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Influence of Quality Characteristics and intake of Acrylamide by Consumers of Roasted Coffee in Kenya: A Review

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Abstract

Coffee is one of the most consumed beverages across the world with increasing demand in non- traditional markets due to its unique sensory and physiological characteristics. However, coffee has been found to have accumulated acrylamides which are carcinogenic and may end up intoxicating consumers. The degree of roasting determines the quality characteristics and the acrylamide levels in the final processed products. The occurrence of acrylamides is as a result of cooking at high temperatures due to Maillard reactions in food stuff as a result of reactions between asparagine and reducing sugars. Acrylamide commonly occurs in foods exposed to high temperatures such as baked products including bread, coffee and fried potato products. In comparison to potato products such as crisps and French fries, only limited studies on their occurrence and their mitigation strategies have been conducted on coffee whose estimated daily intake levels have been estimated to be 14 to 70 µg/day. The toxicants have been shown to be potential carcinogens whose increased exposure through coffee consumption remains a key factor of safety concerns. Besides, several studies have also indicated that there are several other potential adverse health effects to consumers including nervous system failure and infertility at levels exceeding 0.43-1 mg/kg bw/day. Although acrylamide levels and occurrence have been determined in other foods in Kenya, there has been limited research on the quality and acrylamide levels in coffee. This review therefore aimed at determining the levels of acrylamides in the marketed coffee and determination of the levels of intake as a result of coffee consumption. Furthermore, there are no known strategies for reducing their levels as compared to other foodstuff therefore exposing consumers to potential food safety threats. There is need therefore for documentation of potential intoxication from the toxicants are therefore and there is need to assess the levels and potential intake.

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Introduction

The production and consumption of coffee has been increasing over the last half a century.[1] The current consumption patterns are attributable to increased disposable incomes among the middle class earners, improved coffee qualities, and decreasing retail prices.[1] Data from FAOSTAT indicates that more than 70 countries across the world are now producing the crop characterized by considerably high number of small-scale farmers. Some coffee producing countries have seen considerable benefits through higher yields and growing volumes of sales. The coffee sector is however faced with increasing challenges as a result of the climate change and diminishing natural growing conditions and environments. The crop is mainly cultivated as a cash crop and has seen tremendous growth in the international trade estimated at over $19 billion since 2017.[2]

Coffee is usually traded in large quantities with different varieties, forms i.e. processed or raw, quality of the beans and the source of procurement fetching different prices.[3] The two broadly traded varieties are Arabica and Robusta, and are usually sold in roasted or green conditions, while in processed forms, this may be either instant or in soluble form.[1] In most developing countries, coffee is an export crop and has been a major source of valuable foreign exchange.[4]

In Kenya coffee farming supports many smallholder whose livelihoods depend on the crops' cultivation.[5] Although Arabica and Robusta were the two major varieties grown in Kenya, about four cultivars that adapt to both high and low altitudes have been developed from the Arabica variety with Ruiru II variety bring a common clone. The crop thrives well in attitudes of 1 400 to 2 000 meters above sea. Coffee farming is however on the decline due to reliant on many small scale farmers who have been faced with constraints including high production costs, and lack of incentives besides the low economic returns from the cooperatives managing the coffee farmers despite the international market demands for Kenyan coffee 4 (Figure 1).

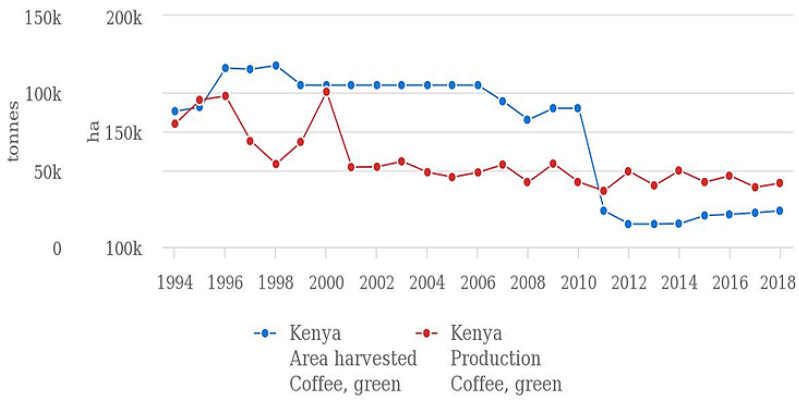

Fig. 1: Coffee production trends, 1994-2018 showing the declining coffee cultivation and production according FAOSTAT.[6]

The Kenyan coffee farming is coordinated by the ministry of agriculture promotes an agricultural sector of Coffee Directorate through Agriculture and Food authority to ensure efficiency in production and postharvest handling.[7] Produced coffee undergoes primary wet, dry processing and grading at the local production sites, often characterized by farmer's cooperative societies and thereafter transported to private service providers and processors for further processing.[8] Although coffee consumption been shown to have various health boosting effects on consumers including lessened risk for heart diseases, cancer, and liver diseases besides the various phytonutrients from the beans among others,[9,10] it faces stiff competition from tea consumption which is the most preferred beverage nationally due to low consumer purchasing powers for the imported coffee which are predominant in the

local markets. This is however changing as a result of increasing middle income earners and increased coffee houses and malls.[8]

Although the consumption of coffee has been on the increase in the past few years,[8,11] there have been concerns on the safety of the beverage due to the presence of acrylamides which occur in roasted beans during processing of coffee.[12–14] There are however, limited studies on the levels and presence of acrylamides in marketed coffee within the Kenyan markets. The current review discusses acrylamides occurrence in processed coffee and the potential safety concerns due to intake of acrylamides through processed coffee consumption based on findings from a comprehensive literature review.

Occurrence of Acrylamides in Foods

Acrylamides commonly occurs in roasted or baked foods.[15,16] The high processing temperatures and the presence of free amino acids and reducing sugars facilitate the occurrence of these toxicants in the processed foods.[14] Given the potential of acrylamides to cause adverse neurotoxic and carcinogenic effects, there is need to ensure that their levels in foods are within safe levels especially for foods that involve high temperature cooking during food preparation including baking, roasting and frying, among others.[16] There is paucity of information on the presence of acrylamides in coffee and there is no data on acrylamide poisoning in the country despite studies showing that they cause widespread human risk exposure[17]

Acrylamides are potential toxicants formed by Maillard reactions at cooking temperatures exceeding 120°C through the reactions of free asparagine, an amino acid and reducing sugars in foods.[18] Acrylamides were first reported by the Swedish National Food Agency in 2002 and the United States of America's food and drug authority (FDA) according to Vattem & Shetty.[19] Since then, various studies have shown that acrylamide exposure through contaminated foods have potential to cause neurotoxic and carcinogenic effects among animal studies[20,21] with human beings being at a high risk of experiencing carcinogenicity[22] besides other health threating conditions.

Table 1: Indicative values for acrylamide levels in foods

Food category	**Indicative value** µg/Kg
French fries, ready-to-eat	600
Potato crisps from fresh potatoes and from potato dough	1000
Potato-based crackers	
Soft bread	
(a) Wheat based bread	80
(b) Soft bread other than wheat-based bread	150
Breakfast cereals (excluding muesli and porridge)	
(a) Bran products and whole grain cereals, gun puffed grain	400
(b) Wheat and rye-based products	300
(c) Maize, oat, spelt, barley and rice-based products	200
Biscuits and wafers	
Crackers with the exception of potato-based crackers	
Crisp-bread	450
Ginger bread	1000
Roast coffee	450
Instant (soluble) coffee	900
Coffee substitutes	
(a) Coffee substitutes mainly based on cereals	2000
(b) Other coffee substitutes	4000
Baby foods, other than processed cereal based foods	

(a) Not containing prunes 50	50
(b) Containing prunes 80	80
Biscuits and rusks for infants and young children	200
Processed cereal-based foods for infants and young children, excluding biscuits and rusks	50

Adopted from[26]

Studies by Lingnert and colleagues[23] have reported that the toxicants mainly occur in plant-based foods, such as potatoes, cereals products, as well as in coffee during the long time and high temperatures cooking combinations. Acrylamides however, are less prone in animal-based foods, such as meat, and fish, among other products, because it only occurs in the presence of reducing sugars which may be absent from animal based foods.[12,18] The presence of acrylamides in foods have however, not been found to be influenced by either the food packaging materials or the environmental conditions but majorly through the Maillard reactions which are complex reactions that occur as a result of amino acids and sugars interactions under high temperature.[24] Foods including fried potatoes such as crisps and French fries and baked cereals and legumes have been found to contain various levels of acrylamides[12,25] with indicative safety limits set at varying concentrations[26] (Table 1). Acrylamides are also water soluble and have been detected in drinking water exposing the consumers to food safety risks.[27,28] In coffee beverages, they diffuse through into the consumers' drink at different levels depending on the surface area to volume ratio of the beans used.[14] In Kenya, limited studies on the occurrence of acrylamides have been conducted, mainly on potato crisps and French fries[29,30] although most foods with potential to accumulate the toxicants remain under studied.

The Occurrence of Acrylamides in Coffee

Coffee is now one of the most consumed beverage across the world and is probably the major drink through which consumers are exposed to acrylamide intoxication.[18] Kenya's altitude, rainfall, volcanic soils, and temperature enhance coffee farming[31] and consumption among Kenyans and foreign visitors has seen a tremendous growth since the last decade[8,31] given the increasing disposable income and luxury associated with coffee drinking.

Acrylamide are heat-caused food toxicants formed through the Maillard reaction between asparagine and reducing sugars when processing food.[32] The levels of acrylamides in coffee are influenced by the degree of roasting, the coffee variety under processing, and the conditions of storage.[32,33] Various ways of coffee brew preparation, depending on regional and personal tastes, may result in distinct amounts of acrylamide in coffee brews and, consequently, to different vulnerability to this compound.[32]

Different coffee products have been shown to accumulate varying levels of acrylamides as reported by Mojska & Gielecińska.[18] Out on 42 coffee samples, composed of 11 instant coffees and three coffee substitutes (grain coffee), the study found that instant coffee had 100% more acrylamide than freshly roasted coffee, while coffee substitutes had 300% more acrylamides. Furthermore, the study also noted that acrylamide levels increased early during the heating process and then reduced as the processing continued. Similar studies have also supported similar findings and it has been shown that lighter colored coffee beans have more acrylamides compared to the darker coffee beans roasted for more extended periods.[34]

Health Effects of Acrylamide Intake

Acrylamides have been shown to be potential risk factor for cancer, according to Wachamo, (2017).[9] The chemicals are dangerous at higher levels, but cannot be removed from coffee once the processing is completed, although many studies suggest that coffee consumption relatively increases the risk of cancer occurrence.[16] Acrylamides are also potential triggers free radicals production among the white blood cells leading to likelihood of diseases as well as inducing inflammation and oxidative stresses responsible for atherosclerosis among frequent consumers of coffee.[35]

Although the recommended safety intake margins for acrylamides have been set at 1-4 µg/kg/bw according to the WHO/FAO-JECFA,[36] there haven't been well established recommended limits given that there have been limited studies on the acrylamides kinetics and behavior in human bodies to make scientific conclusions. The FAO/WHO, (2010) Joint Expert Committee on Food Additives reports that the toxic nature of acrylamides occurs from the fact that the toxicant is converted into reactive epoxy compound within the body and these form a basis for intoxication. Consequently, the higher the levels of consumption, the higher the toxicity among consumers. Exposure to acrylamides intake of by animals and human beings increases the risk of cancer development more so when where the exposure is in high dosages.[38] Therefore, there is a need for more investigations to determine the implications it causes in human health.[17]

High levels of acrylamide in coffee through roasting poses significant health problems among children and adults[39] with children and younger generations being at higher risks given their relatively lower body weights. Besides neurotoxicity and carcinogenicity, other condition have been attributed to the toxicants especially in in younger generations[15] including inadequate responses, sparse learning insufficient brain chemicals that help in signal transformation and loss of body weight. Excess acrylamide levels cause nervous system problems including numbness, muscle weakness, sweating, clumsiness, and unsteadiness.[40] High levels of acrylamide chemicals has been found to promote decreased ability of males to create offspring[40] among laboratory test animals.

The use of coffee has been demonstrated to have potential long-term effects since the levels may be low in coffee. Besides, processed coffee has low acrylamide levels, hence it cannot cause the health effects in the short-term, as suggested by.[39] However, there are other factors which determine whether one is affected upon exposure to acrylamide or not. These factors include duration, dosage, way of contact, state of heath during exposure among others[18] The effects of acrylamide in human bodies have however had conflicting reports as potential precursors responsible for many cancer cases in animals studies, though there is no adequate epidemiological studies to support this especially among human beings as studies have shown potential contribution to cancer occurrence among consumers.[41–43] Therefore, the actual number of consumers exposed to acrylamides risk of exposure in Kenya remains unknown.

Consumer Exposure to Acrylamide

Exposure to acrylamides occurs through oral via consumption of contaminated processed foods and water, dermal route through industrial acrylamides and polyacrylamides and gaseous inhalation through smoking of tobacco.[12,28] The dietary exposure has however been found to contribute to relatively higher levels subject to the contamination levels, estimated to be up to 39% among the high coffee consumers.[41] The various processing parameters for potential foods has also been shown to vary according to USDA resulting to varying levels in the finished products.

The dietary exposure to acrylamides through heat processed foods has continued to raise a worldwide concern as the contaminants easily diffuses into the body tissues including the placenta and into the fetus. They further distribute into the body fluids through accumulation in the body has not been well documented. Assessing acrylamide risks depends on the levels of food substances intake that contain the chemical.[44] Those exposed to higher levels of foods and substances containing Acrylamide are likely to show health effects that could help determine the risks. For instance, Acrylamide in coffee relatively increases the risk of getting cancer across every age group. Acrylamide gets into the body organs through absorption and results to acrylamides metabolism. This metabolism causes gene mutation, tumors development, and other gland defects in animals.

Acrylamide is also responsible dangerous effects on other body systems like the nervous system and studies have also shown a likelihood of paralysis and infertility among males in animal trials dosed with different levels of the chemical.[42] Human studies have given limited evidence on the risk of cancer development in the liver and kidney. Acrylamide is found in coffee and other everyday foodstuffs, children get the most exposure, enhancing risk assessment in terms of body weight losses.[26] Storage of food, ingredients, and conditions involved during processing influence

acrylamide accumulation food.[45] Diet routines, home-cooking, and other choices by different homesteads would help us assess the risks. Health checkups will effectively help to show those affected in terms of exposure to acrylamide levels.[45]

According to Barlow,[46] the margin of exposure (MOE) approach indicates the degree of health concern about the presence of a particular component in food without quantifying the risk. The MOE's use helps risk managers recognize the necessary decisions needed to keep exposure to such substances at low levels possible. For carcinogenic and genotoxic substances, a MOE of higher than 10,000 is of moderate concern to the public health. In Kenya, evaluation of acrylamide exposure through French fries and crisps consumption was ranged from 0•3–0•8 µg/kg body weight per day established on exposure calculations made by FAO/WHO.[46] Acrylamide exposure was at an average of 1 µg/kg body weight a day as the highest exposure in adults was almost 0•5 µg/kg body weight in a day, with 95th percentile figures of practically 1 µg/kg body weight per day. Exposure is high among younger Kenyan people between the age of 15-18 years, as the 95th percentile was 3•4 µg/kg body weight per day.[47] Similar studies on coffee remain absent and there is need for conducting such studies. However, limited dose response studies are still recommended for adequate evaluation of the intake consequences.

The acrylamides concerns across the world raised consumer safety concerns leading to the WHO/FAO to conduct adequate assessments for exposure through food.[48] However, there have been limited doxological data leading to limited information on the probably consequences from their exposure.[48] Furthermore, there is likelihood that low doses in commonly consumed foods among consumers whose potential harm may still be unknown. This therefore requires increased risk assessment to assess the consumption of varying levels of the effects on consumers' health.

Effect of Different Processing Parameters on Acrylamide Levels in Coffee

The occurrence of acrylamides in uncooked raw foods have not been reported and these occur strictly through processing through the Maillard reaction.[12,48] Asparagine has been reported to be the main precursor for the formation of acrylamides[49] and forms significant quantities at elevated temperatures similar to thermal processing. The levels have however been found to increase more than 12 fold in the presence of reducing sugars.[18,49,50]

Other processing parameter such as pH, processing temperature, presence of ocrolein and ammonia among others during processing have been reported to be catalysts for accumulation of acrylamides in processed foods.[51] However, data from most developing countries remain undocumented and in Kenya, this also the case. The occurrence of acrylamides, quantification of their levels, formation in processed foods, as well as exposure among different age categories have been widely studied across different countries, though limited epidemiological studies have reported differing information on cancer disease formation among consumers.[48] There are no enough such studies in Kenya therefore limiting reporting of the occurrence and potential food safety and health concerns for consumers.

Mitigation of Acrylamide in Processed Coffee Products

The levels of acrylamides are highly dependent on the selection of cultivars for processing, the roasting conditions, storage and the brewing processes (Figure 2). Based on the indicated probable consequences of acrylamide, there is an increased need to create rational solutions.[52] Among the various ways of reducing the amount of acrylamide ingested in beverages include, deep roasting of the coffee beans to darker conditions using darker temperatures ranging from 220°C to 250°C considering both the speed and time (20-30 minutes) of roasting, because these conditions contribute to the taste and aroma as suggested by.[52] This is because at higher temperatures, the acrylamides are broken down and therefore less accumulation. Consequently, lightly roasted coffee beans have far much less acrylamides.[42]

Coffee to be processed should be properly selected from desirable raw material (green and quality coffee beans) since varietal effect in the levels of acrylamide have been found to have a significant effect. Studies have shown that the two dominant coffee species Arabica and Robusta, are differentiated by sensorial

possessions and chemical configuration where Robusta coffee species have higher acrylamide content compared to Arabica.[53] The amount of the ultimate contents of acrylamide depends on the various processing conditions involved.[52] Therefore, it is recommended that it be blended with higher amounts of Arabica coffee species to reduce the levels of acrylamides. The storage periods should also be longer because acrylamides are usually unstable during the roasted coffee packaging, as indicated by Figure 2. To reduce the amount of acrylamide in coffee, the products should be stored at room temperatures in closed vacuum packs for 12 months.[52] It is also necessary to prefer shorter brewed coffee over longer ones. which proved to be the best brewing method compared to the other ways. During consumption preparation should also involve a short infusion period for freshly prepared coffee beverage.[52]

Other techniques, such as reducing the key reactants, such as fructose and glucose, and the responsible amino acid, asparagine, prior to the high-temperature heating process by disrupting their reactions with the addition of other amino acids and food-grade acids, can alter the reaction conditions and thereby prevent high accumulation.[35] Moreover, soaking bans may reduce sugar accumulation because the sugars will dissolve in the soaking water, and avoiding temperatures above 190°C is advised.[54]

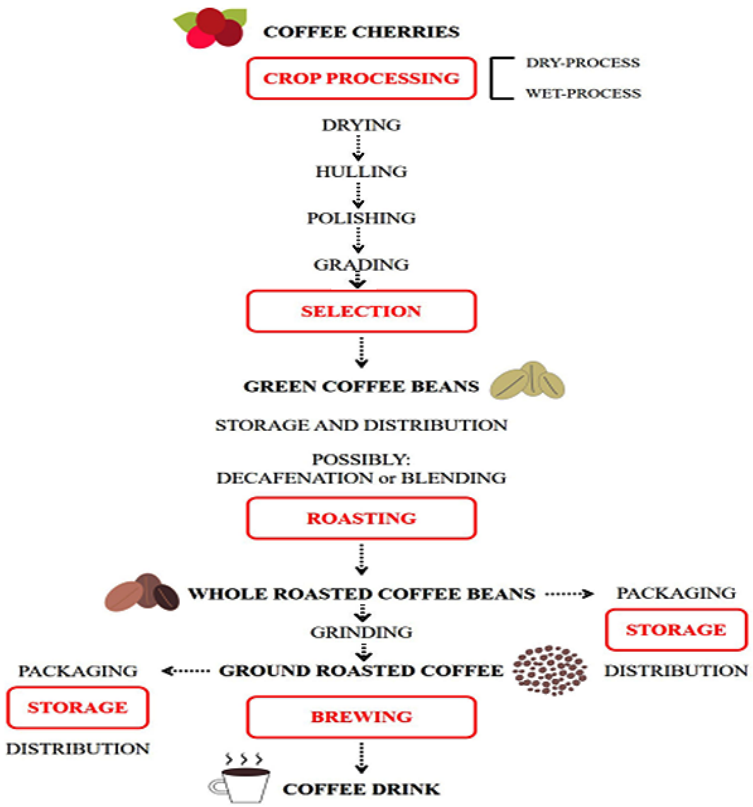

Fig. 2: Processing of coffee showing critical points during coffee processing with the red highlighting critical processing steps.

Methods of Determining Acrylamides in Foods

Several methods have been developed though none has been conventionally agreed on for their reliability in rapid detection and sensitivity.[48] Consequently, there has not been a standardized method and there are new methodologies being developed to date. Significant methods for analyzing presence of acrylamide in the foods are liquid chromatography

with mass spectrometry, LC-MS (/MS), and Gas chromatography with mass spectrometry, GC-MS (/MS).[12] Liquid chromatography a standard technique used in analytical food chemistry for ascertaining the existence of organic trace compounds in food analysis. It uses the resolving power of liquid chromatography together with the detection specificity of mass spectrometry. LC involves the separation of sample components and presenting them on to the mass spectrometer (MS). The MS forms and distinguishes charged ions.

On the other hand, GC-MS (/MS) works on the principle that the sample separates into independent substances when heated. The method uses heated gases which go through a column filled with inert gas, for example, helium. The sample isolated comes out through the column opening as they flow to the MS.[29] For accurate results, analysts prepare food samples through a solid-phase extraction method before analysis by chromatography.[55] This extraction method is essential as it optimizes the example, besides, it reduces background contaminates and may even concentrate the compounds of interest. Analytical instruments used for the quantification and detection of acrylamide include Nitrogen phosphorus detection (NPD), gas chromatography (GC); coupled with electron capture detection (ECD), flame ionization detection (FID), liquid chromatography (LC); coupled with ultraviolet detection (UV), fluorescence detection, or, flame photometric detection (FPD).

Although the various methods have been tested in other studies, in Kenya, there is limited information on the most reliable detection methods and the limited studies have majorly been reliant on high pressure liquid chromatography (HPLC) analysis for potato crisps and French fries.[47,56] It is recommended that other methodologies be assessed and the scope be increased so as to cover other acrylamide accumulating foods such as cereals based baked foods.

Conclusion

Despite urinary excretion, acrylamide is rapidly absorbed and widely distributed throughout the body. Studies have revealed that acrylamide has reproductive, genotoxic, and carcinogenic effects; therefore, it is imperative that consumers consume as little of these contaminants as possible, given the possibility of adverse effects on their nervous systems. Given Kenyan coffee consumers' limited understanding of acrylamide intoxication and their estimated intake levels from locally processed and ground coffee, there is a need to raise awareness about the safety and potential poisoning associated with coffee consumption if contaminants exceed the recommended safe levels. There are also no known levels of acrylamide accumulation in locally processed and ground coffee, necessitating further research on the topic and the adoption of standardized methods for processing coffee with low acrylamide levels by processors.

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Conflict of interest

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References

1. FAO. FAO Coffee Pocketbook;Coffee 2015. 2015.
2. Voora V, Bermúdez S, Larrea C. Sustainable commodities marketplace series 2019: Global market report - Coffee. Int Inst Sustain Dev [Internet]. 2019;12. Available from: https://www.iisd.org/system/files/publications/ssi-global-market-report-cocoa.pdf
3. Lewin B, Giovannucci D, Varangis P. Coffee Markets New Paradigms in Global [Internet]. Paper 3; 2004. Available from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjnypy_yrDqAhVFPBoKHXPLCJcQFjABegQIAxAB&url=http%3A%2F%2Fwww.csa-be.org%2FIMG%2Fpdf_CoffeeMarkets-ArdDp3.pdf&usg=AOvVaw3l5SY496TWVSV0Ak0u0M42
4. Gathura MN. Factors affecting Small-Scale Coffee Production in Githunguri District, Kenya. *Int J Acad Res Bus Soc Sci*. 2013;3(9):132–49.
5. Wambua DM, Ndirangu SN, Njeru LK, Gichimu BM. Effects of recommended improved crop technologies and socio-economic factors on coffee profitability among smallholder farmers in Embu County , *Kenya. African J Agric Res.* 2019;14(34):1957–66.
6. FAOSTAT. Production/crops/kenya, coffee for 1994-2018. Food and Agriculture Organization of the United Nations, Statistical Division (FAOSTAT), Rome, Italy. 2020.
7. Kogo BK, Kumar L, Koech R. Climate change and variability in Kenya: a review of impacts on agriculture and food security. Environ Dev Sustain [Internet]. 2020; Available from: https://doi.org/10.1007/s10668-020-00589-1
8. Gitonga K. Kenya: coffee annual report 2015 [Internet]. 2016. Available from: https://gain.fas.usda.gov/Recent GAIN Publications/Coffee Annual_Nairobi_Kenya_5-13-2016.
9. Wachamo HL. Review on Health Benefit and Risk of Coffee Consumption. *Med Aromat Plants.* 2017;06(04).
10. Samoggia A, Riedel B. Consumers' perceptions of coffee health benefits and motives for coffee consumption and purchasing. *Nutrients*. 2019;11(3).
11. Xinhua. Booming business as more Kenyans take to coffee drinking [Internet]. Business Today. 2019. Available from: https://businesstoday.co.ke/booming-business-as-more-kenyans-turn-to-coffee-shops/
12. Galani JHY, Patel NJ, Talati JG. Acrylamide-forming potential of cereals, legumes and roots and tubers analyzed by UPLC-UV. *Food Chem Toxicol* [Internet]. 2017;108:244–8. Available from: http://dx.doi.org/10.1016/j.fct.2017.08.011
13. Tran KT, Coleman HG, McMenamin ÚC, Cardwell CR. Coffee consumption by type and risk of digestive cancer: a large prospective cohort study. Br J Cancer [Internet]. 2019;120(11):1059–66. Available from: http://dx.doi.org/10.1038/s41416-019-0465-y
14. Guenther H, Anklam E, Wenzl T, Stadler RH. Acrylamide in coffee: Review of progress in analysis, formation and level reduction. *Food Addit Contam.* 2007;24:60–70.
15. Hilbig A, Freidank N, Kersting M, Wilhelm M, Wittsiepe J. Acrylamide toxicity and cholinergic nervous system. *Int J Hyg Environ Health.* 2004;207(5):463–71.
16. Spivey A. A matter of degrees: advancing our understanding of acrylamide. 2010;
17. Esters M, Compounds R, Stadler RH, Theurillat V. Heat-generated toxicants in foods (Acrylamide, MCPD esters, glycidyl esters, furan, and related compounds). Second edi. Chemical Contaminants and Residues in Food. Elsevier Ltd, Woodhead Publishing.; 2017. 171–195 p.
18. Mojska H, Gielecińska I. Studies of acrylamide level in coffee and coffee substitutes: influence of raw material and manufacturing conditions. Rocz Państwowego Zakładu Hig. 2013;64(3):173–81.
19. Vattem DA, Shetty K. Acrylamide in food : a model for mechanism of formation and its reduction. *Innov Food Sci Emerg Technol.* 2003;4(03):331–8.
20. Kreuml MTL, Majchrzak D, Ploederl B, Koenig J. Changes in sensory quality characteristics of coffee during storage.

Food Sci Nutr. 2013;1(4):267–72.
21. Abong GO, Kabira JN. Potential Food Safety Concerns in Fried Potato Products in Kenya. OALib. 2015;2:1–11.
22. Hariri E, Abboud MI, Demirdjian S, Korfali S, Mroueh M, Taleb RI. Journal of Food Composition and Analysis Carcinogenic and neurotoxic risks of acrylamide and heavy metals from potato and corn chips consumed by the Lebanese population. *J Food Compos Anal*. 2015;42:91–7.
23. Lingnert H, Grivas S, Jägerstad M, Skog K, Lingnert H, Grivas S, *et al*. Acrylamide in food : mechanisms of formation and influencing factors during heating of foods Acrylamide in food : mechanisms of formation and in uencing factors during heating of foods. *Scand J Nutr.* 2016;6480.
24. Pundir CS, Yadav N, Kumar A. Occurrence , synthesis , toxicity and detection methods for acrylamide determination in processed foods with special reference to biosensors : A review. *Trends Food Sci Technol*. 2019;85(November 2018):211–25.
25. EFSA. Scientific Opinion on acrylamide in food. EFSA J. 2015;13(6).
26. EC. Update on acrylamide levels in food from monitoring years 2007 to 2010 [Internet]. Vol. 301, Official Journal of the European Union. Brussels.: European Commission; 2013. p. 15–7. Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:301:0015:0017:EN:PDF
27. Tepe Y. Acrylamide in Surface and Drinking Water. In: Gokmen V, editor. Acrylamide in Food analysis, content and potential health effects. First. Elsevier; 2016. p. 275–93.
28. WHO. Acrylamide in drinking-water [Internet]. WHO Guidelines for Drinking-water Quality, Water Sanitation Health, WHO/SDE/WSH/03.04/71. 2011. Available from: http://www.who.int/water_sanitation_health/dwq/chemicals/0304_71/en/index6.html
29. Abong GO, Okoth MW, Kabira JN, Ogolla J, Ouma J, Ngunju CW, *et al*. Physico-Chemical Changes in Popular Kenyan Processing Potato Varieties as Influenced by Storage Condition. *Curr Res Nutr Food Sci* [Internet]. 2015;3(2):112–20. Available from: http://dx.
30. Wambui MJ. Quality characteristics of french fries and quantitative assessment of exposure to acrylamide associated with their consumption in Nairobi , Kenya. MSc. Thesis, University of Nairobi; 2015.
31. Machuka SM. Determinants of Productivity of Small-Scale Holdings of Arabica Coffee and its Supply Response in Kenya: A Case Study of Kiambu County [Internet]. The Open University of Tanzania; 2016. Available from: http://repository.out.ac.tz/1768/
32. Soares CMD, Alves RC, Oliveira MBPP. Factors affecting acrylamide levels in coffee beverages. In: Coffee in health and disease prevention. In Coffee. Academic Press; 2015. p. 217–24.
33. Murkovic M, Derler K. Analysis of amino acids and carbohydrates in green coffee. *J Biochem Biophys Methods.* 2006;69:25–32.
34. Esposito F, Fasano E, De Vivo A, Velotto S, Sarghini F, Cirillo T. Processing effects on acrylamide content in roasted coffee production. *Food Chem* [Internet]. 2020;319:126550. Available from: https://doi.org/10.1016/j.foodchem.2020.126550
35. Ubaoji KI, Orji VU. A review on acrylamide in foods: sources and implications to health. Mgbakoigba J African Stud. 2015;4(1):1–12.
36. WHO/FAO-JECFA. Joint FAO/WHO Expert Committee on Food Additives (JECFA)- sixty-fourth Session. 2005.
37. FAO/WHO. Evaluation of certain contaminants in food: seventy-second report of the Joint FAO/WHO Expert Committee on Food Additives. 2010.
38. Matoso V, Bargi-souza P, Ivanski F, Romano MA, Romano RM. Acrylamide : A review about its toxic effects in the light of Developmental Origin of Health and Disease (DOHaD) concept. *Food Chem.* 2019;283(September 2018):422–30.
39. Wadhawan M, Anand AC. Coffee and liver disease. J Clin Exp Hepatol. 2016;
40. Rifai L, Saleh FA. A Review on Acrylamide in Food: Occurrence, Toxicity, and Mitigation Strategies. Int J Toxicol. 2020;39(2):93–102.
41. Kotemori A, Ishihara J, Zha L, Liu R, Sawada N, Iwasaki M, *et al*. Dietary acrylamide intake and the risk of endometrial or ovarian cancers in Japanese women. *Cancer Sci*. 2018 Oct 1;109(10):3316–25.
42. Pedreschi F, Mariotti MS, Granby K. Current issues in dietary acrylamide: Formation,

mitigation and risk assessment. Vol. 94, *Journal of the Science of Food and Agriculture*. 2014. p. 9–20.

43. Wierzejska R. Coffee consumption vs. cancer risk - a review of scientific data. Vol. 66, Roczniki Państwowego Zakładu Higieny. 2015. p. 293–8.
44. Rashighi M, Harris JE. Acrylamide Intake through Diet and Human Cancer Risk Lorelei. *Physiol Behav*. 2017;176(3):139–48.
45. FAO/WHO. Health Implications of Acrylamide in Food. Vol. 90, Joint FAO/WHO Consultation and Workshop proceedings. 2002.
46. Barlow SM, Boobis AR, Bridges J, Cockburn A, Dekant W, Hepburn P, *et al*. The role of hazard- and risk-based approaches in ensuring food safety. *Trends Food Sci Technol*. 2015;46(2):176–88. 2011;1–21.
47. Ogolla JA. Acrylamide contamination in commercial potato crisps in kenya : levels of intake and effects of processing parameters in local cultivars. MSc thesis, University of Nairobi; 2013. Available from: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiD3I6bmrPqAhVD1hoKHepHA6gQFjAAegQIBhAB&url=http%3A% 2F%2Ferepository.uonbi.ac.ke%2Fbitstream%2Fhandle%2F11295%2F55937%2FOgolla_Acrylamide%2520contamination%2520in%2520
48. Lineback DR, Coughlin JR, Stadler RH. Acrylamide in Foods : A Review of the Science and Future Considerations. *Annu Rev Food Sci Technol.* 2011;1–21.
49. Granvogl M, Jezussek M, Koehler P, Schieberle P. Quantitation of 3-aminopropionamide in potatoes - A minor but potent precursor in acrylamide formation. *J Agric Food Chem.* 2004;52(15):4751–7.
50. Granvogl M, Schieberle P. Thermally generated 3-aminopropionamide as a transient intermediate in the formation of acrylamide. *J Agric Food Chem.* 2006; 54(16):5933–8.
51. Yasuhara A, Tanaka Y, Hengel M, Shibamoto T. Gas chromatographic investigation of acrylamide formation in browning model systems. *J Agric Food Chem.* 2003; 51(14):3999–4003.
52. Schouten MA, Tappi S, Romani S. Acrylamide in coffee : formation and possible mitigation strategies – a review. *Crit Rev Food Sci Nutr* [Internet]. 2020;1–15. Available from: https://doi.org/10.1080/10408398.2019.1708264
53. Wairegi LWI, Bennett M, Nziguheba G, Mawanda A, Rios C de los, Ampaire E, *et al*. Sustainably improving Kenya's coffee production needs more participation of younger farmers with diversified income. *J Rural Stud* [Internet]. 2018;63(July):190–9. Available from: https://doi.org/10.1016/j.jrurstud.2018.07.009
54. Endeshaw H, Belay A. Optimization of the roasting conditions to lower acrylamide content and improve the nutrient composition and antioxidant properties of Coffea arabica. PLoS One [Internet]. 2020;15(8 August):1–18. Available from: http://dx.doi.org/10.1371/journal.pone.0237265
55. Al-Fekaiki DF, Niamah AK, Al-Sahlany STG. Extraction and identification of essential oil from Cinnamomum Zeylanicum barks and study the antibacterial activity. *J Microbiol Biotechnol Food Sci.* 2017;7(3):312–6.
56. Obed Mainya N, Kituyi L, Wanjau T. Analysis of Levels of Acrylamide in (Solanum Tuberosum) Potato Chips and Crisps. *Int J Adv Res.* 2019;7(1):321–7.