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Assessment of human exposure to pesticides by hair analysis: The case of vegetable-producing areas in Burkina Faso

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ABSTRACT

The present work assesses human exposure to pesticides in vegetable-producing areas in Burkina Faso, using hair as an indicator. The study design includes a comparison between operators who are occupationally exposed while working in the fields and a reference population (i.e. not occupationally exposed) to evaluate both occupational and indirect exposures. Hair samples from volunteers ($n = 101$) were positive for 17 pesticides (38 analyzed). Acetamiprid, desethylatrazine, carbofuran, and deltamethrin were detected for the first time in field samples. With a maximum of 9 residues per sample, pesticide exposure was ubiquitous in both populations. Contamination by acetamiprid, cypermethrin, and lambda-cyhalothrin (used in vegetable production) prevailed in operator samples. For other pesticides, such as imidacloprid and deltamethrin, no significant difference was found. This indicates a potentially large environmental exposure (dietary intake or atmospheric contamination) or the prevalence of other contamination sources. The present findings are concerning, as detected levels are globally higher than those previously reported, and indicate exposure to endocrine disrupting chemicals and probable carcinogens. Hair was found to be a suitable matrix for biomonitoring human exposure to pesticides and assessing dominant factors (i.e. sex, age, and protective equipment) in subgroups, as well as identifying geographical contamination patterns.

1. Introduction

The worldwide application of pesticides in agriculture, veterinary medicine and for vector control has led to the multiplication of potential routes of exposures. Studies have shown that less than 0.1% of pesticides applied for pest control reach their target pests (Pimentel, 1995). A large fraction is therefore lost and will be likely to influence the environment and human health. Pesticides spread in the environment via multiple pathways, including runoff, permeation through soil, atmospheric transfers, accidental release, etc. (McKnight et al., 2015), ultimately affecting non-target organisms. Human exposure to pesticides can occur indirectly from environmental contamination (dietary intake or atmospheric contamination) or directly from occupational, agricultural, and household use (Clementi et al., 2008). Pesticide operators are persons who mix, load, and apply pesticides (EFSA, 2014). Operators are likely both directly and indirectly exposed, which puts them at higher risk of both acute intoxication and long-term adverse health effects. Non-occupationally exposed population (workers, bystanders, inhabitants of treated areas/households) is expected to suffer only from indirect exposure. Pesticides can cause multiple adverse health effects, ranging from moderate toxicity to severe neurotoxicity, endocrine disruption, cancer, etc. (Ouédraogo et al., 2011), increasing the need to develop suitable approach for biomonitoring in human matrices.

Agriculture plays a vital socioeconomic role in Burkina Faso, in terms of export, employment opportunities, and food self-sufficiency (Ouédraogo et al., 2011). Agricultural losses caused by insects and diseases can exceed 30% (Toé, 2010a). In response, pesticides are applied to maintain sufficient yields. Vegetables are produced during the dry season (October to June). Gardening areas are composed of contiguous plots covering surfaces of a few square kilometers (located at shores of lakes, in order to access water). Each plot is generally harvested by a group of individuals, and produce is intended for sale. In theory, this practice refers more to market gardening but the large surface areas cultivated also make it comparable to large agricultural production. Over the past decades, fruit and vegetable production has

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steadily grown, particularly in West Africa. The potential for this sector to improve the local economy and aid in the fight against poverty has been recognized in governmental strategies for rural development (MAHRH, 2007).

An estimated 85% to 95% of the country's population draws its subsistence from agriculture (Ouédraogo et al., 2011), which supposes a widespread potential for pesticide exposure. In practice, exposure is influenced by specific conditions, under which pesticides are handled (such as packaging, environmental conditions, personal protective equipment, etc.). Studies conducted in Burkina Faso underlined the lack of knowledge regarding the good agricultural practices and use of unsuitable and obsolete pesticides (Ouédraogo et al., 2011; Toé, 2010b). Improper packaging and high illiteracy rates in rural areas were among the main problematic hampering compliance with recommendations provided on pesticide labels. At a national level, various strategic plans have been proposed to ensure environment and health protection regarding pest control and pesticide handling (Mbengue Faye et al., 2010; MECV, 2005a; Toé and Pare, 2011). Nevertheless, most of these documents are poorly applied, due to the lack of human and financial resources.

Although hazardous conditions have been identified, there is a considerable paucity on data concerning human exposure to pesticides in rural areas. To the best of our knowledge, only one evaluation was conducted in this domain in Burkina Faso (Toé et al., 2000). In the absence of existing monitoring, the present study aimed to propose and implement a comprehensive indicator of population exposure to pesticides identified during field campaigns. Recently, hair tends to become the most used "alternative matrix" for biomonitoring human exposure to contaminants (Esteban and Castaño, 2009). Unlike other biological matrices, no metabolism nor excretion occurs after incorporation in hair (Aleksa et al., 2012). Hair offers a stable matrix that accounts for long-term effects of environmental contaminants (Appenzeller and Tsatsakis, 2012), whereas blood, urine, saliva, breath and sweat only provide information regarding recent exposure over a maximum of several days (Tsatsakis et al., 2010). As a safe, non-invasive matrix, human hair has numerous advantages, including easy collection, low sampling cost, easy transport and storage, and not requiring medical staff.

The present study assessed the suitability of using hair as an indicator of human exposure to pesticides in rural areas of a Sahelian country. Hair samples were collected from 101 volunteers in 10 villages located in gardening areas around Loumbila Lake. Participants were selected from two distinct population groups: gardeners (operators) and non-occupationally exposed individuals (reference population). The aim was to assess both occupational and indirect exposures. In parallel, volunteers were asked to answer a questionnaire about their personal hygiene and agricultural practices. Multiresidue analysis was performed using the modified QuEChERS procedure proposed by Lehmann et al. (2017b). This method was initially validated for 28 multi-class pesticides. An attempt was made to validate 10 additional persistent organic pollutants (POPs) using similar validation parameters. Finally, analyses and survey results were used to derive populations' exposure, dominant influencing factors (sex, age, location, and personal protective equipment), and provide a comprehensive evaluation of advantages and limitations of using hair as a matrix for biomonitoring human exposure to pesticides. This work is part of a four-year study assessing pesticide use and the effects on the environment and human health in market-gardening areas in Burkina Faso. Field surveys conducted in previous phases provided a comprehensive characterization of agricultural practices (pesticides used, application frequency, and application equipment, etc.) and assessment of environmental contamination (water and vegetable contamination, and dietary intake; Lehmann et al., 2017c).

2. Material and method

2.1. Chemicals, reagents, and standard solutions

Standards of analytes, -C13 labeled and deuterated compounds were purchased from Sigma-Aldrich (Switzerland), Dr. Ehrenstorfer (Germany), and Toronto Research Chemicals (Canada). Individual solutions of each target analyte and deuterated compound were prepared in the appropriate solvent, prior to respective preparation of the stock solutions in acetone and methanol, and storage at −20 °C (Supplementary information (SI), Section S1).

Methanol (MeOH) HPLC grade was acquired from Carlo Erba Reagents (France), isooctane and acetone for residues analysis from Acros Organics (Belgium), formic acid from Sigma-Aldrich (Switzerland), and acetonitrile (ACN) from Biosolve Chimie SARL (France). Sodium dodecyl sulfate (SDS), anhydrous magnesium sulfate ($MgSO_4$), and sodium acetate (NaAc) were purchased from Sigma-Aldrich (Switzerland). For dispersive solid-phase extraction (dSPE), 12 mL centrifuge tubes containing pre-determined amounts of SPE sorbent Supel™QuE *Z*-Sep+ (500 mg) were obtained from Sigma-Aldrich (Switzerland). Whatman Mini-UniPrep G2 syringeless 0.45 µm filter vials were purchased from GE Healthcare Life Science (Switzerland). Syringe filters (0.22 µm) were purchased from WWR (Switzerland).

2.2. Study populations

Field samples were collected in February 2016 from 101 volunteers living in 10 villages located on the shores of Loumbila Lake (20 km from the capital of Burkina Faso; Fig. 1 and SI Fig. S1). Loumbila Reservoir has a long history in gardening as one of the pioneers in this domain. It is located in one of the most intensive gardening area in Burkina Faso.

Two populations were randomly selected in the study area to distinguish between occupational and environmental exposure: 56 gardeners (operators) and 45 non-users (reference population). Operators were occupationally exposed by using pesticides for vegetable production in local market gardens. The reference population comprised individuals who were not occupationally exposed to pesticides but lived in the same area. This criterion is important, as the reference population would be therefore more representative of the environmental contamination of the study area. Members of this group covered various professions: merchants, homemakers, students, medical staff, restaurateurs, fishermen, builders, mechanics, butchers, stockbreeders, teachers, lumberjacks, and entrepreneurs. The studied population was 40% of female, which was in accordance with the large proportion of female gardeners working in the studied area (Agence de l'eau du Nakambé, 2014). Volunteers' ages ranged from 16 to 73 years (Fig. 2). Each participant was asked to answer a questionnaire about their personal capillary hygiene practices (hair washing and cutting frequency, cosmetic products used, etc.) and use of pesticides (type, application conditions, personal protective equipment, etc.). The study was approved by the National Ethics Committee of Burkina Faso (deliberation no. 2015–12-010). All participants were fully informed about the procedure and objectives (in their local language, when needed) and provided written consent to take part in the study.

2.3. Hair treatment and pesticide extraction

2.3.1. Hair collection

About 300 mg of hair was collected from each volunteer, preferentially from the posterior vertex region of the scalp, as close as possible to the skin. A new pair of scissors was used for each participant. Sample collection was performed by local medical staff. Except for four respondents who refused to give an answer, each man had a haircut within the last month. Men generally shaved their hair in the