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Original article

The clove tree and its products (clove bud, clove oil, eugenol): prosperous today but what of tomorrow's restrictions?

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Summary

Context of the study – **The clove tree, farmed primarily in Indonesia, Madagascar, the Comoros, Tanzania and Sri Lanka, produces two major commodities: the clove and the eugenol-rich essential oil. At the present time, the clove caters to the spice market, which is concentrated in India, as well as the market for the traditional Indonesian cigarette, the *kretek*, which accounts for 70% of world output. The essential oil extract is exploited for its various properties: plasticising, anaesthetic, antimicrobial and organoleptic, which are deployed in the cosmetics, dentistry and agro-food sectors. Several innovative, often cutting edge, applications are currently being researched, taking advantage of its profile as an organic product derived from green chemistry, implicated in the agroecology approach. The main areas concerned are medicine, agri-food and agronomy.** *Aim of the study* – **We are considering a series of plausible hypotheses of evolutions in demand on the international market, to assess how the development of current and potential applications might steer the market in the coming years and decades. We are exploring their impact on the offer of producing countries, and therefore, on the incomes of local farmers and distillers.** *Methodology* – **Our approach is based on an extensive bibliography.** *Remarkable results* – **The clove sector is under threat from various sources: American cigarette manufacturers' offensive to conquer the vast Indonesian market, disregard for quality, inter-annual variation of production, competition between clove producing countries, as well as substitute products, impact of oil extraction methods on firewood consumption. A few forward-looking elements are given, particularly concerning the impact of climate change and the COVID-19 pandemic.** *Conclusion* – **These threats need to be anticipated and taken into consideration by all actors of the sectors for the clove and its products to continue providing a reliable source of income to thousands of small farmers in the producing countries.**

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Significance of this study

What is already known on this subject?

- The clove tree, farmed by small farmers in Indonesia, Madagascar, the Comoros, Tanzania and Sri Lanka, produces two major commodities: the clove and the eugenol-rich essential oil.

What are the new findings?

- World demand for cloves is driven by the Indonesian cigarette and spice markets. Essential oil and eugenol are in demand in the cosmetics, dentistry and food industries. But, today, economic and environmental threats weigh on these industries.

What is the expected impact on horticulture?

- This paper develops a prospective vision by explaining these threats and proposing measures so that the clove sector can continue to provide a living for farmers in producing countries.

Keywords
global market, environmental impact, product quality, prospective analysis, smallholders, *Syzygium aromaticum*, value chain

Introduction

The clove is the dried flower bud of the clove tree, *Syzygium aromaticum* (L.) Merr. & L.M. Perry, a tree belonging to the Myrtaceae family, originating from a small geographic area corresponding to a few islands in the Moluccas (Indonesia). It is currently cropped in several tropical countries situated, for the most part, on the Indian Ocean rim (Figure 1). The market is organised around six major production zones: Indonesia (the Moluccas and the islands of Java and Sulawesi), the east coast of Madagascar (Analanjirofo and Atsinanana regions), the islands of the Mozambique Channel (Zanzibar, Pemba in Tanzania, Anjouan, Moheli in Comoros), central Sri Lanka, southern India, and the south-west of the state of Bahia in Brazil (Figures 1 and 2, Table 1). Some minor producing countries such as Kenya, China, Malaysia and Grenada maintain a small output. The primary producer is Indonesia, which supplies more than 80% of its output to its domestic market, followed by Madagascar, whilst India, the United Arab Emirates and Indonesia (*via* the hub of Singapore) are the principal importers (Table 1, Figures 1 and 2).

Clove trees are usually farmed by families of small holders for whom it represents a major source of income (Blakeney and Mengistie, 2012; Danthu *et al.*, 2014; Penot *et al.*, 2016). In Indonesia, there are more than a million such farmers. In Madagascar, more than 30,000 farmers and in Brazil 4,000

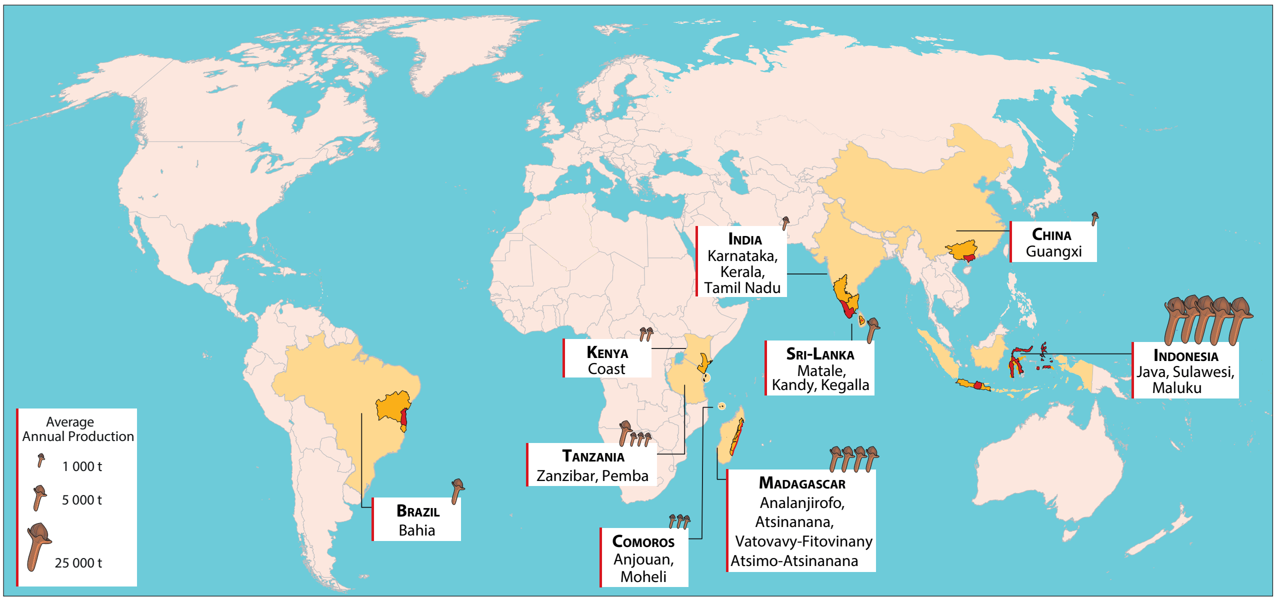

Figure 1. Location of the main clove production regions (in red) in the world and estimation of their production over the period 2012/2018 (UN Comtrade 2018; Trade Map 2019).

Table 1. Main countries involved in the world clove market. The figures correspond to averages calculated over the 2012/2017 period for production, and 2012/2018 for exportations and importations; they are expressed in tons (FAOStat, 2019; DASD, 2018; Trade Map, 2019).

Main countries involved in the clove chain	Production (T)	Exportation (T)	Importation (T)
World	161,504	58,172	52,915
Producer/Exporter/Importer/Consumer			
Indonesia	122,454	10,748	6,630
Producer/Exporter			
Madagascar	19,405	19,194	–
Tanzania	6,829	≈5,020*	–
Brazil	≈5,000	3,080	–
Sri Lanka	5,517	3,834	–
Comoros***	2,328	4,327	–
Kenya	1,973	372**	–
China	1,229	105	145
Importer/Processor/Consumer			
India	1,220	964	15,279
Europe (including the Netherlands)	–	≈1,646 (686)	>3,900 (1,027)
Importer/Consumer			
North America (USA, Canada)	–	–	1,928
Saudi Arabia	–	–	1,882
Asia (including Pakistan, Malaysia)	–	–	>5,000 (1,607, 2,176)
South and Central America (except Brazil)	–	–	≈1,200
Africa (especially Egypt and Maghreb)	–	–	>700
Russia	–	–	296
Importer/Exporter (Hub)			
Singapore	–	8,642	8,895
United Arab Emirates	–	2,336	3,254

* 2014 to 2018; ** 2012 to 2017; *** inconsistency between sources of information.

farmers live, at least partially, from clove farming, which they have been integrating into their agro-systems for more than a century (de Oliveira *et al.*, 2007; Cocoual and Danthu, 2018; Arimalala *et al.*, 2019). On the Tanzanian islands of Zanzibar and Pemba, as well as the Comorian islands of Anjouan and Moheli, clove trees are farmed mostly by small-scale farmers (Martin, 1991). However, the clove is much more than just a spice.

It is the source of clove essential oil, obtained by hydro-distillation of the tree's different components, including leaves, cloves and stems. Indonesia and Madagascar are the main essential oil producers. The annual volume of essential oil produced globally, around 6,000 tons, is far less than that of the major essential oils, such as orange (51,000 tons) and mint (32,000 tons), but in excess of the global output of the essence oil of the hybrid lavender (lavandin) (between 1,200

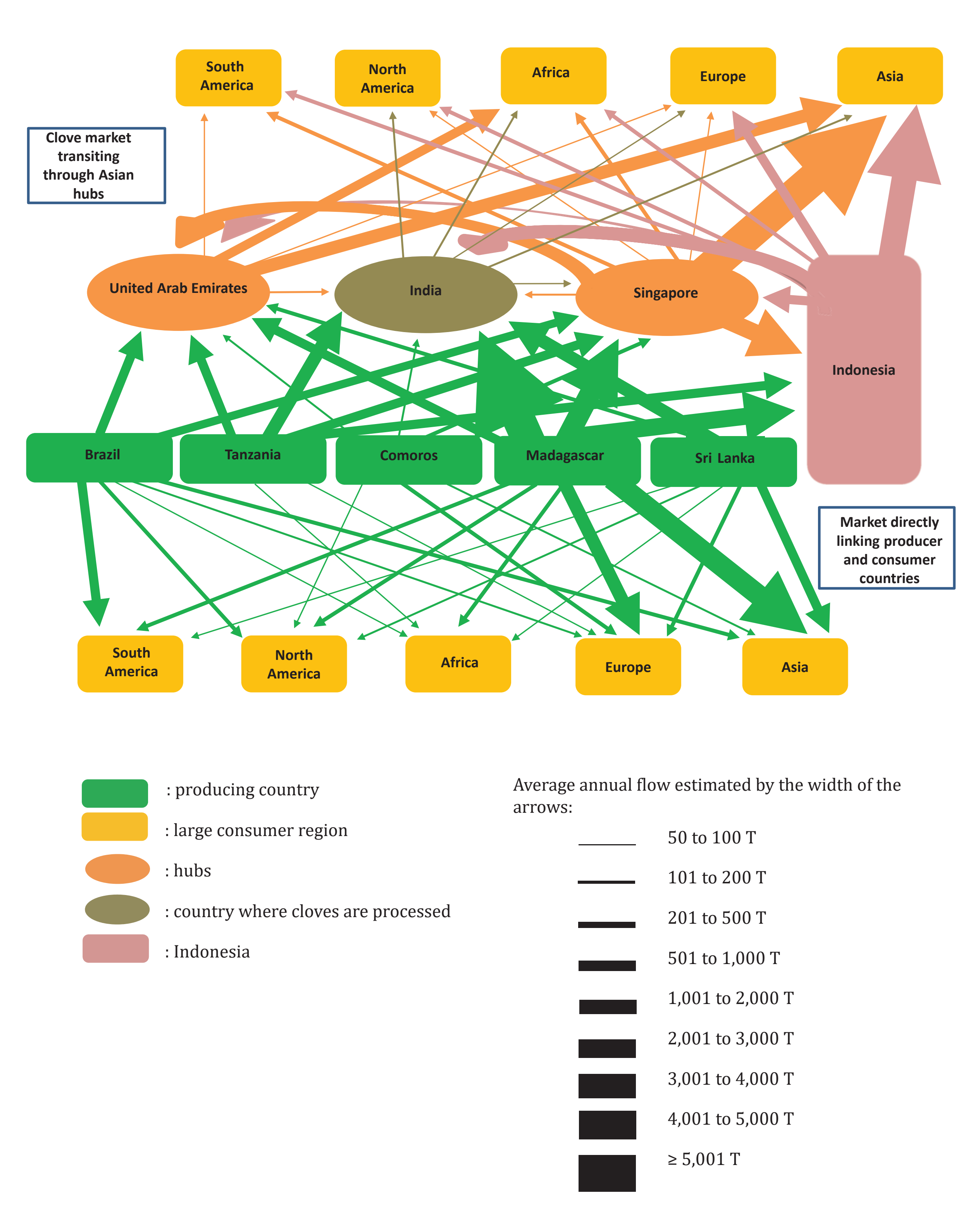

FIGURE 2. Schematic representation of the world clove market (years 2012/2018) (UN Comtrade 2018; Trade Map 2019).

Table 2. Relative weight of the main spices on the international market, expressed as the annual average of international trade over the period 2012/2018 (in millions US$) (Chomchalow, 2001; Trade Map, 2019).

Spice (and nomenclature)	Part of the plant used	Weight in the international market, in value (import, 10^6 US$)		
		2012/2016	2017	2018
Pepper (090411, 090412)	Fruit (berry)	2,731	2,474	1,683
Chili (090420 to 090422)	Fruit	1,313	1,467	1,667
Ginger (091010 to 091012)	Rhizome	759	844	940
Cinnamon (090610 to 090620)	Bark	404	617	724
Cloves (090700 to 090720)	Flower bud, stem	376	623	501
Cardamom (090830 to 090832)	Fruit (capsule)	372	562	581
Vanilla (090500 to 090520)	Fruit (capsule, «pod», «bean»)	329	1,292	1,485
Cumin (090930 to 090932)	Seed	309	391	422
Nutmeg and Mace (090810 to 090822)	Seed and aril	256	203	191
Saffron (091020)	Stigma	200	288	301
Coriander (090920 to 090922)	Seed	185	174	160
Turmeric (091030)	Rhizome	180	265	305

and 1,500 tons), or ylang-ylang, which is barely more than a hundred tons (Kraus, 2015; Giray, 2018).

The chemical composition of clove essential oil is well established. It varies according to the organ distilled, its maturity, the harvest zone, and the distillation conditions. It has some forty components, sometimes in trace quantities, including eugenyl acetate and β-caryophyllene. However, its principal characteristic and major interest lies in its richness in eugenol, a small molecule with the formula $C_{10}H_{12}O_2$ (4-allyl-2-methoxyphenol), belonging to the family of phenylpropenes. Eugenol is omnipresent in clove, in relative contents varying from 70 to 90%, the highest proportions of which are found in the extracts from the stems (Nurdjannah *et al.*, 1991; Leepa and Sapna, 2008; Razafimamonjison *et al.*, 2013, 2014, 2016b).

The oleoresins (or concretes), which are more discrete, are obtained by extraction from the cloves using an organic solvent (petrol ether, benzene or, more ecologically, ethanol) or by supercritical CO_2 extraction (Nurdjannah and Bermawie, 2001; Leela and Sapna, 2008). These preparations have the advantage, compared with essential oil, of concentrating the clove's aromatic components, and not just the volatiles, giving a complexity of aromas and a flavour close to that of the clove.

The different clove products (clove, essential oil, concrete and eugenol) have numerous and diverse applications. These fall into two categories: current uses, often derived from past practices, and potential research-based applications, often with promising leads, studied in small-scale, experimental conditions, which require fine tuning (Mohammadi Nejda *et al.*, 2017). A number of articles have been published in recent years about these applications including these preliminary assessments by Burt (2004), Leela and Sapna (2008), Kamatou *et al.* (2012), Nowak *et al.* (2012), Affonso *et al.* (2012), Dias and Moraes (2014), Cortés-Rojas *et al.* (2014), Raja *et al.* (2015), Kaufman (2015), Ravindran (2017), Khalil *et al.* (2017), as well as Kaur and Kaushal (2019).

Our aim is not to produce a new synthesis of the uses of the clove, but to evaluate, on the basis of these reviews and an extensive bibliography, how the development of current and potential applications might steer the market in the coming years and decades. Based on a series of plausible hypotheses of evolutions in demand on the international market, we will explore their possible impact (positively or negatively) on the offer of producing countries, and therefore, on the incomes of local farmers and distillers in the clove supply chain.

This three-part article starts with a review of the current uses of cloves, essential oils and extracts of eugenol, which presently structure the market. The second part deals with the conceivable innovations, associated mostly with the properties of eugenol. The third part is prospective, concentrating on the potential directions in which the clove market might evolve, and their impact on the sector and its stakeholders.

Current uses of clove: products in demand and a diversified market

Clove

Annual world clove output (code "0907: clove: whole fruit, cloves and stems" in the standard international trade classification) stands at more than 160,000 tons (Table 1). Lagging far behind pepper and chilli, today's annual global market for cloves, worth more than 500 million dollars, has been stable for several years. It represents around 4% (in value) of the international spice trade, ranking the clove between 5th and 7th in the world, depending on the year (Table 2).

Whilst the greatest volumes are traded on the Asian market, clove is consumed in practically every country on the planet. The greatest proportion of world flow transits through two hubs: the UAE and, primarily, Singapore. However, a major direct trade flow of cloves links producing and consuming countries (Table 1, Figure 2), in particular between Brazil and the countries of North and South America, as well as connecting Madagascar and Sri Lanka with the countries of Asia and Europe (Figure 2). Consequently, by virtue of its historical status as a colonial power in Indonesia, the Netherlands still play an important role as a trading hub for the European market.

Indonesia's place in this market is quite complex: whilst it imports, directly or indirectly, from Madagascar or Tanzania via the Singapore hub, and exports to nearby countries (Vietnam, Malaysia, China) and the Indian sub-continent (Figure 2), importation, whilst tolerated, has only officially been permitted since very recently.

Table 3. Top 3 countries importing Malagasy cloves (% of the total volume of Malagasy exports) (UN Comtrade, 2018; Trade Map, 2019).

Year	Importing country of Malagasy cloves		
	First	Second	Third
1990	Singapore (85.8)	France (4.8)	Netherlands (1.9)
1991	Singapore (71.0)	USSR (6.8)	Saudi Arabia (4.7)
1992	Singapore (42.8)	Russia (9.6)	Saudi Arabia (5.2)
1993	Singapore (60.5)	USA (8.5)	France (8.2)
1994	Singapore (63.7)	USA (6.2)	Netherlands (6.1)
1995	Singapore (63.4)	United Arab Emirates (8.3)	USA (5.9)
1996	Singapore (55.4)	France (9.9)	USA (6.2)
1997	Singapore (55.8)	India (13.8)	USA (6.3)
1998	Singapore (61.1)	India (8.6)	Indonesia (5.2)
1999	Singapore (86.3)	USA (3.6)	India (2.7)
2000	Singapore (78.3)	Indonesia (10.0)	Hong Kong (2.0)
2001	Singapore (69.3)	Indonesia (20.1)	Netherlands (2.9)
2002	Singapore (67.0)	India (6.3)	Mauritius (3.8)
2003	Singapore (68.1)	India (6.4)	USA (3.9)
2004	Singapore (81.2)	USA (3.1)	Netherlands (1.8)
2005	Singapore (65.5)	USA (8.6)	Viet Nam (5.6)
2006	Singapore (49.9)	India (10.9)	Viet Nam (5.8)
2007	Singapore (41.5)	India (22.4)	Pakistan (5.0)
2008	Singapore (54.5)	Viet Nam (7.2)	India (6.8)
2009	Singapore (43.5)	India (23.1)	Viet Nam (9.8)
2010	Singapore (42.8)	India (12.2)	Viet Nam (7.6)
2011	Singapore (47.4)	India (25.7)	Indonesia (7.5)
2012	India (27.4)	Singapore (24.6)	Indonesia (7.3)
2013	India (30.0)	Singapore (23.3)	Viet Nam (10.5)
2014	India (39.9)	Singapore (13.8)	Belgium (7.9)
2015	India (53.4)	Singapore (13.3)	Viet Nam (7.4)
2016	Singapore (36.0)	India (35.1)	Viet Nam (9.8)
2017	Singapore (34.3)	India (33.9)	Viet Nam (16.5)
2018	India (33.1)	Singapore (30.0)	Indonesia (13.0)

The primary commercial destination for the cloves is the manufacturing of Indonesia's traditional cigarette, the *kretek.* From a craft practice started in Java around the 1870s, this industry now accounts for up to 90% of Indonesia's clove harvest (Hanusz, 2000; World Bank, 2017a). Depending on the year, a high proportion of the cloves produced in Madagascar, the Comoros and Zanzibar has been exported to Indonesia to compensate for the shortfall between domestic production and consumption. Currently, the *kretek* is the cigarette of choice of 91% of Indonesian smokers, mostly men, representing a population of more than 54 million smokers (Palipudi *et al.*, 2015). This population is expanding as much in neighbouring countries as in Indonesia (Arnez, 2009; Roemer *et al.*, 2014), and according to the World Bank (2017b) could rise to 95 million by 2025. The *kretek* is now an established and socially important feature of Indonesian culture, as well as a major economic sector, employing more than 300,000 workers in the manufacturing sector alone (Arnez, 2009; World Bank, 2017b), despite the decline due to the mechanisation of the manufacture of traditional hand-rolled *kreteks* (Medvedeva, 2015).

The agri-food industry is the second-largest consumer of cloves. The spice, which is never used fresh, comes in two forms: the whole clove and the crushed clove, which is then added to spice mixes. On every continent, cloves have found their way into gastronomic preparations including dishes, sauces, and drinks, with the possible exception of Japanese cuisine (Hirasa and Takemasa, 1998).

India is the world leader in the spice market, accounting for 21% of global spice exports in 2016. 85% of Indian exports are in the form of whole spices (fruits, seeds, flowers, bark, roots), the remainder is in the form of ground spices or blends (masala, curry…), of which some include cloves (Spice Board of India, 2019). These exports are composed mainly of home-grown spices, but also include re-exports of spices, which are either grown in small quantities, or not at all, in India. This is the case with cloves, which as a result, India imports in vast quantities (Table 1, Figures 1 and 2). Madagascar, Tanzania and, closer to home, Sri Lanka are India's main suppliers. In recent years, India has become Madagascar's number one client (Table 3).

Essential oil, oleoresins and eugenol

The production of clove essential oil is more difficult to assess than the cloves, as there are not as many statistics available. The main producer today is Indonesia (4,000 tons yr^{-1} approx.) (Alighiri *et al.*, 2017), which accounts for 60% of world output (Bustaman, 2011). Madagascar produc-

FIGURE 3. A wood-fired still producing clove essential oil in the area of Fénérive-Est, Region Analanjirofo, Madagascar. Notice the bare fire and the dilapidation of the equipment, which results in low yield and an important volume of wood used per batch of distillation, which has more often become fruit trees (mango tree, lychee tree, breadfruit trees or old clove trees). Photo E. Penot.

es around 2,000 tons yr^{-1}. The Comoros do not produce any clove essential oil, preferring to reserve their wood resource for the distillation of ylang-ylang flowers, of which the essential oil is more profitable (Penot and Danthu, 2019).

The interest of the clove essential oil and the eugenol derives from a convergence of factors: they are natural products, in ready abundance, easy to produce (Chaieb *et al.*, 2007b; Raja *et al.*, 2015; Pavela and Benelli, 2016; Kaufman, 2015). They represent a compelling advantage in that the cost of production is low, as in Indonesia and Madagascar distillation of clove leaves is carried out by smallholders in a multiplicity of small, antiquated and simple distilleries (Figure 3), in a labour context where manpower is low-cost (3.5 \$ day^{-1} in Indonesia and 1.2 € day^{-1} in Madagascar). Finally, clove oil and eugenol are recognised as fit for human consumption, at least in doses of less than 2.5 mg kg^{-1} of body weight (Gardner and Mac Guffin, 2013; Raja *et al.*, 2015).

The flavour notes expressed by clove essential oil are used as a base factor for a number of well-established names in perfumery (such as *Chypre* created by perfumer François Coty in 1917 and marketed until 1950, or *Mitsouko* created by Jean Paul Guerlain in 1919, still in production), as well as more recent ones (such as *Coco* by Chanel, *Ysatis* by Givenchy and *Vitriol d'Œillet* by Serge Lutens). They are signature fragrances belonging to a number of olfactory families including oriental, woody, chypre.

However, the value of clove oil is not limited to its aromatic potential. Table 4 illustrates the diversity of current uses and shows that there is considerable scope for developing further uses, in often unexpected and surprising fields.

The antibacterial and antifungal activities of clove essential oil, like many spice oil, is significant against many food spoilage bacteria, pathogens and fungi (Burt, 2004; Kamatou *et al*., 2012; Liu *et al*., 2017).

In aromatherapy, the essential oil is generally appreciated as an anti-infectious agent, with broad-spectrum antibacterial (against gram- and gram+ bacteria), antiviral, antifungal and antiseptic properties. It is indicated in cases of dental infection, toothache (the essential oil is more effective than pure eugenol), tonsillitis and viral hepatitis, amongst others. It is recognised as a stimulant. (Franchomme *et al.*, 2001). The essential oil can be found systematically on the aromatherapy shelves of pharmacies throughout the developed world, with clear recommendations for caution in its application, as it can be irritant, and even harmful if ingested or applied undiluted to the skin.

Cloves have been used since the 16th century to treat toothache (Molnar, 1942). Nowadays, the temporary dressings used routinely by dentists are made from zinc oxide and eugenol. The eugenol acts on the dental pulp as an anaesthetic and anti-inflammatory (Markowitz *et al.*, 1992; Barja-Fidalgo *et al.*, 2011; Pavithra, 2014), which explains the omnipresent aroma of cloves in dental surgeries.

Eugenol is used routinely in fish farming and fishkeeping as an anaesthetic to mollify the fish during manipulations, such as artificial reproduction procedures, marking, transport (Munday and Wilson, 1997; Neiffer and Stamper, 2009; Javahery *et al.*, 2012).

The germicidal properties of clove essential oil have recently been applied as an organic alternative to chlorpropham for preventing potatoes from sprouting, resulting in prolonged storage times (Kleinkopf *et al.*, 2003; Finger *et al.*, 2018).

Even if further studies are needed to clarify their exact action and establish its regular use in animal production, the integration of essential oil in ruminant and monogastric animal feed is a practice that is becoming common in Northern countries (Simitzis, 2017). By example, a supplementation with a blend of cinnamaldehyde and eugenol improve growth performance of beef heifers and milk production of dairy cows (Cardozo *et al*., 2006; Wall *et al*., 2014; Simitzis, 2017).

However, some older uses of eugenol have become obsolescent. The paint and varnish industry utilised the plasticising and solvent capacity of eugenol from an early stage. In fact, the production of clove essential oil was boosted by World War 1, during which eugenol was used as a plasticising agent in the varnish applied to the wings of aeroplanes (Gatefossé, 1921). In the 1930s, this sector accounted for 5% of the essential oil produced (François, 1936). Likewise, at the beginning of the 20th century, eugenol extracted from clove was the base for the hemisynthesis of vanillin (Otto, 1909; Lampman *et al.*, 1977). However, this industrial usage of eugenol extracts has only ever represented a marginal outlet for clove (François, 1936). Today, synthetic vanillin (annual production 16,000 tons) is produced in other ways, from coniferin, lignin, guaiacol (Borges da Silva *et al.*, 2009) or ferulic acid extracted from plant waste matter (Chattopadhyay *et al.*, 2018).

Table 4. Uses of clove essential oil, eugenol and derivative molecules: tested properties, and foreseeable applications or applications under development.

Target and mechanism of action	Applications	References
Antibacterial activity		
Effective on a large range of Gram-positive (*Bacillus, Staphylococcus, Listeria*) and Gram-negative (*Escherichia*, *Pseudomonas*, *Salmonella*, *Yersinia*) bacteria. Acts by altering membranes of bacteria; develops strong inhibition of bacteria biofilm formation; action that can synergize with that of antibiotics.	In the area of Food: Food safety; "active" packaging; in Medicine and dentistry, combination of therapy limiting risk of developing antibiotic resistance. In Agriculture, possibility of developing an agroecological treatment against *Ralstonia*, agent of bacterial rot of many crops (tomato, potato).	Burt, 2004; Chaieb *et al*., 2007a; Huang and Lakshman, 2010; Kamatou *et al*., 2012; Woranuch and Yoksan, 2013; Raja *et al*., 2015; Yadav *et al*., 2015; Pulikottil and Nath, 2015; Liu *et al*., 2017; Deberdt *et al*., 2018
Antifungal activity		
Very effective against *Candida*, *Penicillium*, *Fusarium*, *Aspergillus*, *Colletotrichum*, *Botrytis*. Methyl eugenol may have an increased action compared to eugenol. Acts by modifying the fluidity and the membrane permeability, limits the formation of biofilms.	In medicine and dentistry, fight against candidiasis, synergy with various antibiotics (fluconazole, amphotericin B, *etc*.) by limiting resistance. Green chemistry: post-harvest bio protection of fruits against anthracnose; combats aflatoxin production. In the food industry: limits fungal contamination of food and improves postharvest quality of citrus during cold storage.	Ranasinghe *et al*., 2002; Chaieb *et al*., 2007a, b; Barrera-Necha *et al*., 2008; Combrinck *et al*., 2011; Boulogne *et al*., 2012; Kamatou *et al*., 2012; Abbaszadeh *et al*., 2014; Pulikottil and Nath, 2015; Chillet *et al*., 2017; Xia-Hong, 2007; Matan and Jantamas, 2014; Chen *et al*., 2016; Liu *et al*., 2017; de Figueiredo *et al*., 2019
Antiviral activity		
Tested against human herpes viruses; synergy with certain antivirals such as acyclovir.	In medicine and dentistry, treatment against HSV-1 and HSV-2.	Benencia and Courrèges, 2000; Pulikottil and Nath, 2015
Anticancer activity		
Eugenol would induce growth inhibition and apoptosis of cancer cells, in synergy with anti-cancer drugs such as gemcitabine. Would be effective against melanomas, skin tumours, gastric cancers, leukaemia. Would limit angiogenesis of malignant tumours.	Controversial area. Some studies show that eugenol would have a real potential for anticancer action. On rats, eugenol would have the ability to prevent the development of cancerous tumours. Not cited among anti-cancer plants by Wang et *al*. (2012).	Bakkali *et al*., 2008; Manikandan *et al*., 2010; Hussain *et al*., 2011; Kamatou *et al*., 2012; Jaganathan and Supriyanto, 2012; Wang *et al.,* 2012
Antiparasitic activity		
Eugenol would act by altering membranes of the genus *Leishmania* (transmission by phlebotomas) and may have an action against *Plasmodium*.	Effective against leishmaniasis, without showing cytotoxicity against mammalian cells; possible anti-malaria action.	Ueda-Nakamura *et al*., 2006; Kamatou *et al*., 2012; Raja *et al*., 2015
Anti-inflammatory and analgesic activity		
Clove essence, eugenol, acetyl eugenol and eugenol derivatives have a strong anti-inflammatory potential by inhibiting cyclooxygenases, responsible for the production of prostaglandins or the production of pro-inflammatory cytokines.	Efficiency widely used in dentistry. Numerous animal and human trials for more general use.	Markowitz *et al*., 1992; Kamatou *et al*., 2012; Han and Parker, 2017; Raja *et al*., 2015; Koh *et al*., 2013; Kumar Maurya *et al*., 2020
Anesthethic activity		
Well-explored area, in dentistry and fish farming.	Widely used in fish farming; tested on post-larvae and young adults of shrimp.	Markowitz *et al*., 1992; Munday and Wilson, 1997; Parodi *et al*., 2012; Javahery *et al*., 2012
Antioxidant activity		
Various mechanisms of action: sequestration of free radicals, chelation of metallic ions, sequestration of superoxide ions.	Clove extract and eugenol have strong antioxidant potential, although the mechanisms of action are not clearly established; eugenol polymers have high antioxidant activity; possible source of natural and cheap antioxidant in order to limit lipid oxidation in food processing.	Ogata *et al*., 2000; Gülçin *et al*., 2004; Tomaino *et al*., 2005; Van Zyl *et al*., 2006; Chaieb *et al*., 2007b; Parle and Khanna, 2011; Kamatou *et al*., 2012

Table 4. Continued.

Target and mechanism of action	Applications	References
Repellent and insecticidal activity		
Some trials have shown that clove essence is among the essential oils that have a strong repellent capacity against mosquitoes (genus *Aedes*, *Culex* and *Anopheles*) and larvicide against mosquito larva; action against mites (genus *Tineola*); eugenol and derivatives also develop insecticide properties against lice or weevils.	Could be the base for anti-mosquito formulation, if its irritation and its volatility are mastered. The latter could be solved by adding a fixating agent such as vanillin and define its efficacy compared to DEET, the molecule is largely used nowadays. Protection action against weevil in synergy with the deltamethrine. Preserving fabrics of animal origin (woollen…) and paper products.	Plarre *et al*., 1997; Huang *et al*., 2002; Trongtokit *et al*., 2005; Maia and Moore, 2011; Parle and Khanna, 2011; Boulogne *et al*., 2012; Dias and Moraes, 2014; Thomas *et al*., 2017; Marintan *et al*., 2018; Plates *et al*., 2019
Herbicidal and germicidal activity		
Clove essence and eugenol have a strong herbicide and germicide action on numerous plants.	Delay the germ development during potato storage. Application in organic agriculture, if the application methods are mastered.	Tworkoski, 2002; Kleinkopf *et al*., 2003; Evans *et al*., 2009; Cortés-Rojas *et al*., 2014; Finger *et al*., 2018
Attractive action of insects (para-pheromone)		
Male fruit flies (*Tephritidae*, *Bactrocera* or *Ceratitis*) are attracted to methyl eugenol and its derivatives.	In research areas being in progress: use as para-pheromone in traps for fruit flies.	Hee and Tan, 1998; Vargas *et al*., 2000; Hee *et al*., 2015
Nematicidal activity		
Fight against soil nematodes.	The first laboratory research studies gave promising outcomes: using of oils or simply the ground clove buds mixed to culture substrate.	Meyer *et al*., 2008; Wiratno *et al*., 2009
Enrichment of animal diets		
Inclusion in livestock diet, effects on growth performance, digestive system, pathogenic bacterial population, lipid oxidation.	Improvement of animal performance and product quality (milk).	Cardozo *et al*., 2006; Wall *et al*., 2014; Simitzis, 2017
Base of new molecules		
For more than a century, chemistry has developed numerous active molecules from eugenol; nowadays, this research area is very active.	Using specific properties of methyl eugenol (para-pheromone), the iso-eugenol or eugenol polymers (antioxidant), for the synthesis or biosynthesis of numerous 'natural' bioactive compounds but they are less available; a possibility for the production of organic vanillin from iso-eugenol.	Lampman *et al*., 1977; Huang *et al*., 2002; Zamzuri and Abd-Aziz, 2012; Kaufman, 2015; Riyanto *et al*., 2016
Uses as diesel additives		
Adding eugenol or its derivatives enhances combustion and reduces the ignition duration.	Additive for better yield for diesel motors, less polluting.	Kadarohman *et al*., 2012
Use of oleoresin in pharmaceutical and food processing.		
The clove bud oleoresin, highly concentrated products has the same properties as the essence and could be used as alternative.	Possible alternative to antioxidant.	Li and Xu, 2016

Tomorrow's uses: a bright future for the clove

This second chapter presents an overview of potential or future uses for cloves and the research avenues currently being considered.

Table 4 presents a synthesis of the applications for clove and its molecules currently under research. These perspectives, for the most part, build on properties already known, in search of more finely tuned and targeted, "state-of-the-art" applications. The avenues currently being investigated are at different phases of experimental development from laboratory testing to trials in controlled conditions, *in vivo* or *in vitro*, to small-scale development. These trials have mobilised a large number of research teams throughout the world.

These trials are concentrated mainly in the areas of medicine, agri-food and agronomy. The antiviral, anticancer, anti-inflammatory and analgesic activities of clove essential oil, eugenol and its derivatives are essentially being explored from a medical approach. The herbicidal properties or as defense compounds against animals and micro-organisms and as insect attractants (para-pheromones) fall within the scope of agronomy.

It must be noted that clove products are generally organic at farm gate as farmers do not use any chemicals, whatsoever, or even fertilizers for production. The entire value chain is organic. The authors of these studies highlight therefore the fact that the use of these molecules is compatible with the development of organic products, derived from green chemistry, ecological pest management and agro-ecology. They emphasize the effectiveness of these molecules on a wide array of parasites and diseases as much in agricultural contexts as medical, an effectiveness associated with the large number of interacting molecules, which offer multiple mechanisms of action thus limiting the risks of resistances developing. Finally, they highlight the low toxicity against non-targeted organisms including humans, and the relative harmlessness of the product residues, even if this aspect is not entirely conclusive, whereby chronic toxicity, cytotoxicity and mutagenicity of eugenol and other accompanying molecules still requires studying (Mohammadi Nejad *et al.*, 2017), as well as the effects of long-term exposure to sub-lethal doses on the targeted and non-targeted organisms (Pavela and Benelli, 2016).

In agri-food, clove essential oil, eugenol and its derivatives such as iso-eugenol, are being studied for the use in the conservation and increased shelf life of many foodstuffs and prepared dishes in respect of their antimicrobial and antioxidant activities. Compelling results have been obtained from experiments, for example, on tomato juice, salad leaves, frankfurters, dairy products, tofu and bananas (Tiwari *et al.*, 2009; Hamad and Hartanti, 2015; Zhang *et al.*, 2017; de Figueiredo *et al.*, 2019). Within the same sector, the plasticising properties of eugenol also open up promising uses in the field of "active" bioplastic films, or in gelatin or chitosan based films, which are edible and biodegradable enabling better conservation of foodstuffs, whilst reducing the content of chemical preservatives (Gómez-Estaca *et al.*, 2010; Woranuch and Yoksan, 2013; Figueroa-Lopez *et al.*, 2018). In the case of a plastic film which contains 3% clove essential oil, the shelf-life of a fillet of fish can be extended from four to eight days (Yang *et al.*, 2016).

The combination of carboxymethyl cellulose (CMC) coating and clove oil has good potential for application as an alternative to synthetic fungicides for improving postharvest quality and prolonging the shelf life of oranges during cold storage (Chen *et al.*, 2016). These innovations however come up against the fact that clove essence can sometimes alter a product's organoleptic qualities (Ribes *et al.*, 2019).

Technology currently under research in this field could be applied in the medical sector, in particular, to blood sampling containers of which the most common plasticising agent was DEHP (until it was progressively withdrawn from sale), which had the defect of releasing phthalates (Omer *et al.*, 2016).

Trials have shown that clove essence has a strong repellent capacity against mosquitoes of the *Aedes*, *Culex* and *Anopheles* genera (Trongtokit *et al.*, 2005). It could therefore be included in anti-mosquito repellents, on condition that its irritant properties and its volatility are restricted (this is achieved by adding a fixative such as vanillin), and its effect calibrated in relation to DEET (N,N-diethyl-3-methylbenzamide), which is currently the most widely used molecule (Maia and Moore, 2011). In the same field, the old practice of placing cloves in wardrobes to protect woollens against moth damage (Plarre *et al.*, 1997) is transposable to the conservation of paper and protection against insect damage in documentation centres and archives (Marintan *et al.*, 2018).

Other pest control applications include: methyl-eugenol which presents para-pheromone properties to protect orchards (mangos, papayas, citrus fruits, coffee…) and tropical cultures (tomatoes, chilli...), against fruit flies by trapping the males of the species responsible for major harvest losses, thus avoiding pesticides (Hee *et al.*, 2015). The antibacterial (against bacterial wilting in Solanaceae, in particular tomatoes), antifungal (against fusariose disease in vanilla) and nematicide activity of eugenol opens perspectives for the bio-control of bio-aggressors in the growing of vegetables or high added value products, which researchers are in the process of investigating (Xia-Hong, 2007; Meyer *et al.*, 2008; Wiratno *et al.*, 2009; Huang and Lakshman, 2010; Deberdt *et al.*, 2018).

This is an opportunity to turn the clocks back on vanilla, the production of which could become efficient and profitable again, by eugenol bio-transformation, using micro-organisms, modified or otherwise. This avenue is particularly lucrative at this time where the price of vanilla has soared to record highs (multiplied by 15 between 2012 and 2017) and where industries, Chinese in particular, are on the lookout for the lowest costing alternatives (Chalmin and Jégourel, 2019). Many studies are already in progress (Zamzuri and Abd-Aziz, 2012; Kaur and Chakraborty, 2013; Kaufman, 2015; Singh *et al.*, 2019). But well beyond the production of vanilla alone, Kaufman (2015) demonstrated that eugenol can be used as a starting point material for biosynthesis of a multiplicity of useful molecules, as well as other structurally interesting and bio-active components.

Thus, our analysis shows that the prospects and potential for developing new uses are mobilising a great deal of energy among researchers and industrialists and that many avenues for development are being considered. These future outlets could make the clove tree the basis of a set of high-tech applications, produced at low cost and with high added value, meeting the demand for natural, organic, ecological and ethical products.

A bright future, but subject to conditions

Where its uses are concerned, the clove seems to have a bright future, combining its current uses with these new directions in valorization. Its place in the global market seems to be assured, and its production should therefore continue to be a source of revenue for the small farmers of Indonesian, Madagascar, Zanzibar and the Comoros, who grow and/or distil it. However, this dynamic is subject to several conditions, some linked to the sector and the clove market, others linked to the global economic or ecological context such as climate change, or the very current crisis linked to COVID-19.

What future for the *kretek*?

At the present time, the global clove market is still driven by developments in the Indonesian *kretek* market. This market is however under threat from two sources.

The first is associated with the public health risk (Palipudi *et al.*, 2015), despite the perception that the harm from *kreteks* appears to be generally lower than that from classic cigarettes (less nicotine, less tar). They even appear to be genuinely capable of reducing pulmonary inflammation (Roemer *et al.*, 2014; Piadé *et al.*, 2014).

The second threat comes from the competition that American cigarettes, seeking new outlets, particularly in Asia, represent to the *kretek* in a context of shrinking markets in Northern countries, associated with anti-smoking campaigners and the development of the electronic cigarette. This competition takes the form of an offensive against the Indonesian market and protectionism by the American market. On Indonesian soil, a number of actions aimed at conquering this vast pool of smokers, including joint ventures with local manufacturers (Philip Morris became a major shareholder in the capital of Sampoerna, one of the main *kretek* manufacturers (Medvedeva, 2015)) and attempts to win a new customer base, mainly female.

The penetration of American cigarettes into the Indonesian smokers market currently remains limited (Lawrence and Collin, 2004; Schewe, 2017), but the campaign is also taking place on American soil. A law was passed in 2009 banning the sale of flavoured cigarettes, including *kreteks*, with the exception of mentholated cigarettes manufactured in the USA, a measure officially to reduce youth smoking, who often start smoking after experimenting with flavoured cigarettes. This law has been perceived by the Indonesians as an aggressive measure (Soeparna, after 2010). This dispute was settled by the WTO in 2014 by a trading compromise between the USA and Indonesia, which nonetheless does not renege on the import ban of *kreteks* to the USA (ICTSD, 2014). The *kretek* market is therefore tense, with scenarios for development but also assumed restrictions. Thus, even if the Indonesian demography and the evolution in behaviour, which could increase the number of female smokers, could argue in favour of the market's expansion, the threat from American cigarette producers and the public health imperatives could cause it to shrink. The main consequence of this risk would be for Indonesia to become self-sufficient in cloves, thus reducing, if not, removing the output of exporting countries, with Madagascar in the front-line, a third of whose production goes to feeding the *kretek* industry (Table 3). This dynamic appears furthermore to have started in the past few years due to a good clove harvest in Indonesia, a greater capacity to satisfy the domestic market and an increase in exports. A situation that leads to a sharp fall in world commodity prices and poses a risk for the countries whose exports serve as a variability adjustment factor between Indonesian production and consumption (Hadiyantono, 2018).

This dynamic is moreover already established as shown in Table 3. From the 1990s, the number one importing country of Malagasy cloves was Singapore, which assumed the role of warehouse, a hub for the re-export on to several countries, mainly Indonesia (World Bank, 2017a; UN Comtrade, 2018). Whereas since 2012, this first position has been shared with India and its spice industry (Hari Babu, 2017), which soaks up between a quarter and a half of Madagascar's output.

What about quality?

The demand from Indonesia and India, until recently, has been mostly for volume and less for quality: the poor or limited grade quality (CG3) cloves satisfied the market, whether they were chopped for incorporating into *kreteks* or ground for adding to masala spice mix.

However, the quality factor has been emerging as a consideration for some years now for some specific uses (cosmetic, spice…).

There has always been a flow for better quality cloves, which went mainly directly between the producing countries and consuming countries in the North (Figure 2). Where *kreteks* are concerned, quality has emerged as an issue in relation to the product's penetration of the international market (Godoy and Bennett, 1990). Added to which, for some years, India has been establishing quality standards in order to gain a greater share and considered value on the international spice markets. Furthermore, the Spice Board, created in 1987 by the Indian Ministry of Commerce controls the quality and uses this criteria to distinguish the more deserving exporters.

FIGURE 4. Drying of clove buds in Sainte-Marie (Madagascar). Photo P. Danthu.

FIGURE 5. Hand cleaning of cloves at a Comorian Exporter (Mutsamudu, Anjouan). Photo P. Danthu.

A further matter to be considered is the means by which producers would be rewarded for the quality of their product.

The standard of cloves is governed today by ISO 2254:2004, based mainly on the proportion of "headless" cloves (having lost their flower bud), the quantity of filth and extraneous matter, the moisture and volatile oil content. There are three distinct grades of quality: CG1: premium grade; CG2: intermediary grade; CG3: standard grade. However, there are currently four possible analyses: (i) it is difficult for the sector to ensure these standards are adhered to, in particular where moisture content of cloves dried in the open, subjected to climatic variations, is concerned; (ii) the organoleptic quality is given little consideration, the only reference indicator being the essential oil content; (iii) the sanitary quality of the cloves is not assessed, whereas their production, especially in the drying and sorting stages, on mats laid directly on the soil, is often conducted in conditions random hygiene (Figures 4 and 5); (iv) Malagasy, Indonesian and Comorian exporters rarely, if at all, compensate producers for the quality of their cloves. They send the cloves mainly of second and third grade to market (CG2 and CG3), those which correspond to the most common uses. The premium grade cloves CG1, usually selected during a manual sorting process carried out by the wholesaler or the exporter (Figure 5), are reserved for the North European and American retail clove spice market and represent around 1% of world trade. Whilst they incur added value of around 2,500 \$ ton^{-1} compared to the average price of the inferior grade cloves, which is about 8,000 \$ ton^{-1}, none of it reaches the producers.

Failure to reflect the quality in the price paid to producers and collectors is inevitably going to result in a neglect of cleanliness in the harvesting and drying procedure, regardless of the fact that information is available, such as the guidelines produced by the CTHT in Madagascar (CTHT, no date). This non-valorization of the product has the perverse effect of encouraging adulteration throughout the entire clove supply chain, whereas the field-based quality is generally excellent, thus requiring the exporters to introduce a supplementary final sort before export. This is an age-old problem which is prevalent in all countries and all sectors (Hussain *et al.*, 2018). Where clove is concerned, François (1936) commented as early as the 1930s, describing an almost institutionalised system of adulteration of clove consignments in Zanzibar, Khatri *et al.* (2017) in India, as well as Cocoual and Danthu (2018) in Madagascar. There are numerous adulteration practices in clove products, particular at collectors' level: adding moisture to batches, not removing filth, adding post-distillation cloves or powdered stems. The scale of this practice may result in an exporter being excluded from the international market.

In Zanzibar, several manufacturers produce and export organic clove (Akyoo and Lazaro, 2007). A number of exporters in Madagascar also began to offer organic clove for sale on the international market. The company Jacaranda and the Fanohana cooperative are two such producers, amongst others, that have reported a successful experience producing and exporting cloves (as well as other products) bearing "AB" and "Fairtrade" labels. However, these examples are rare and concern a small proportion of the cloves on the market and the premium paid to smallholders is also very limited and does not generate high interest and incentives for producers.

The valorization of high end cloves could be implemented by introducing a branding process which recognises a product by its origin and its quality, thus ensuring its local development, heritage protection and product valorization, on the same model as other spices such as Kampot pepper (Cambodia) or Penja white pepper (Cameroon), which are covered by a PGI process (protected geographical indication) (AFD and FFEM, 2010). This process is currently being set up for clove in Zanzibar and Pemba (Chinedu *et al.*, 2017; ITC, 2018) with the promotion of the brand "Zanzibar exotic and original cloves". The process is assisted by a strong implication from government in the control of the sector and a strong public-private partnership (ITC, 2018), contextual factors which are not presently in place in Madagascar or the Comoros (Penot and Danthu, 2019).

If therefore, a label or PGI recognising "Zanzibar origin" emerges, it is possible that this will alter consumer behaviour in the North, as well as the price and trade flows of cloves on the international market.

This raises the question as to whether the "conventional" sectors without a label or any certification to protect clove products could be penalised, even though the present methods of production and remuneration levels throughout the sector make Malagasy and Comorian clove a quality, organic product, *de facto*. If this is the case, a counter strategy needs to be developed. This is already under consideration in Madagascar initiated by the private sector stakeholders, in particular the consortium representing clove exporters, the *Groupement des Exportateurs de Girofle de Madagascar* (Dama, 2019), as well as projects financed in the Comoros by funding bodies, such as the ITC and AFD (Agence Française de Développement).

However, the requirements to launch such an initiative do not appear, as yet, to be assembled. This requires the convergence and implication of all the players in the sector, whereas these, particularly those up the supply chain, are not organised. Multi-stakeholder platforms are under construction in Madagascar and the Comoros, but it will be some time before they come into effect. Likewise, it will take time for the other parties required (politicians, tourist promoters, advertisers, for example) to become implicated, who could be motivated by the springboard to notoriety and profits which such a label often brings in its wake (Suh and MacPherson, 2007; AFD and FFEM, 2010).

How sustainable is eugenol production?

The development of uses for eugenol from cloves and its derivatives in different spheres of application is associated with the remarkable chemical properties of these molecules, but is equally reliant on economic factors such as availability, low production costs and the natural and ecological image they convey. An exponential growth in demand could be foreseeable in the coming years (Lima *et al.*, 2019).

However, the comparative advantage of clove eugenol could come under scrutiny if a more economic production pathway for eugenol presents itself or if the production and marketing costs of eugenol from clove increase too greatly relative to existing alternatives. This factor should be considered, as it is possible to extract eugenol from a number of different plants, many of tropical origin, even if their eugenol content is often inferior to that of the clove (Table 5). It is conceivable but unlikely that eugenol and its derivatives will be extracted from cinnamon or *Pimenta* spp. On the other hand, this may be the case for certain species or varieties of basil (genus *Ocimum*), a plant that is easy to grow on a large scale. These hypotheses depend very much on the relative price of the products. Researchers, however, have perhaps already taken a head start, as studies are under way to test production methods for producing eugenol by biosynthesis (Koeduka *et al.*, 2006) or from genetically modified plant matter, the first results of which have been obtained from transgenic poplar (Lu *et al.*, 2017). Finally, as a point of note, the possibility exists to synthesize eugenol by allylation of gaïcol (already used for synthetic vanillin), on an industrial scale (Raja *et al.*, 2015). There is no lack of potential competition for clove essential oil.

All the more so, given that, as with the cloves, the production of eugenol, the quality of which is controlled by ISO

Table 5. Some plants rich in eugenol, according to Raja *et al.* (2015); Kaufman (2015), and specific references.

Family	Species	Common name	Area of existence	Plant parts	Eugenol content of the essence	Reference
Myrtaceae	*Pimenta racemosa*	Indian wood	Caraïbes, introduced in tropical area	Leaves	A chemotype rich in eugenol, 45/56%	Abaul *et al.*, 1995
	Pimenta dioica	Jamaica Pepper	Central America, Caribbean, planted in tropical areas	Leaves	64%	de Oliveira *et al.*, 2007, 2009; Zabka *et al.*, 2009
Lauraceae	*Cinnamomum macrophyllum*	Cinnamon tree	Tropical Asia, planted	Leaves	92%	Hammid *et al.*, 2016
	Cinnamomum zeylanicum	Cinnamon tree	Sri Lanka, Southern India, planted in tropical areas	Leaves	77/79%	Paranagama *et al.*, 2001; Patel *et al.*, 2007
Lamiaceae	*Ocimum basilicum*	Basil	Ubiquitous	Aerial parts	Varies according to chemotypes	Krüger *et al.*, 2002; Telci *et al.*, 2006; Zheljazkov *et al.*, 2008
	Ocimum tenuiflorum (syn.: *O. sanctum*)	Basil tulsi	Indian subcontinent	Aerial parts	Rich in methyl eugenol	Kothari *et al.*, 2005; Zheljazkov *et al.*, 2008
	Ocimum gratissimum	Clove basil, African basil	Pantropical, invasive	Aerial parts	43%	Pessoa *et al.*, 2002
Solanaceae	*Petunia hybrid* cv. Mitchell	Petunia	–	Flower	Rich in iso-eugenol	Koeduka *et al.*, 2006

3142:1997, is also subject to different acts of adulteration. These include adding miscible fluids that are undetectable to the eye, such as turpentine or castor oil, and more recently brake fluid, which adulterate the consignment irrevocably and prevent it from being in any way rectified. These risks of adulteration create the necessity to check each batch, and furthermore represent a threat to the integrity and sustainability of the clove oil production sector. At present quick reliable means of detection of adulteration, such as Raman spectrometry, offer an unprecedented opportunity for detection (Vargas Jentzsch *et al.*, 2018), but which still need to be generalised. Beyond the problems posed by adulteration, essential oil produced by distillation could, in the case of niche markets such as cosmetics and perfumery, be surpassed by oleoresin, particularly if produced organically (with organic or non-hazardous solvents or by the supercritical CO_2 method). However, this production will be beyond the means of small farmers and distillers, falling moreover into the industrial domain.

At the current time, however, the most immediate threat to the sector and its sustainability in the midterm, particularly in Madagascar, is the environmental impact, in particular for essential oil that required distillation and high consumption of firewood.

The production of essence by a multitude of small antiquated wood-fired stills requires harvesting fuel wood which is exhausting the resources and causing deforestation (Dama, 2016; Razamamonjison *et al.*, 2016a). In the region of Analanjirofo, in particular, the ecological consequences are already marked and significant. The distillers over-exploit the last remaining strips of forest, burning local species and felling fruit trees (mango, lychee, clove, jack fruit) to fuel their stills (Danthu *et al.*, 2014) (Figure 3). At present, the situation is approaching breaking point, and has even breached it in some districts. Beyond the major environmental threat, this situation will rapidly entail a noticeable rise in production costs compromising the sector's current state of economic profitability. In reaction, producers and manufacturers are beginning to organise themselves, supported by various scientific projects (funded, by example, by the EU, in Madagascar). These projects combine several modalities such as: renewing or rehabilitating the stock of traditional stills, optimising the conduct of distillations, developing (re) afforestation actions in combustible wood, improving the preparation of the wood that feeds the stills (drying, cutting) (Razafimamonjison *et al*., 2016a).

However, this is a vast operation as it concerns, in Madagascar, an estimated pool of between 8,000 and 10,000 still and an annual consummation of 500,000 to 800,000 m^3 of wood requiring the reforestation of a surface estimated at 50,000 ha, in a context where awareness of the extent of the threat is not entirely shared by all the stakeholders in the sector.

What influence will climate change have on the production of cloves?

In recent years, the production of cloves seems to have been influenced by climactic conditions, on a global scale (Tridge, 2018). In 2018, the harvest recorded in Madagascar was a previously unseen calamity, no doubt due to unusually moist conditions. Malagasy production represented around 10 to 20% of an average year (Chalmin and Jégourel, 2019). This observation is the same in Comoros, Brazil and Zanzibar, whose production fell from 7,000 tonnes in 2017 to 1,300 in 2018, while Indonesian production, benefiting from favorable climatic conditions, was, at the same time, very high (Chalmin and Jégourel, 2019; Hadiyantono, 2018). The question this raises and which is causing concern to the stakeholders in the sector, is whether these are the first significant indications of a climate change effect.

What is the potential impact of the COVID-19 pandemic?

This last part, very prospective, intend to evaluate the consequences of the health crisis linked to COVID-19 and its propagation on all continents. It impacts all horticultural sectors, however, depending on the sector considered, this impact will be different and more or less strongly linked to the duration of this pandemic.

Concerning the clove sector, it is impossible to predict the impact of the economic crisis resulting from COVID-19 on household consumption in major consumer countries.

Moreover, the impact of this pandemic on the economic situation of the two main country clove purchasers (Indonesia and India), is still unknown. This concerns both industrial buyers or distributors and other stakeholders such as transporters, banks and freight forwarders.

However, the question will only arise for clove at the end of 2020, at harvest time. We can optimistically expect that by that time the overall COVID-19 situation will have improved and that a certain “liberation euphoria” on markets will lead to renewed interest on the markets.

As far as clove oil is concerned, the eugenol market has not been impacted by the pandemic as demand remains strong for the main outlet which is the production of vanillin obtained from eugenol, which is recognized as natural by the USA (but artificial by the EU).

Moreover, eugenol is mainly used in food, pharmaceuticals (dental care), livestock feed and cosmetics, sectors that seem not to have been really affected by COVID-19. This is not the case for perfumery, where all circuits have been stopped or very slowed down in 2020 (no tourism, closure of duty-free shops...). As a result, the sector of raw materials for perfumery will probably suffer economic aftermath in the coming months with a significant drop in the price of raw materials.

This crisis could benefit producing countries provided that they know how to adapt to market requirements, in terms of delivery times and quality, and offer products at competitive prices. These issues, already present before the crisis, are likely to be exacerbated by it.

Conclusion

The small clove grower in Madagascar, Indonesia, Tanzania and the Comoros is the point of origin for a supply chain to sectors and trading circuits that distribute clove products to the entire planet, for a variety of different applications, some high-tech, often with added value.

This production has already known, in its past, some harsh vagaries: macroeconomic such as the decline in price before the 2010s, as well as monetary, political, or meteorological crises, such as cyclone damage (Danthu *et al.*, 2014; Penot and Danthu, 2019). However, producers will have no more control tomorrow than they did today or yesterday, over the evolution in international market demand or the prices of the product.

At present, a certain number of negative evolutions, some short term, could disrupt the future of the clove supply chain, and therefore, the living standard of the small farmers.

A set of anticipatory responses may be proposed, including the following:

- at the producer level: combating adulteration practices; reducing the ecological impact of oil production; diversifying production in order to develop alternative crops to cloves in the event of climatic or economic hazards;
- at the level of industrialists: promoting and rewarding the quality of cloves and oils;
- at the level of exporters (Malagasy and Comorian, in particular): diversifying the customer base so as not to be constrained by monopolistic demand.

While some of these proposals are already being implemented, they are still far from being generalised. They will only be fully effective if a dialogue is established and sustained between all the players in the sectors, including the State, enabling diagnosis to be shared and concerted action to be developed within the framework of inter-professional platforms. However, in Madagascar and Comoros, where these platforms have yet to be built (after many failed attempts), the challenge remains (Penot and Danthu, 2019).

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