggle to produce quality cocoa. These issues are not going to be solved by simply providing some fertilizer and seeds and expecting the quality and quantity of cocoa to improve. A more considered and holistic approach is required that looks beyond the immediate supply chain. Without adequate education, water supply, access to energy, access to finance and tackling gender inequalities, efforts to improve the sustainable production of cocoa will be limited.

The cocoa value chain is exposed to multiple types of shocks. Crop pests and diseases (e.g. cocoa swollen shoot virus, black pod, mirids) are frequently occurring and are a key challenge for the sustained production of cocoa. Other shocks include impacts of climate change, such as heavy rainfalls, floods, droughts and bushfires, which lead to yields losses, destruction of roads and infrastructure and community facilities, and, consequently threaten food security, through decrease of income of people engaged in the cocoa sector.

Cocoa has a long supply chain from small farmers, often in remote, less well-developed tropical regions of the world, to factories and consumers mainly in developed

industrial countries. Like any crop, it is susceptible to changes in the weather, to pests and diseases and to social and economic factors. About two thirds of the cocoa crop ends up in chocolate products, with the remainder going mainly into beverage and bakery products [Afoakwa 2010]. Characteristics of the final chocolate product strongly depend on the processes done at the very beginning of the supply chain. Traceability systems become important to identify what supplier's produce, how they produce and when the products will be delivered among echelons [Deasy et al. 2002] as well as identification of inputs or raw materials. Globalization and internationalization of companies led to investments in different parts in the world due to various reasons such as low labor cost, low cost materials, relaxed regulations, strategic locations, partnership and alliance and access to raw materials. For the food industry, that the movement of the products mostly starts from developing countries, where raw materials are usually still abundant, to the developed countries, where most of the processing industries are located. In order to respond this trans-boundaries and trans-national supply chain, companies needs to carefully arrange their supply chain in order to meet the consumers' demand and managing uncertainties [Afoakwa 2015]. The aim of the study was to present the latest results on traceability and supply chain in the processing of cocoa beans.

SUSTAINABLE DEVELOPMENT

Increased awareness of consumers and producers at all stages of the food chain enables increased supervision and ensuring security through the establishment of common and consistent standards and effective communication.

One successful initiative is the Fairtrade movement which has an alternative approach to international trade and campaigns to raise awareness. Fairtrade ensures a fair price is paid directly to farmers by guaranteeing a minimum price which is above the cost of production, irrespective of the world price. Manufacturers wishing to use the Fairtrade mark on the wrappers of chocolate products must apply to the relevant national organization, which will be affiliated to Fairtrade Labelling Organizations International (FLO). The International Cocoa Organization (ICCO) and several chocolate manufacturers have projects in place aiming to achieve sustainable development. These involve farmer training, support for co-operatives and improved supply chain efficiency ensuring a higher proportion of the world price reaches the farmers. In addition, traceability of cocoa bean supplies is assured for the manufacturers.

TRACEABILITY IN FOOD CHAIN OF COCOA

Traceability in food chain of cocoa under EU law [Regulation (EC) 178/2002], means the ability to track any food or substance that will be used for consumption, through all stages of production, processing and distribution. The traceability of raw materials is a basic requirement for quality, food safety and sustainability. Ideally it should be possible to trace a particular lot of cocoa beans from the end user back to the farmers who produced it (backward tracking). However, the smallholder nature of the crop and the

mixing and blending export systems used in some cocoa producing countries make this very difficult to achieve [Saltini and Akkerman 2012]. Traceability in food chain is nowadays a fundamental requirement, which is becoming mandatory in almost all developed countries. The aim of a traceability system is to collect in a rigorous way all the information related to the displacement of the different products along the supply chain. This information proves essential when facing food safety crisis, and allows efficiently managing the consequent product recall action [Dabenne and Gay 2011]. To ensure the safety and quality of food products, consumers can identify extrinsic indicators and cues convey information about the products through certification and labelling, which available on the point of purchase [Caswell 2006] and obtained standard information of the food. One of the challenges with supply chain traceability is the exchange of information in a standardized format between various links in the chain [Saltini and Akkerman 2012]. In the food industry, raw material batches from different suppliers may be mixed. If a food safety problem comes from a certain raw material batch, all finished products containing raw materials from that batch have to be identified and recalled. Thus, the magnitude of a recall directly depends on batch dispersion in production and distribution. Recently, researchers found that the best solution to reduce batch dispersion is to reduce processing batch size and batch mixing. However, it was also found that reducing batch size leads to losses in production efficiency, due to increased production setup times, setup costs, cleaning efforts, etc. [Saltini and Akkerman 2012].

The newest way of solving traceability issues and ensuring transparency is by using blockchain technology to store data from chemical analysis in chronological order so that they are impossible to manipulate afterwards. A blockchain is essentially a distributed database of records in the form of encrypted "blocks", or a public ledger of all transactions or digital events that have been executed and shared among participating parties, and can be verified at any time in the future. Research conducted so far suggest that using blockchain technology can advantageously help to achieve traceability [Aung 2014]. In addition, blockchain technology allows all stakeholders to check the entire history and current location, for example, of a product [Galvez et al. 2018].

PESTS AND DISEASES OF COCOA

The cocoa tree is susceptible to a number of diseases and pests that affect the yield of pods from the trees. Many diseases and insect pests are known to attack the cocoa tree and the pods leading to economic loss. Most of these diseases are caused by fungi and viruses [Afoakwa 2015].

In all countries the primary of registration is to protect human health. The FAO code of conduct on importation of chemicals is based on the principle of prior informed consent, where importing countries have a right to know about pesticides that have been banned or restricted in other countries. The acceptable levels of active ingredients in foods are determined by the committee on pesticide residue of FAO/WHO, known as the Codex Codex Alimentarius Commission – CAC. Created in 1963 the CAC implements the Joint FAO/WHO Food Standards Programme which is aimed at protecting the health of consumers and ensuring fair trade practices in the international market, including cocoa. If

for any reason the residua levels in any commodity exceed the CAC levels, that particular commodity could be rejected by the importing country.

Control of the pests and diseases is achieved by a combination of using appropriate planting material, good growing practices, sanitation and careful application of approved pesticides. In some areas, cocoa growing is not viable because of the effects of pests and diseases. Due to the high costs of pesticides, most small-holders do not use them [Beckett 2008, Afoakwa 2010].

The influence of climate change is yet another important factor. Whether caused by human activity or not, the average temperature is rising. Insects are usually dormant at low temperatures (below 12°C), i.e. in late autumn, winter and early spring. These periods are getting shorter, so the insects have more opportunities to multiply. To make matters worse, the insects attract rodents that also attack the bags that hold the cocoa. With fewer means for pest control on the one hand and with growing insect and rodent populations on the other, the problem is becoming difficult to manage.

THE PROCESSING OF COCOA BEANS

After harvesting, the cocoa beans undergo complex processing that alters their original chemical and physical properties in order to increase the seeds' palatability and to obtain chocolate flavours [Beckett 2008, Aculey et al. 2010].

The simplified scheme of cocoa bean processing is shown in Figure 1. The primary processing include the fermentation and drying stages. The secondary processing converts cocoa beans into finished products, and it involves: roasting, alkalization, and conching [Prabhakaran Nair 2010].

The cocoa tree produces pods containing a pulp and the raw beans. The outer pod is removed together with some of the pulp and the beans are fermented. This enables chemical compounds to develop inside the beans, which are the precursors of the flavour in the final chocolate. Failure to carry out this stage properly cannot be rectified by processing at a later date. This is also true of the subsequent stage, when the fermented beans are dried. Poor control here can give rise to moulds, which give a very unpleasant-flavoured product, even if the fermentation has been carried out correctly. Similarly where beans

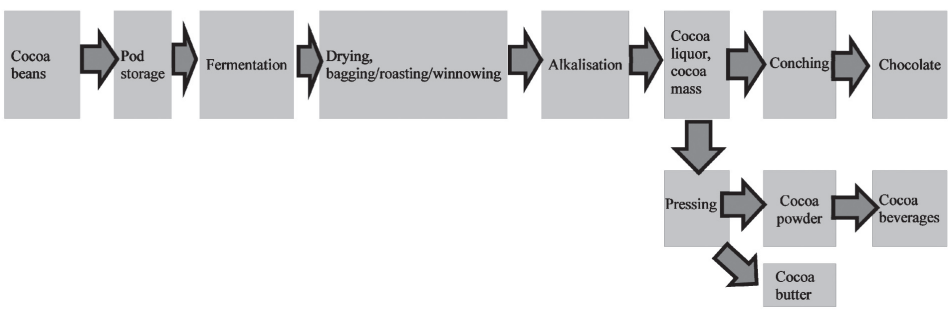

Fig. 1. The processing of cocoa beans (own elaboration)

Rys. 1. Przetwarzanie ziaren kakaowych (opracowanie własne)

are accidentally contaminated with smoke from a faulty drier, the resulting cocoa will be unusable. In addition, correct transport conditions are required when the beans are moved from the country of growing to that of chocolate manufacture. On arrival in the processing factory, it is necessary to clean the beans to remove metal and stones and other extraneous material that might contaminate the product. Further flavour development is subsequently obtained by roasting the beans. This also loosens the shell round the outside of the bean, and enables them to break more easily. Some chocolate manufacturers' prefer to heat the surface of the beans, to facilitate shell removal, and to carry out the full roasting of the cocoa bean centres, either as whole pieces or as a liquid following grinding. The beans are then broken, and the relatively lighter shell particles removed by a winnowing. The presence of shell in the final chocolate is undesirable as it will impair the flavour, as well as causing excessive wear to the subsequent grinding machine [Beckett 2008, Afoakwa 2010]. Publications related to the geographical origin of chocolate and cocoa beans, and to the cocoa variety concern the differentiation of the products by their fatty acid profiles [Acierno et al. 2016] and the examination of the volatile and non-volatile profiles [Afoakwa et al. 2010, Farah et al. 2012]. However, the majority of these studies aim to characterize and improve the aroma quality of cocoa and chocolate, and just few of them regard chocolate authenticity [Cambrai et al. 2010, Acierno et al. 2016]. Considering the fact that chocolate is a complex matrix, it is difficult to pinpoint particular markers for its authenticity. Traditional techniques cannot fully satisfy the new needs of food authentication, as they just focus on specific markers or particular undesired compounds, which cannot characterize a product according to the origin or the production steps. Therefore, an analytical fingerprint approach may be more suitable. This methodology is a non-selective way of analysis and takes into account a complete spectrum or an image of the test material. Combining analytical techniques with statistical analyses, the fingerprint aims at having a more complete description of the product and can be a tool to help track the path of a product based on its physical and chemical properties [Capuano and Van Ruth 2012].

It is very important for the parties in the cocoa chain to co-operate to face the new challenges. Reliable information is needed on the type and quantity of pesticides that are used in each shackle of the chain. Packaging materials should be optimized to repel insects and to withstand the strains of long storage. The exchange of best known practices is an important tool for improving quality throughout the chain and to maintain the position of cocoa as a base for popular consumer goods. One of the tools in hazard analysis and critical control points (HACCP) that can also be used as a stand alone measure is the warehouse logbook, in which every action in the warehouse is recorded: landing of goods, sweeping, fumigating, delivery, etc. The logbook tracks every event in the warehouse and the actions undertaken by the warehouse keeper, making the work transparent. The logbook will show that the warehouse keeper has done his/her utmost to maintain the quality of the goods. Pilots have been carried out with the use of radio frequency identification (RFID) technology for tracking and tracing of cocoa beans. With readers attached to shovels and transmitters to the fences between heaps of cocoa beans in bulk, mistakes are avoided as to which cocoa should be delivered to a certain customer, thereby contributing to the guarantee of the origin of the cocoa that is being transported [Czarniecka-Skubina and Nowak 2012].

TRANSPORT OF COCOA BEANS

Cocoa is traditionally stored and transported in jute (or occasionally sisal) sacks containing 60–65 kg of dry beans. Jute sacks have a number of positive features: they are strong; stackable (do not slip over each other); breathable (allow moisture to pass through); and are made from natural biodegradable fibers. There are a number of shipment methods and the one actually used will depend upon the facilities available at the ports and quantities shipped. The main systems are:

- breakbulk – jute sacks are stacked directly into the hold of a ship;
- containers – stuffed with sacks (12.5 to a maximum of 18 t) or loose filled; loose-filled ones normally contain 17.5–25 t of beans;
- barges – floated into specially designed mother ships;
- mega-bulk – cocoa beans are loaded direct into the hold of a ship.

On the surface of the grain are laid is usually covered with moisture absorbent material such as jute. There should be a minimum of 1m between the top of the cocoa and the hatches. The hold should have forced air ventilation. Bulk shipment methods are gaining in popularity for cocoa transported to Europe and it is estimated that about 70% of cocoa beans shipped to northern European ports now use one of these bulk methods. The critical factors are moisture of cocoa at loading, the rate of temperature change experienced, effectiveness of ventilation systems, duration of the voyage and speed of discharge [Afoakwa 2010].

Careful supplier selection and auditing is important to ensure that incoming ingredients will be microbiologically safe for use in the chocolate making process, particularly because the microbiological safety of the chocolate products relies entirely on the use of safe ingredients and the control of cross contamination during processing and packing. Regular risk-based microbiological monitoring of incoming raw materials should be carried out. Ingredients should be inspected on arrival to ensure they are in good condition, with no damage, or signs of pest activity.

TRANSPORT BULK CHOCOLATE

Most bulk chocolate is now transported in a liquid form in tanks, an appreciable market still exists for block or pelleted chocolate. In both cases the preferred packaging method is polyethylene-lined multiply paper sacks. Liquid chocolate can be poured into a case, generally corrugated board, lined with a polyethylene bag. When the chocolate has set, the bag and chocolate can easily be removed and is very stable for transportation [Afoakwa et al. 2010].

CHOCOLATE PRODUCTION

The production of chocolate and its derivatives, both at a small-scale and on an industrial level, involves the following stages: kneading, mixing the ingredients of the chocolate to be processed until a homogeneous paste is obtained; followed by laminating, for smoothing the paste and leaving it without granules; conching, to eliminate bitterness,

acidity, and some of the remaining moisture; tempering (heating) to obtain a stable crystallization o the cocoa butter and, therefore, a smooth chocolate; and finally molding, which can be combined with the addition of optional ingredients. Here, the chocolate is poured into molds to give it the desired shape, and then it is demolded. Chocolate may also be coated or panned, with or without additional ingredients, such as nuts, seeds, or fruits, and finally, packaged [De La Cruz and Pereira 2009, Gutiérrez 2017]. The flow pattern of the raw material during cocoa bean processing and industrial structure is shown in Figure 2.

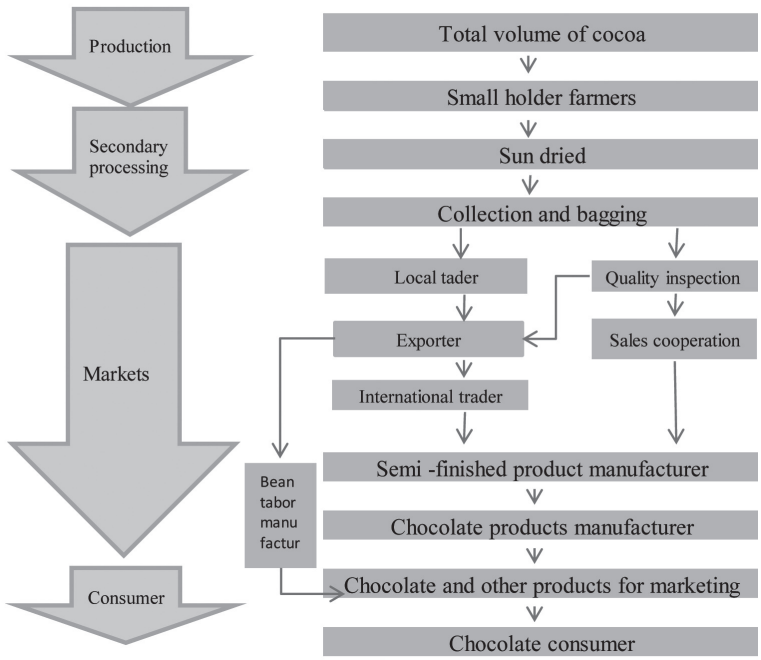

Fig. 2. Raw material during the processing of cocoa beans and industry structure (own elaboration)

Rys. 2. Surowiec podczas przetwarzania ziaren kakaowych i struktury przemysłu (opracowanie własne)

PACKAGING AND STORAGE

The temperature of storage packaging and packaging of chocolates is usually maintained between 18 and 20°C, with a relative humidity of less than 50% to prevent condensation on the product [ADM Cocoa International 2009, Gutiérrez 2017]. Since, after cooling, about 25% of the cocoa butter is still in a liquid state, the products are stored for about 24 h to pack the latent heat of crystallization and allow the liquid cocoa butter to solidify [Ali et al. 2001]. It is extremely important to avoid fluctuations in temperature during storage, because they can accelerate the formation of opaque appearance and the development of fat and loss of polyphenols [Gutiérrez 2017].

A batch number or lot number is critical for traceability. All packages with the same batch number are considered to be the same in all respects. If the consumer, retailer or manufacturer identifies a problem with a product, the batch code allows the product to be traced back to a specific batch. Products with the same batch code can then be recalled or withdrawn from the supply chain. The manufacture of chocolate goods would not exist but for the consumer. What is seen on the market shelves is seldom the chocolate itself, but usually the container. The type of packaging to be used is normally determined by the sales and marketing departments. It is however important to realize, however, that the packaging should not only be attractive at point of sales, but should also protect panned products. Problems such as moisture transfer, scratching, splitting and light induced rancidity must be prevented in order to preserve texture, flavour and appearance. Wrapping material suppliers can be of great assistance in this respect. A highly glossy surface is one of the biggest attributes of most panned confections. Once hazing, bloom and scratches have started to form on panned chocolate, the customer will think that the product is old and stale, no matter how fresh it might be. In all cases, a storage test should be carried out to determine the right packaging material. Traceability – thanks to the labeling on the label, you can trace the way back of the product and analyze the production process and other links in the chain in order to determine at what stage non-conformities may occur, which result, for example, in coating the product. Such an analysis is possible thanks to the records at all stages, the awareness of the employees of each unit involved in the process and the reliable performance of all records.

One of the tools enabling tracking the product's path and identifying it is the bar code system, which is placed on the packaging of the product. The International Article Number (also known as European Article Number or EAN) is a standard describing a barcode symbology and numbering system used in global trade to identify a specific retail product type, in a specific packaging configuration, from a specific manufacturer.

In modern logistics, EPC/RFID technology complements barcodes. The electronic product code (EPC) is designed as a universal identifier that provides a unique identity for every physical object anywhere in the world, for all time. The electronic product code structure is defined in the EPCglobal Tag Data Standard. Ease of use, possibility of simultaneous reading and saving many labels, the increased amount of information that can be sent in this way, multiple write, the ability to update and encrypt data, minimization mistakes and work during the collection of data, as well as great convenience in their application, they make RFID technology more and more examples applications: storage systems, road, air and sea transport, tracking and inventory of goods, document management [Czarniecka-Skubina and Nowak 2012].

MAPPING INTEGRATED SUPPLY CHAIN SYSTEMS AND PROCESSES

People have been mapping supply chains as long as they have been making maps but traditional maps only provide a summary view – they do not show how supply chains change in real time. Modern supply chain mapping is the process of engaging across companies and suppliers to document the exact source of every material, every process and every shipment involved in bringing goods to market. Accurate supply

chain mapping only became possible with the rise of online maps and the social web. The first online supply chain mapping platform was developed at the Massachusetts Institute of Technology in 2008 (the underlying open source technology is the basis for Source map).

A supply chain process map shows the path supplies take from raw materials to manufacturers to consumers and afterwards. It provides a quick visual overview of the flow of merchandise through a particular industry. The supply chain map is a matrix of vertical aligned areas (supply, product, demand), and cross-functional (or horizontal) processes such as product design or demand forecasting. The map is intended for use as a reference tool during a strategic review or the design phase of supply chain architecture. Recently, large commercial chains and chocolate suppliers have formed teams whose goal is supply chain mapping witch allows a company to identify bottlenecks by: providing visibility into how processes are carried out; identifying where the processes are executed; identifying who is doing what within the processes; revealing how processes affect other processes; and determining why a process is being executed. Mapping also makes it easier to identify activities within a process that are not adding value; these can then be targeted for elimination and/or modification.

CONCLUSIONS

The complex characteristics of chocolate related to the supply chain, the technology involved in the production, and the ingredients' composition complicate the assessment of the typical features of this product and the verification of its authenticity. Therefore, the discovery of markers related to e.g. the botanical and geographical origins of the beans would be a first step towards the development of a reliable method for authentication which in turn would underpin sustainable production and would help to preserve stakeholders' confidence [Saltini and Akkerman 2012]. Besides consumers, stakeholders include farmers, shipping organizations, processors, and distributers. Mass spectrometry, spectroscopic and separation techniques have been applied to assess the food's geographical origin [Luykx and van Ruth 2008] and species authentication [Acierno et al. 2016].

Traceability systems are highly valuable tools from which, if well designed and well integrated with the production operations, food producers can benefit in terms of safety issues as well as in the daily operational activities. Fair trade can be part of a solution, helping to ensure decent incomes for farmers and a long-term supply of quality product to companies.

In the 21st century, a sustainable cocoa agricultural supply chain is not solely about practicing farm cultivation. Rather, it includes transportation, warehousing, manufacturing and distribution, and it requires considering not only what it is best for the survival of the companies, but what is best for the biodiversity and for environment.

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ŁAŃCUCH DOSTAW I IDENTYFIKOWALNOŚĆ W PRZETWARZANIU ZIARNA KAKAOWEGO

Streszczenie. Kakao pochodzi z ziarna drzewa kakaowego (*Theobroma cacao* L.) i jest głównym składnikiem w produkcji czekolady. Kakao jest ważnym towarem w handlu międzynarodowym. Podróż z drzewa kakaowego do tabliczki czekolady nie jest skomplikowana, ale potrzeba kilku etapów, z których każdy wymaga specjalnego traktowania w celu uzyskania najlepszego produktu końcowego. Kakao to produkt, na który jest stosunkowo stale rosnący popyt. Ilość zbieranego kakao jest uwarunkowana podażą, ale znacząco kształtują to nieprzewidywalne czynniki – warunki pogodowe i środowiskowe na plantacjach, choroby i patogeny roślin, aktualne uwarunkowania geopolityczne. W niniejszym przeglądzie nakreślono zrównoważony rozwój, pochodzenie kakao (identyfikowalność) i łańcuch dostaw w przetwarzaniu ziarna kakaowego. Przedstawiono metodę identyfikacji kakao w łańcuchu dostaw, podobnie jak niektóre nowe technologie, np. RFID (ang. *radio identification*) i mapowanie systemu łańcucha dostaw.

Kluczowe słowa: kakao, łańcuch dostaw, identyfikowalność, bezpieczeństwo żywności, zrównoważony rozwój, czekolada