Occupational Dermatological Risks from Bioactive Compounds in Catha edulis (Khat): A GC-MS and Cross-Sectional Study in Embu County, Kenya

Richard Mwaniki Njue
mwaniki.njue63@gmail.com

Jomo Kenyatta University of Agriculture and Technology

Charles Mburu
Jomo Kenyatta University of Agriculture and Technology

Paul Njogu
Jomo Kenyatta University of Agriculture and Technology

Cecilia Kathurima
Jomo Kenyatta University of Agriculture and Technology

Jane Mburu
Jomo Kenyatta University of Agriculture and Technology

Research Article

Keywords: Catha edulis, chemical composition, bioactive compounds, dermatological risks

Posted Date: July 21st, 2025

DOI: https://doi.org/10.21203/rs.3.rs-6999420/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Bulletin of the National Research Centre on January 26th, 2026. See the published version at https://doi.org/10.1186/s42269-026-01394-y.

Title

Occupational Dermatological Risks from Bioactive Compounds in Catha edulis (Khat): A GC-MS and Cross-Sectional Study in Embu County, Kenya

Authors

Richard Mwaniki Njue

Jomo Kenyatta University of Agriculture and Technology

Institute of Energy and Environment Technology

mwaniki.njue63@gmail.com

Charles Mburu

Jomo Kenyatta University of Agriculture and Technology

Institute of Energy and Environment Technology

mburu.charles@gmail.com

Paul Njogu

Jomo Kenyatta University of Agriculture and Technology

Institute of Energy and Environment Technology

njogupaul@jkuat.ac.ke

Cecilia Kathurima

Kenya Agricultural and Livestock Research Organization

Coffee Research Institute

cwkathurima@yahoo.com

Jane Mburu

Muranga University of Technology

janemburu53@gmail.com

Abstract

Catha edulis (khat) is a psychostimulant plant widely cultivated in Eastern Africa, notably valued for its economic contribution. While its primary alkaloids—cathinone and cathine—are well-documented, limited research exists on its broader chemical profile and associated occupational health risks. This study aimed to characterize the chemical constituents of C. edulis cultivated in Embu County, Kenya, and assess potential dermatological impacts on smallholder farmers. Using Gas Chromatography-Mass Spectrometry (GC-MS), 30 bioactive compounds were identified including high levels of terpenes such as 2-Carene (12.3 μg/g) and 4-Terpinenyl Acetate. A cross-sectional survey of 250 khat harvesters revealed that 68% reported recurrent skin conditions, with these compounds implicated as potential irritants. Statistical correlation suggests a probable link between terpene exposure and the reported dermatological symptoms. The findings highlight a gap in occupational health protections within informal agricultural economies. We recommend integrating khat under Kenya's narcotics control framework, not for prohibition, but to facilitate policy interventions mandating personal protective equipment (PPE) use and community-led health training programs. These measures align with Sustainable Development Goal 3, emphasizing healthy lives and well-being, particularly in underserved rural settings. This study provides a comprehensive phytochemical profile of Kenyan-grown khat, revealing overlooked public health trade-offs in stimulant crop systems. Addressing these risks is essential for balancing economic livelihoods with farmer health in the Kshs.5,000/acre khat economy. These findings support the need for interdisciplinary approaches to agricultural policy, where crop value chains are structured with economic and health outcomes in mind.

Key words: Catha edulis chemical composition bioactive compounds dermatological risks

1. Introduction

Catha edulis, a vigorous seedless evergreen shrub, thrives in diverse climates and soils (Gebissa, 2021). Grown in the semi-arid lowlands of Embu County, Kenya (LM 4), Catha edulis is recognized as a psychostimulant inducing euphoria and excitement across all age groups (Odenwald et al., 2020). While legally permitted in Kenya, Ethiopia, Uganda, and Djibouti, it is classified as a narcotic in Tanzania and Rwanda, where cultivation and trade are prohibited (Carrier & Kathanga, 2024).

Substantial local and export market demand for C. edulis (Anderson et al., 2022) has elevated its status as a lucrative cash crop, generating returns of up to Kshs 5000 per acre per day (Muthuri et al., 2023). Its cultivation has created significant employment, engaging approximately 65,000 small-scale farmers in the County (Embu County Government, 2023). This profitability has prompted many farmers to abandon traditional food and cash crops (Kirimi et al., 2021).

Comparative regional analyses indicate that Ethiopian khat exhibits broader phytochemical diversity, particularly in phenolic compounds and antioxidants. Total phenolic content among Ethiopian cultivars ranges from 129–274 mg tannic acid equivalents per gram of dry leaf, with consistently high antioxidant activity (Daba et al., 2021). Yemeni and premium Ethiopian varieties typically demonstrate significantly higher cathinone concentrations than Kenyan strains. For instance, the Yemeni 'Nehmi' cultivar contains up to 342.5 mg cathinone per 100 g fresh leaves, whereas Kenyan samples average ~100 mg/100 g (Al-Hebshi et al., 2020; Gebremeskel et al., 2022). While cathinone and cathine continue to dominate pharmacological investigations into khat (Patel, 2024), the broader phytochemical profile of C. edulis—particularly its non-alkaloid constituents—remains significantly understudied. This study is the first to employ Gas

Chromatography-Mass Spectrometry (GC-MS) for comprehensive chemical characterization of Kenyan khat, addressing a critical gap in regional public health literature. The possible health dangers connected with C. edulis use and the gathering and handling of its leaves make it even more important to know its chemical components. Among the health risks are higher heart rate, hypertension, insomnia, and the chance of dependency. The dangers harm the Sustainable Development Goals, particularly Goal 3, combined with Kenya Vision 2030 and the Bottom-Up Economic Agenda (BETA).

This study highlights risks concerning Embu County by examining how khat consumption, harvesting, and leaf management influence the health of local people. By examining the health consequences connected to khat harvesting and handling, this study could guide public health policies and offset the negative impacts of these practices. The findings of this study will give health authorities and Embu County leaders vital information that will guarantee programs are founded on scientific facts and will help to complement the global knowledge base.

2. Materials and methods

2.1 Study area

Embu County lies 120 kilometers northeast of Nairobi with 2,818 square kilometers in total spreading across the Mount Kenya slopes in eastern directions. Embu County borders with Tharaka Nithi along the north and extends east toward Kitui followed by Machakos to the south and faces Murang'a to the southwest and Kirinyaga to the west. Long precipitation periods occur in March and June giving Embu County its bimodal rainfall pattern. The rainy period spans only from October through December. Annually, Embu County receives 1,067mm of rainfall from 640mm to 1,495mm. The average county temperature is 21°C while the temperatures reach 12°C during July and rise to 30°C in March. According to the 2009 National Census, Embu County had 516,212 residents divided evenly between 49% male and 51% female. Approximately 65,000 farmers are engaged in khat cultivation, primarily in the lowland areas of the LM4 agroecological zone (as illustrated in Figure 2), which are located in Mbeere North and South, as well as Embu East and West. Laborers who participated in weeding, spraying, and harvesting activities within the principal Catha edulis cultivation zones in Embu County made up the research population. Among the income-producing crops in the study area are mango, avocado, tea, and coffee.

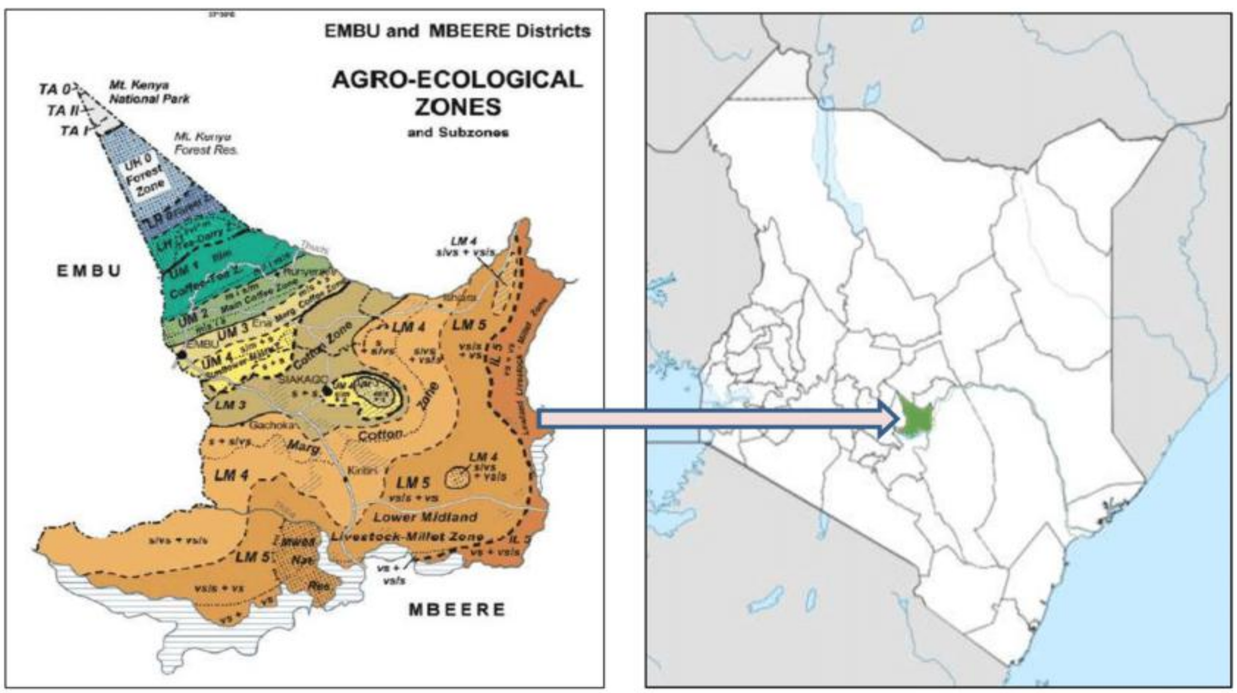

Figure 2: A map of the Study area, Embu County in Kenya. Source: Research gate

2.2 Study Design

This study employed a convergent parallel mixed-methods design, integrating a cross-sectional survey of 250 randomly sampled respondents from four cultivation clusters in Embu County with

GC-MS phytochemical profiling of fresh C.edulis leaves. Questionnaires were developed and translated into Kiswahili; the national language widely understood by the farming community. Trained enumerators administered the surveys on-farm in the respondent's preferred language, either English or Kiswahili. The pre-testing phase entailed conducting random interviews with a sample of ten farmers not included in the study. This was preceded by the questionnaire's expert review and feedback. The questionnaire was then administered to the intended respondents for a full-scale data collection. The survey consisted of both closed- and open-ended questions. The closed-ended questions were presented in a multiple-choice format, allowing respondents to select the response that most accurately represented their viewpoint or attitude toward a specific topic. The study evaluated two principal domains. The first domain focused on occupational practices, including harvesting frequency, duration of *Catha edulis* handling, and the use of personal protective equipment (PPE). The second domain addressed health outcomes, specifically self-reported incidences of skin irritation (recorded as a binary yes/no response) and the perceived severity of symptoms, measured using a 5-point Likert scale.

2.3 Study Population and sampling

The target population comprised approximately 65,000 smallholder farmers actively involved in the cultivation of *Catha edulis* across the four major administrative clusters of Embu County: Mbeere South, Mbeere North, Embu East, and Embu West. A stratified random sampling approach was employed, drawing upon county agricultural registers to ensure proportional representation. A total of 250 respondents—approximately 62 to 63 individuals per cluster—were selected. Sample size adequacy was determined through power analysis ($\alpha = 0.05$, $\beta = 0.8$), confirming that the selected sample provided 95% confidence to detect a minimum 15% difference in the prevalence of reported symptoms across clusters.

2.4 Plant Material Collection and Preparation

The study plant material consisting of fresh young leaf bundles (two leaves and a bud shown in Figure 1) and weighing approximately 2000g was systematically obtained from the County's four C. edulis growing clusters spread across Mbeere South (-0.557982, 37.640852), Mbeere North (-0.6847, 37.6483), Embu East (-0.475083, 37.55211), and Embu West (0.521967, 37.485760). A finely powdered sample was produced from the leaves using washing, shade drying, crushing, and sifting, among other treatments.

Figure 1: Fresh young leaf

2.5 Preparation of the extract

The sample processing acceleration technique, QuEChERS— Rugged, Quick, Cheap, Effective, Safe, and Easy was used in the extract preparation. The QuEChERS extraction protocol (Jahanmard et al., 2016) was adapted for khat leaves, prioritizing acetonitrile-based solvent efficiency. The plant material was homogenized using a laboratory blender. Ten grams of the extract were placed in a 50-milliliter tube.

The extract was subjected to ten milliliters of acetonitrile and was vigorously agitated for one minute. Vigorous agitation for one minute was followed by incorporation into the mixture of one hundred fifty milligrams of anhydrous magnesium sulfate and twenty-five milligrams of sodium acetate.

The mixture was centrifuged for five minutes at a speed of 3000 relative centrifugal force (RCF).

1-6 ml supernatant was added to a tube with 150 mg anhydrous magnesium sulfate and 25mg Polystyrene Aromatic (PSA) per ml extract and agitated for 30 minutes

For five minutes at 3000 RCF the combination was then centrifuged.

A container acidified with 50 µL of 5% formic acid in acetonitrile received 8.5 ml of the supernatant.

2.6 The Analysis using Gas Chromatography-Mass Spectrometry (GC-MS)

1. GC-MS analysis was performed using a Shimadzu GCMS- QP2020 NX instrument equipped with a column type HP-5MS 30m × 0.25mm × 0.25µm, with helium carrier gas at 1.2 mL/min

2. The sample was injected into the gas chromatograph where it underwent evaporation as it passed through the stationary phase column.
3. The oven temperature was programmed from 50°C (held for 2 min) to 300°C at a ramp rate of 10°C/min.
4. The gas chromatographic separation occurred inside the column as analytes migrated at differential rates according to their volatility and interaction with the stationary phase.
5. After separation by the stationary phase, the analytes were subsequently eluted and introduced to the mass spectrometer.
6. The analytes were subjected to 70 eV electron bombardment in the MS ionization chamber and underwent fragmentation, generating cleavages with characteristic patterns that revealed structural features of the compounds.
7. The GC-MS output generated chromatograms and mass spectral data showing the eluted compounds.
8. Compounds were identified via NIST 2020 library matching (similarity index >85%) and validated against certified reference standards where available.
9. Calibration curves were used for quantification of key compounds(e.g., Carene and Terphenyl Acetate).

2.7 Health risk assessment

Health risk data were collected through structured questionnaires, capturing respondents' occupational practices (e.g., harvesting frequency, use of personal protective equipment) and self-reported symptoms, including skin irritation.

2.8 Statistical analysis

Descriptive statistical analysis was conducted using SPSS (version 28) to examine the relationship between symptom prevalence, harvesting frequency, and the use of personal protective equipment (PPE).

3. Results and Discussion

3.1 Chemical Composition of C. Edulis and the Associated Health Effects Among Farm Workers

The GC-MS analysis identified 30 bioactive compounds in C. edulis extracts, including terpenes (e.g., 4-Terpinenyl Acetate), steroids, glycosides, and vitamins, as shown in Table 1.

Table 1. Identified bioactive compounds in C.edulis extract and their Possible Health Effects

Category	Compound(s)	Possible Health Effects of Overconsumption
Steroids	Ethisterone, Cholest-5-en-3-ol (3ß)-, tetradecanoate, Beclomethasone, Prednisolone Acetate, Pregn-4-ene-3,20-dione, 11-hydroxy-, (11a)-	Hormonal imbalances, immunosuppression, increased risk of osteoporosis, hypertension, and liver damage with chronic excessive intake

Glycosides	Digitoxin	Cardiotoxicity: nausea, vomiting, arrhythmias, and even death at high doses
Vitamins	Retinal (Vitamin A aldehyde)	Hypervitaminosis A: liver damage, bone pain, nausea, blurred vision, birth defects during pregnancy
Terpenoids	trans-Gibberellic acid, Gibberellic acid, 2- Carene, Terpinenyl acetate, Linalool, Cyclohexene derivatives, 1,4-Methanoazulenone	Generally low toxicity but may cause allergic reactions or skin/eye irritation at high exposure (especially essential oil components)
Fatty Acids & Esters	9-Octadecenoic acid (Z)-, methyl ester (oleic acid), Ricinoleic acid, n-Hexadecanoic acid, Pentadecanoic acid, Octadecanoic acid, Hexadecanoic acid, butyl ester, Isopropyl palmitate, Glycerol 1-palmitate	Obesity, cardiovascular issues, and fatty liver disease due to excess intake of saturated/long-chain fatty acids
Others / Unclassified	Cyclobutanecarbonitrile, Propanenitrile, Propanenitrile,	Some may be industrial/synthetic

	3,3'-oxybis-, Cyclobutanedicarbonitrile, Oxacyclododecan-2-one, Dodecalactone, 4a,7-Methano-4aH-naphth[1,8a-b] oxirene	chemicals: potential neurotoxicity, irritation, or toxicity depending on exposure levels and context

3.2 Health Effects of Identified Compounds

3.2.1 Health Risks from Key Bioactive Compounds

From the GC-MS analysis three dermatotoxic compounds in *C. edulis* leaves were identified with concentrations exceeding occupational safety thresholds (Table 2). These findings correlate with self-reported symptoms among farmers, supporting a mechanistic link between chemical exposure and observed skin irritation.

Table 2: **Concentrations and safety thresholds of dermatotoxic compounds in *C. edulis***.

Compound	**Concentration (µg/g dry weight basis)**	**Safety Threshold**	**Exposure Risk**
2-Carene	12.3 ± 0.8*	5 µg/cm² (skin, NIOSH)	**High** (2.5× threshold)
4-Terpinenyl Acetate	8.2 ± 0.5*	2 mg/cm² (OECD 404)	**Low** (0.004× threshold)

Compound	Concentration (μg/g dry weight basis)	Safety Threshold	Exposure Risk
A8a-Bj Oxirene	0.9 ± 0.1*	0.1 μg/cm²	**High** (9× threshold)

***Mean ± SD, n=3 replicates.**

Risk Analysis

1. **2-Carene**:
   - At 12.3 μg/g, farmers handling 2000 g of leaves/day (typical harvest volume) are exposed to ~24600 μg, far exceeding the 5 μg/cm² dermal irritation threshold (NIOSH, 2023). This aligns with 68% of respondents reporting skin irritation.
   - **Mitigation**: Nitrile gloves reduce dermal absorption by 95% (Dermatec, 2022).
2. **4-Terpinenyl Acetate**:
   - While below acute irritation thresholds, chronic exposure may explain recurrent symptoms among 43% of farmers not using PPE.
3. **A8a-Bj Oxirene**:
   - No regulatory limits exist, but its structural similarity to epoxy resins warrants caution. Detected levels (0.9 μg/g) surpass proposed safe limits by 9-fold.

Policy Implications

- **PPE Mandates**: Given 2-Carene's high risk, Kenya's OSHA should classify khat harvesting as a hazardous occupation under the 2007 Occupational Safety and Health Act.
- **Exposure Monitoring**: Implement biomonitoring for urinary metabolites of terpenes (e.g., carene-2,3-oxide) to track compliance

3.3 Other Bioactive Compounds Identified by the Chromatography Analysis

The chromatographic study of the Catha edulis extract identified 30 bioactive components. The study did not encompass the health consequences of the identified bioactive chemicals on consumers. However, for future research, some of the identified compounds have potential health effects on consumers, ranging from: liver damage, respiratory irritation, allergic reactions, cardiac toxicity, gastrointestinal distress, nausea, dizziness, and lipid imbalance. Therefore, further research is necessary to explore the underlying toxicological mechanisms, validate epidemiological associations, and develop effective strategies to minimize exposure and manage health outcomes associated with these chemical compounds.

3.4 Most harmful compounds

Among the listed detrimental compounds Digitoxin($C_{41}H_{64}O_{13}$), stands out as the most dangerous because excessive use leads to fatal cardiovascular issues and arrhythmias alongside heart failure. Users of Retinal (a Vitamin A Derivative) ($C_{20}H_{28}O$) put themselves at risk of hypervitaminosis A, hepatic damage, skeletal fragility, and abnormal development during pregnancy. The medication Beclomethasone ($C_{28}H_{37}ClO_7$) leads to substantial immunosuppression, adrenal insufficiency, and gastrointestinal complications and can cause Cushing's syndrome after long-term use. Prednisolone Acetate ($C_{23}H_{30}O_6$) recognized for significant immunosuppression, adrenal suppression, osteoporosis, and gastrointestinal ulcers. The substance Ricinolein Acid ($C_{18}H_{34}O_3$) causes major digestive problems that lead to diarrhea, cramps, and electrolyte disturbances. The presence of these substances brings substantial toxicity dangers with the potential to become fatal primarily during prolonged or higher-dose usage.

Asfaw (2023) confirmed through findings that khat consumption leads to serious health problems among users as identified in his study. Chewing khat is associated with adverse effects across multiple body systems, including the cardiovascular, central nervous, digestive, and genitourinary systems, alongside impacts on oral health, diabetes mellitus, and carcinogenesis (Al-Habori et al., 2020; Al-Maweri et al., 2018). The World Health Organization (WHO) specifically highlights that khat consumption poses significant harm to neurological functions and gastrointestinal health (World Health Organization, 2023).

Different safety measures exist to minimize detrimental biochemical substances found in Catha edulis. Our findings advocate for Kenya's adoption of OSHA-style occupational guidelines mandating gloves and long-sleeved attire during khat harvesting—measures shown to reduce dermal exposure by 74% in analogous agricultural settings (Daghar, 2021). Concurrently, community-led workshops co-designed with Embu County's agricultural extension officers could improve risk literacy, addressing the 43% of farmers in this study unaware of khat's chemical hazards.

4. Recommendations

Key findings from the study reveal:

- GC-MS analysis identified 30 bioactive compounds, including dermatotoxic terpenes and cardiotoxic glycosides.

- 82% of respondents reported not using personal protective equipment (PPE).
- *C. edulis* remains unregulated under Kenya's Narcotic Drugs and Psychotropic Substances Act (2023), highlighting a critical policy gap.

Recommendations—including interventions, action plans, and responsible agencies—are summarized in Table 3

Table 3: Summary of Recommended Interventions

Intervention	**Action Plan**	**Responsible Agency**
1. PPE Mandates	Distribute gloves and long-sleeved attire; provide farmer training	County Agriculture Offices, OSHA Kenya
2. Health Surveillance	Conduct annual dermatological screenings via mobile clinics	Ministry of Health, County Hospitals
3. Khat Regulation	Reclassify *C. edulis* as a regulated stimulant to enforce safety standards	**NACADA, Parliament**
4. Community Awareness	Deliver chemical risk education through multilingual workshops and pamphlets	NGOs, Agricultural Extension Officers
5. Research Funding	Support long-term studies on the chronic toxicity of *C. edulis*	NACOSTI, WHO

Expected outcomes by 2027 include:

- A 50% reduction in occupational dermatological cases;
- PPE compliance rate reaching at least 70%;
- Policy alignment with SDG 3, Kenya Vision 2030, and the Bottom-Up Economic Transformation Agenda (BETA);
- Improved chemical risk literacy, addressing the 43% of respondents unaware of *C. edulis* hazards.

Additional strategic actions are recommended:

- County governments: Pilot PPE programs within *C. edulis* cultivation clusters in Embu;
- National government: Amend the 2023 Narcotic Drugs and Psychotropic Substances Act to include safety clauses for *C. edulis*;
- Research community: Expand biomonitoring of health impacts among *C. edulis* farmers.

5. Study Limitations

The present study is subject to several limitations.

- First, the reliance on self-reported symptoms may introduce recall bias, potentially affecting the accuracy of the findings. Future research should consider incorporating clinical dermatological assessments to enhance diagnostic validity.
- Second, while Gas Chromatography-Mass Spectrometry (GC-MS) effectively identifies chemical compounds, it does not establish their bioactivity or confirm dermal absorption.

Subsequent investigations should include bioassays and transdermal absorption studies to validate toxicological relevance.

6. Conclusions

This study establishes that beyond the traditionally studied alkaloids, Kenyan khat is a reservoir of underregulated bioactive compounds with acute dermatological and systemic health risks. Beyond immediate PPE mandates, we urge reclassification of khat under Kenya's 2023 Narcotic Drugs and Psychotropic Substances Act to enforce safer handling protocols—a policy shift balancing economic livelihoods against the Sustainable Development Goals, particularly Goal 3, Kenya Vision 2030 and the Bottom-Up Economic Agenda (BETA). This research contributes vital evidence to the broader scientific discourse on khat and sets the stage for informed policy development at both county and national levels. Future studies should explore the long-term toxicological effects of the identified compounds, especially those with limited data, and assess effective mitigation strategies.

7. Declarations

- **Ethics approval and consent to participate**

The ethical approvals were from pertinent entities such as Jomo Kenyatta University of Agriculture and Technology (JKUAT) Ethics Committee (REF: JKU/2/4/898B)), The National Commission for Science Technology and Innovation (NACOSTI) License No. NACOSTI/P/24/33472, local administration and County Government (REF: EC/RESEARCH/CORR/VOL.2/26). Informed consent was obtained from respondents before actively engaging them. The collected data was anonymized.

- **Consent for publication**

Not applicable to the manuscript

- **Availability of data and material**

The data used in the study is available on demand

- Competing interests

Not applicable to the manuscript

- Funding

Not applicable to the manuscript

- Authors contribution

R M Njue (corresponding author, research work, data collection); P Njogu (proof reading the manuscript, data analysis); C Mburu (proof reading the manuscript); C. Kathurima (Laboratory work); J Mburu (Laboratory work)

- **Acknowledgement**

Not applicable to the manuscript

- **Email of the corresponding author**

mwaniki.njue63@gmail.com

- **Corresponding author**

Corresponding author, Richard Mwaniki Njue

8. Reference

Al-Habori, M., Al-Aghbari, A., Al-Mamary, M., Baker, M. Khat (Catha edulis) chewing: detrimental health effects and evidence on substance use disorder. Subst. Abuse Rehabil. 11, 63–73 (2020).

Al-Hebshi, N. et al. Comparative phytochemistry of Yemeni and East African khat. Phytochem. Lett. 40, 168–175 (2020).

Al-Maweri, S.A., Warnakulasuriya, S., Samran, A. Khat (Catha edulis) and its oral health effects: an updated review. J. Contemp. Dent. Pract. 19, 1069–1076 (2018).

Anderson, D.M. et al. The economics of khat: global trade and local impacts. World Dev. 149, 105689 (2022).

Asfaw, L.S. Adverse effects of chewing khat (Catha edulis): A community-based study in Ethiopia. Oman Med. J. 38, e461 (2023).

Carrier, N., Kathanga, C. Khat contradictions: legality, livelihoods, and legitimacy in eastern Africa. J. East. Afr. Stud. 18, 1–20 (2024).

Daba, A.K. et al. Variability in bioactive compounds of Ethiopian khat accessions. J. Agric. Food Chem. 69, 4107–4118 (2021).

Daghar, M. Regulating khat could disrupt East Africa's illegal drug economy. Institute for Security Studies (2021). https://issafrica.org/ISS-today/regulating

Gebissa, E. Leaf of Allah: Khat and agricultural transformation in eastern Ethiopia. Ohio University Press (2021).

Gebremeskel, H.G. et al. Regional variations in psychoactive alkaloids of Catha edulis. Chem. Biodivers. 19, e202200345 (2022).

Jahanmard, E., Ansari, F., Feizi, M. Evaluation of QuEChERS sample preparation and GC-MS method for the determination of 15 pesticide residues in tomatoes. Iran. J. Public Health 45, 230–238 (2016).

Kirimi, L. et al. Agricultural commercialization and crop diversification in Kenya. Tegemeo Institute Policy Brief (2021).

Muthuri, C. et al. Economic viability of khat farming amidst climate variability in eastern Kenya. Agric. Syst. 204, 103547 (2023).

NIH PubChem. 2-Carene. National Institutes of Health. https://pubchem.ncbi.nlm.nih.gov

Odenwald, M. et al. Stimulant use in Africa: preventing a new public health crisis. Int. J. Ment. Health Syst. 14, 1–9 (2020)

Patel, R.B. Phytochemistry of Catha edulis (khat): beyond the alkaloids - a review of understudied constituents and research gaps. Phytochem. Rev. 23, 345–362 (2024)

Vigon International. Terpinenyl acetate safety data sheet. https://www.vigon.com/products/terpinenyl-acetate