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REVIEW

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Women in agriculture: pathways of pesticide exposure, potential health risks and vulnerability in sub-Saharan Africa

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Abstract

Background: Pesticide exposure and its adverse impacts remain a major problem for women's health, but a comprehensive scientific literature and summaries are still missing. With a specific focus in sub-Saharan Africa, this paper provides an overview of the scientific literature on how women deal with and are exposed to pesticides and the specific circumstances that might affect their health. We identified previously published studies from Google Scholar, Pubmed, and other electronic libraries.

Main body: In addition to huge burden in the household, there is considerable evidence that women's role in smallholder as well as commercial farming has become more visible and intense in sub-Saharan Africa. However, it is evident that women are a major risk group disproportionately exposed to and are affected by pesticides through multiple pathways. Closely linked to their biological characteristics, lifestyle and behavior, women experience acute-to-chronic diseases from pesticides. Women's exposure to pesticides either during pregnancy or breastfeeding can pose a serious health risk for the fetus and the newborn babies.

Conclusion: Occupational as well as non-occupational exposure from pesticides seems to be grossly underestimated for women due to the perception that their work is not hazardous for their health and are not at risk of exposure. This is often the case why research on pesticide exposure and its adverse impacts for women's health remains scarce in sub-Saharan Africa, where pesticides are often misused and poorly regulated. Therefore, further research that addresses women's exposure to pesticides are strongly suggested.

Keywords: Adverse impacts, Biological characteristics, Pesticide exposure, Sub-Saharan Africa, Women, Working conditions

Background

With unpaid household work, women's role in agriculture becomes more visible and intense in most of Africa over the last few decades [1]. Male out-migration brought a high proportion of rural households headed by women and they shoulder the responsibility for household survival and have increasingly assumed agricultural responsibility in their own farms or have taken over any opportunities in commercial agriculture [1]. Women's agricultural work is intense as they work on family owned farms, as wage workers on others farms, or as laborers in exchange for similar work on their family farms [2, 3]. Due to commercialization of agriculture in most of Africa, women constitute a large proportion of the labor force especially in the floriculture and horticulture sectors [4–8].

Although estimates vary, data from Food and Agriculture Organization [3] shows that women constitute approximately 50% of the agricultural labor force in Africa. According to International Labour Organization [1], women account almost half of the labor force

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in world's agriculture, representing 47% in Africa. As to Jacobs and Dinham [9], women in many countries of Africa make up a significant proportion of agricultural work; 90% of hoeing and weeding and 60% of harvesting and marketing. Nevertheless, these figures may not take into account women's contribution in unpaid agricultural tasks in family fields or as laborers in other farms, seasonal and part-time work in the informal sector. Despite women's increased role in paid and unpaid agricultural work, they remain central in unpaid household work.

Despite African women's substantial engagement in agriculture as well as household work, pesticide use, exposure and its adverse impacts for their health has yet not received the attention it deserves. Most occupational studies have been mostly focused on male farmers or farm workers [10–13] and even much of the evidence come from studies in developed countries, where pesticide usage is highly controlled [14]. Using gender division of labor in African agriculture as an argument, several studies [15–17] often view men as pesticide applicators and are thought to be occupationally exposed. Women's exposure from pesticides, on the other hand, are often assumed less and grossly underestimated [18]. However, this is a misinterpretation and not relevant for many rural African women.

Women can be exposed directly to pesticides as applicators, indirectly as farm workers or household managers. As opposed to the common view that pesticide spraying is primarily done by men, studies carried out in Uganda [17, 19], Ghana and Mali [20], again Ghana [16] and South Africa [22], indicate the significant role of women in pesticide application, tasks traditionally been labeled as men's domain.

Where women do not directly engage in pesticide application, they can be disproportionately subject to exposure through other tasks in the farm. These are weeding, harvesting, planting, or packaging either in their own fields [19, 20] or employment in the floriculture or horticulture sectors [4, 7, 8, 21].

In addition to exposure from field work, women may face indirect exposure from pesticides due to their gender roles in the household. In addition to responsibility for washing contaminated clothing and equipment, pesticide storage [16, 19, 20, 22], empty pesticide container disposal [16, 20, 23, 24], domestic pest control [9, 16, 20], malaria control [25–27] or spray drift [24, 28] are the other sources of exposure.

These engagements explain that agricultural sectors or domestic settings for women are particularly hazardous. Because they assume these tasks with little education [7, 19–22], information or training [6, 20, 29–31], and safety equipment [4, 5, 7, 9, 16, 17, 19, 32–34] exacerbated by poverty [9, 18]. Moreover, women work in environments where potentially hazardous pesticides are used, often with little protection. Market liberalization, privatization of agricultural inputs and ineffective enforcement of pesticide legislation in most of Africa have led to the use of most toxic and persistent pesticides in agriculture [19, 35]. These pesticides remained illegally available through parallel open markets and are reasonably priced and are intensively used in African agriculture, where women's contribution is substantial.

In addition, women are also particularly susceptible to pesticides than men due to biological factors. Relatively higher levels of adipose tissue or hormonal changes in women's life events during pregnancy, lactation, or menopause increases their susceptibility to pesticide risks [9, 18, 36, 37], causing acute-to-chronic diseases. Children of exposed mothers, either during pregnancy or breastfeeding, may also experience developmental disorders and other serious conditions [38].

Though women's health has aroused public concern, the magnitude and nature of exposure and its subsequent adverse health impacts for women living and working in agricultural settings in sub-Saharan Africa received inadequate attention in policy, research and advisory. This paper seeks (i) to present an overview of the existing scientific literature on how and why women are exposed and are potentially at risk from pesticides taking into account biological and social parts of their lives and (ii) to identify knowledge gaps in current research for further investigation. With special attention to the situation in sub-Saharan Africa, published studies including scientific reports from international organizations have been consulted from English peer-reviewed journals collected primarily from Google Scholar, PubMed, and other electronic libraries.

Pathways of women's exposure to pesticides

Occupational exposure

Research on occupational exposure from pesticides for women remains scarce and tends to consider male farmers or farm workers. Part of the reason why exposure from pesticides for women do not receive the attention it deserves is that only men are thought to be occupationally exposed because of the gender division of labour as well as the social construction of pesticide application as men's work [15–17]. This is supported by an evidence that field pesticide applicators in the flower farms in Ethiopia [21], again smallholder farms in Ethiopia [39], commercial farms in Zimbabwe [32], horticultural farms in Kenya [8], vegetable farms in Ethiopia [35], rice farms in Sierra Leon [40], and flower and onion farms in Tanzania [12] were men.

However, there are other examples in sub-Saharan Africa, where women are similarly engaged in direct

application of pesticides. In the study done in the Tororo district of Eastern Uganda in the four randomly selected parishes, 80% of female-headed households apply pesticides on their farms [19]. As has been shown in a study carried out in the Mt Elgon region of Uganda covering two districts, 38% of women apply pesticides on their coffee tress [17]. Another example of women applicators is found in the Brong Ahafo region of Ghana [20], where 18% of women apply pesticides on their vegetables. Another important illustration is documented in a survey conducted in Kwa-Zulu-Natal South Africa, where 45.6% of women reported direct handling of pesticides on their subsistence farms [22]. In the Ashanti region of Ghana [41], all the selected women ($n=58$) were pesticide applicators on their vegetables. According to Zseleczky et al. [16], pesticide application is primarily viewed as men's task in the Brong Ahafo region of Ghana, but some women reported application of pesticides on their own tomatoes. In the same region in Ghana, 94% of women involved in high-exposure activities such as mixing pesticides for applying in their vegetable farms [20].

When women engaged in direct applications, the equipment or the pesticides used are usually those with potential contamination. For example, in Uganda [19], women often use the local methods of application, i.e., using a plastic basin and a broom made of grass and use it manually, a potential contamination of the workers. These women may also face the greatest risks from pesticides that are classified as potentially hazardous. For instance, the pesticides used in this farm include the moderately hazardous endosulfan and the obsolete or not classified profenofos [19], thought to be endocrine disruptors and cholinesterase inhibitor or neurotoxin, respectively [36]. Also in another farms in the Brong Ahafo region in Ghana [20] and Offinso district of Ashanti region in Ghana [41], where women apply pesticides, they, respectively, use DDT and endosulfan, chlorpyrifos, dimethoate, carbofuran and others on their crops (see Table 1), thought to be endocrine disrupters, probable carcinogens, and so on. Inefficient enforcement of legislations over pesticide sales [19, 35] creates a suitable environment for illegal vending of pesticides that have been banned or severely restricted from use. These pesticides are often applied with inadequate personal protective clothing, limited personal hygiene, and knowledge [17, 19, 21, 42].

When women do not directly apply pesticides, they can be disproportionately subject to exposure from residues remaining on soil, foliage or crops [43]. In smallholder farms in Uganda [19] and Ghana and Mali [20], women were seen weeding in the field, obviously done during the peak spraying season when high residues are transported as aerosols, with significant potential exposure for them. Similarly, in the flower farms of Ethiopia [4, 7, 21, 44] and horticulture farms in Kenya [8], where women make up a significant proportion of workers, they were employed on temporary positions for planting, weeding, thinning, checking for disease, harvesting, packaging or transporting, which are perceived to be highly hazardous. As women are often employed informally in these sectors, education or training are almost not offered for them as compared to the formal work forces [6]. As floriculture and horticulture sectors are high users of pesticides including those classified as potentially hazardous, women can face adverse consequences on their health due to social and biological factors. All these findings presented in this review reflect that women who are not involved in direct application of pesticides can also be exposed through other tasks in the farm, calling for more knowledge-based and gender-oriented research and interventions.

Non-occupational exposure

In addition to direct exposure in the field as pesticide applicators or farm workers, women can be exposed in the domestic setting through washing pesticide contaminated clothing and equipment. Contaminated clothing used in the field, either by women themselves or household members, is usually brought into home for washing. This has been well documented in South Africa [22], Uganda [19], Ghana and Mali [20], again Ghana [16] and other continents in the developing world [18], where washing clothes is traditionally perceived as woman's work. This can be a further source of exposure for women as pesticide residue is often brought home on clothing. As has been reported in the Brong Ahafo region of Ghana [16, 20], women experienced headaches when washing their husband's pesticide contaminated clothing. This has an implication that women who are not involved in direct handling of pesticides can be exposed indirectly through daily domestic chores.

Another important pathway of exposure to analyze is from pesticide contacts at home. In studies carried out in Ghana and Mali [20] and South Africa [22], 8% and 13.4% of women, respectively, store pesticides at home. They also store the backpack sprayers in various parts of their homes because they have more control over these places than others [16, 20]. Without sex differentiation, studies done in Arumeru district in Arusha region in Ghana [15] and Tororo district in Eastern Uganda [19] found that 89.5% and 54% of the farmers, respectively, store pesticides in their homes. Storage at home may put women and their children at a greater risk of intentional or un-intentional poisonings [22], as they are more likely to come into contact with the stored pesticides in their homes [18]. Zseleczky et al. [16] noted that most women

Table 1 Summaries of reports on exposure and health impacts

Publication	Methods used	Study population	Findings
[19]	Pesticide use and exposure among framers was studied through qualitative and quantitative data. Individual in-depth interviews, focus group discussions, and a household survey were used. This was supplemented by interviews with retailers and agricultural staff at district and sub-county levels, combined with field observations	Eastern Uganda: 200 smallholder farmers including 144 male and 64 female-headed households in Paya sub-county, Tororo district	Exposure to permethrin, profenofos, cypermethrin, endosulfan and dimethoate were associated to an increased risk of skin irritation, cough/throat irritation, headache, dizziness, breathing difficulties and nausea
[39]	A mixed methods research consisting of a survey, key informant interviews and document review were used to asses knowledge, pesticide practices and associated toxicity symptoms among farmers	Southern Ethiopia: 100 smallholder farmers in two rural *kebeles* of Finchawa and Tullo in Hawella Tula sub city in Hawassa city administration, Sidama	About 91.8% of the respondents were males and 8.2% females. Exposure to endosulfan, diazinon and flazasulfuron was associated to headache, skin rash, slow heartbeats, chest pain, mood change, dizziness, skin or eye burning, eye pain and coughing
[7]	Structured interviews and walk-through surveys were used to explore pesticide use on male and female flower farmers. In addition, blood samples were collected from the target population to assess concentration levels of serum cholinesterase	Southern Ethiopia**:** 588 (311 female and 277 male) flower farm workers from 15 different flower farms	Out of 277 males, 148 were pesticide applicators and 129 non-applicators. Females had been working in planting, weeding, cultivating and harvesting flowers inside the greenhouses. Linked to exposure to organophosphates and pyrethroids, the blood measurements indicated a higher levels of abnormal cholinesterase among female greenhouse workers, female and male packinghouse workers, male sprayers and non-sprayers. Out of the 154 pesticides used in the farms, 55% were unregistered, one pesticide was classified as class Ib, while 27.4% were class II
[17]	A survey was used to assess pesticide exposure and self-reported symptoms among male and female farm workers	Mt Elgon region of Uganda: 71 men and 55 women coffee farm workers covering two districts: Sironko and Namisindwa	About 52% of men and 36% women apply pesticides. Cough was reported among 48% of male and 38% of female farmers, while headache and skin itching were reported among 9% and 5% of women and men, respectively, linked to exposure to cypermethrin. Others pesticides were mentioned in local names
[28]	Several research tools such a survey, urine and fractional exhaled nitric oxide were used to investigate the relationship between exposure to organophosphates and pyrethroids with asthma-related outcomes among women	The Western Cape province of South Africa: 211 female (89 farm workers and 24 farm residents) and 98 residents surrounding farms	Urinary pesticide metabolites measurements indicated higher levels of exposure of farm workers to a number of organophosphates and some pyrethroids. Women with depressed cholinesterase levels had an increased odds of having allergic airway inflammation, based on the fractional exhaled nitric oxide determination. Asthma and allergic outcomes were higher among town residents than the other groups
[52]	Self-administered questionnaires were used to assess pesticide exposure among women. Besides, measurement of urinary organophosphate and pyrethroid metabolite concentrations were assessed to investigate the relationship between residue levels and neurotoxic symptoms among female farm workers and residents in neighboring towns	Western Cape of South Africa: 211 female farm workers and residents in neighboring towns in table, wine grape and fruit producing areas	Among all the farm workers, only 2% of women were pesticide applicators. The urinary pesticide metabolites measurements shows high levels of exposure of participants to chlorpyrifos, methamidophos, azinphos methyl, monocrotophos, terbufos, parathion, and fenamiphos, deltamethrin, permethrin, cypermethrin and cyfluthin, several of which belong to the WHO pesticide class II and Ib. Out of 186 urine samples collected, 18 had a creatinine concentration outside the WHO recommended range

Table 1 (continued)

Publication	Methods used	Study population	Findings
[21]	A questionnaire and walk-through survey were conducted to explore the respiratory and dermal symptoms experienced by workers and the control groups	Oromia region of Ethiopia: 213 workers from 3 rose flower farms and 60 control groups from supermarkets	20.6% were male sprayers and non-sprayers and 79.3% females working in cutting and weeding in the greenhouse and bundling, quality control, and packing of the flowers, storage, and transport outside the greenhouse. Flower farm workers inside the greenhouse, female cutters and weeders and male sprayers had a higher prevalence of respiratory and dermal symptoms than workers outside the greenhouse, linked to exposure to organophosphates, carbamates and pyrethroids, most of them are classified as class Ib and II by WHO
[42]	A household survey was conducted to assess knowledge, pesticide use and poisoning symptoms among farmers	Uganda: 204 farmers in the three major potato-growing agroecological zones	58% and 42% of the respondents were males and females, respectively. Exposure to a number of fungicides and insecticides are associated to skin itching and, burning, coughing, a runny nose, teary eyes, and dizziness among male and female smallholder farmers
[8]	A survey and clinical examinations were used to assess the poisoning symptoms experienced by horticultural farm workers and residents and their possible association to pesticide exposure	Lake Naivasha of Kenya: 801 (352 male and 449 female) horticultural farm workers and residents in five communities (i.e., Kamere, Kwa Muia, Kioto and Karagita)	About 88.5% of males were pesticide applicators while 61.6% of females working in planting, weeding, harvesting and pruning. Those who weeded, planted, and harvested flowers reported the highest proportion of symptoms such as respiratory; skin, joints and bones; and nervous systems than sprayers
[24]	The association between pesticide exposure and cholinesterase levels among women currently living on a farm and residents living in towns neighboring the farms was assessed through self-administered questionnaires and blood metabolite concentration of organophosphates and carbamates. In addition, fractional exhaled nitric oxide measurement was also used to assess allergic airway inflammation among the target groups	Western Cape of South Africa: 211 women (113 women currently living on a farm and 98 residents in towns in surrounding farms)	Blood metabolites measurements indicated high levels of exposure of participants to cholinesterase-depressing pesticides such as the organophosphates (chlorpyrifos, diazinon, dichlorvos, and malathion) and carbamates (i.e., carbaryl). As the fractional exhaled nitric oxide measurement shows those with lower cholinesterase levels had almost fivefold increased odds of having highly probable allergic airway inflammation. Asthma and allergic outcomes were higher among town residents surrounding farms than the other groups
[4]	A mixed methods approach comprising survey, in-depth interviews and field observations were used to assess the occupational induced health problems among floriculture workers	Oromia region of Ethiopia: 612 flower farm workers in the nine floriculture farms in Sebeta town and the surrounding	Women workers constitute almost 80% of the employees of the flower sector. About 52.4%, were temporary employed, 22.3% permanent and 25.3% daily laborers. About 51.6% were working in greenhouses (which included supervisors, coordinators and cleaners), 27.0% pack house, 15.9% spraying and 5.5% were irrigation. Skin problems, respiratory problems, fatigue, headache and sleepiness in both sexes were reported

Table 1 (continued)

Publication	Methods used	Study population	Findings
[32]	Blood was measured to establish levels of poisoning by organophosphates and/or carbamates. A survey was used for data on knowledge, attitudes and practices of pesticides among farm workers	Kwekwe district, Zimbabwe: 246 (149 male and 97 female) farm workers in the eleven commercial farms of Kwekwe district	About 60.6% of the respondents were males and 39.4% females. The blood metabolites measurements indicated high levels of exposure of participants to organophosphates, pyrethroids and carbamates. Out of 98% respondents whose blood was tested, 24.1% had an abnormal cholinesterase level. Among these, the most affected were sprayers (50%), followed by those who worked in previously sprayed areas 49%, loaders (31%), mixers (29%), repairers (22%), waste disposers (9%) and store managers (7%). Compared with males, who were all pesticide applicators, female farm workers were more likely to have an abnormal cholinesterase levels than males
[53]	A survey was conducted to compare reproductive outcomes among female farmers working in the irrigation scheme and drylands	Kwa-Zulu-Natal, South Africa: 911 women farmers in the irrigation scheme and drylands	45.5% of women were sprayers. About 887 of women reported 4796 pregnancies, 322 spontaneous miscarriages, 137 infant deaths. They were exposed to a wide variety of pesticides, several of which belong to the WHO pesticide classes I and I
[41]	In addition to survey, blood cholinesterase measurement was performed among farmers and the control groups	Ashanti region, Ghana: 63 male and female farmers and 58 farmers who did not apply pesticides for the last 2 months	The majority of men were pesticide applicators. Blood results shows a higher levels of exposure of participants to organochlorine, organophosphate, pyrethroid, carbamate insecticides. Levels of cholinesterase were significantly lower in exposed farmers than in controls. Low cholinesterase level has been associated with an elevated risk of body weakness and headache
[23]	An association between women's exposure to pesticides and birth defects was investigated through a survey. Further, information on birth defects was obtained from a hospital. The cases were children who were diagnosed with selected birth defects and the controls were children born in the same areas as the cases	Eastern cape of South Africa: 89 case mothers and 178 control mothers	Most of the case mothers were working in vegetable gardening and subsistence farming. About 80% of the cases and 74% of the controls were involved in food gardening and farming. Babies with birth defects were 7 times more likely to be born to occupationally exposed women and were twice as likely to be born to women who were involved in dipping livestock used to prevent ticks and 6.5 times more likely to be born to women who were using empty pesticide containers for carrying domestic water

are unable to face difficult situations in their agricultural production, thus, are more likely to consume pesticides intentionally.

There are also grave concerns for women's exposure from re-using empty pesticide containers for household purposes. In Tanzania, empty pesticide containers have been reused by women for storing cooking oil, water, milk, flour, salt, and kerosene [5]. In South Africa, women reused containers for fetching and storing water [23]. The children were seen drinking water with the empty containers [20]. After tomato harvesting in Ghana [16] and Mali [20], women usually bring the large drums, previously used for mixing pesticides, to their homes and re-use them to store water. Though children are at a particular risk of exposure, women are in charge of the domestic duties with the containers [18]. As to Food Agriculture and Organization [45], re-using empty pesticide containers might increase the risk of non-occupational exposure via ingestion due to the possible presence of residues. While the greatest exposure and potential health problems from pesticides are expected to occur among those who are occupationally exposed, a study in Eastern Cape of South Africa [23] noted that babies with birth defects were 6.5 times more likely to be born to women who were re-using empty pesticide containers for storing water. In another region in South Africa [24], low level of cholinesterase among women has been partly associated with the re-use of empty pesticide containers for household purposes.

There are also grave concerns on women's exposure from domestic use of pesticides, but detailed information on it is hardly available. Studies from Ghana illustrate that pesticides are sprayed postharvest in order to make the grain look fresh and attractive to consumers [16, 20]. Jacobs and Dinham [9] added that pesticide application in and around homes is primarily the responsibility of women. Residues from such pesticide usage may contaminate food sources, with potential risks to those handling the grain, traders and consumers [16, 46]. Moreover, with less developed immune systems, pesticide residues in the home is also particular concern for children because they are more likely to spend more time at home, their hand-to-mouth behavior, higher absorption rates, and less ability to metabolize and eliminate chemicals [47].

Though the use of DDT for malaria control has declined in some countries of Africa due to resistance [48–50], it is still a potential pathway of exposure for most women. Women can be potentially exposed to indoor spraying as they usually spend most of their time in and around homes for domestic tasks [18]. In studies carried out in Ethiopia [25, 26], an increased concentrations of DDT residues and its metabolites have been detected in breast milk of mothers' in malaria endemic areas. In South Africa, higher plasma DDT level was detected among women who were subject to indoor spraying for malaria control [27]. This implies that a mother is transferring contaminated food to a breastfed infant building up in his or her body [19], risking the life of future generations [51].

Another source of pesticide exposure for women is from a spray drift in a farm, where women undertake fieldwork, or a drift reached their home. Women are also more likely to be exposed from contamination of food, water, and clothing through spray drift reached their home because they shoulder huge responsibility in the household in addition to field production [18]. In a study carried out in the Western Cape of South Africa, asthma and other allergic symptoms have been reported among women farm residents, partly associated with a drift that reached their home [24, 28].

Health impacts of pesticide exposure

Occupational or non-occupational exposure from pesticides has been associated with several health problems for women, although difficult to prove direct links [51]. According to Garcia [36], pesticide risks will be the same for males and females, but sex differences in biological characteristics leads to an increased susceptibility for the latter. As women have a relatively higher level of adipose tissue on average and experience hormonal changes in their life events during pregnancy, lactation, or menopause [9, 18, 36, 37], they are more likely to absorb certain pesticides in their bodies from contaminated environments than men, with harmful consequences on their health.

Contrary to the view that pesticide impacts on health is highest for those handling pesticides directly, evidences show that women who were not applicators, experienced similar or worse health problems than their male counterparts. Compared to males, who were all pesticide applicators, women workers in the commercial farms of Zimbabwe [32] and women planters, weeders and harvesters in the flower farms of Kenya [8] experienced an abnormal level of cholinesterase and central nervous problems, cardiovascular and gastrointestinal diseases, respectively, linked to exposure to organophosphates and carbamates [32]. These women work in fields when pesticides are sprayed or enter the fields that was previously sprayed, thereby making frequent contacts with residues. Further, they were not well trained on pesticide hazards and had little access to safety equipment.

Linked to exposure to organochlorines [41], organophosphates, carbamates [7, 24, 28, 41], and pyrethroids [7, 28, 41], male and female pesticide applicators in smallholder farming in Ghana [41], female farm workers and male applicators in the flower farms in Ethiopia [7]

and female farm workers in the Western Cape of South Africa [24, 28] manifested an abnormal level of cholinesterase. As to Ndlovu et al. [24], female farm workers were exposed through direct occupational exposure in the field in addition to other forms of exposure at home, for example, living with an applicator (30%), using empty containers for household purposes (11%) and drift reached their home (57%).

Respiratory and dermal symptoms, thought to be linked to exposure to organochlorines [19, 39], organophosphates [19, 21, 28, 39], carbamates [21], pyrethroids [17, 19, 28], and fungicides [42] have been reported among male applicators and female flower farm workers in Ethiopia [21], male and female farmers in Uganda [17, 19, 39, 42] and Ethiopia [39] and women farm residents in South Africa [28]. In most cases, especially in the flower farms, women constitute the majority of the labor force. As to Mwanga et al. [28], pathways of exposure for women residents may be probably either via spray drift reached their home that contaminates surfaces, food, and water, or through household use of pesticides.

Relative to women's share in agriculture in sub-Saharan Africa, there are relatively few studies documenting adverse impacts of pesticides on women's health. In a rural South African study, Heeren et al. [23] reported birth defects that occurred after women came into contact with the organophosphates and carbamates during farming, re-using empty pesticide containers for water storage, and involved in dipping livestock to prevent ticks. An increased risk of reproductive impairment, diabetes, hypertension, and cancer among female horticultural workers in Tanzania, linked to exposure to organochlorines [5] have been documented. In another study carried out in South Africa, spontaneous miscarriages and infant deaths have been noticed among occupationally exposed women to methamidophos, monocrotophos, methyl carbamate, deltamethrin, cypermethrin, dimethoate, lambda-cyhalothrin, paraquat, glyphosate, several of which belong to the WHO pesticide class II and Ib in South Africa [53]. An increased risk of miscarriages, premature deliveries and spontaneous abortions has been directly associated with women's engagement and their exposure in greenhouses [1]. Garcia [36] found that women who were exposed to pesticides experienced reproductive problems or birth defects in their children. Women are also more likely to be susceptible than men to hormone-related cancers as many of the pesticides are endocrine disrupters. Hormone-related cancers such as breast, endometrium, ovary, bone, and thyroid tumors are common among women [36]. In another study undertaken outside Africa, we found some other cases of chronic diseases among women. An increased risk for cancer among spouses of pesticide applicators [54], linked to women's exposure to organophosphates have been reported. Problems in the placenta, the fetus, premature births, miscarriage and endocrine disruption, linked to exposure to organophosphates during pregnancy [41] are also noted. Pregnancy complications and adverse impacts on the fetus and child development, linked to prenatal exposure to organophosphates and carbamates [55] and miscarriages and still births, linked to exposure to organophosphates (i.e., chlorpyrifos), pyrethroids and herbicides (i.e., 2,4D) [56] are common. There are also other cases of higher levels of thyroid hormones among women living in a heavily contaminated area [57], higher pesticide levels in the urine among spouses of pesticide applicators who were present in a field during 2,4-D application [58].

A number of studies reported the adverse impacts of pesticides on children's health whose parents are either occupationally or non-occupationally exposed, although data are scarce in sub-Saharan Africa, where the problem might be different. Women's occupational exposure to pesticides either during pregnancy or breast feeding has been possibly associated with an increased risk for the fetus as well as the newborn babies. In sub-Saharan Africa in general, parental occupational exposure was associated with a risk of diabetes among infants [59]. In California, where the participants were born to Mexican immigrant mothers, abnormalities of the lung in children have been reported [38]. In order to protect women and their children, researchers need to integrate both occupational and non-occupational exposure for women and its consequent adverse impacts on their health, so that evidence-based intervention measures can be made.

Factors that aggravate women's exposure

Working and safety conditions

In its 2015 report, United Nations [60] documented that more than 40% of the population lives in extreme poverty in sub-Saharan Africa, where women constitute half of the population. The majority of women continue to be disproportionately poor, unemployed, working in low wages [60], illiterate and not well-informed about their rights, reflecting relative disadvantage compared to men and are typically unprotected from pesticide hazards [22, 61]. London et al. [18] argued that "since women are concentrated in the most marginal positions in the formal and informal workforces", there is little opportunities for them to control their exposure. p. 46. It seems also clear that poverty for women often means moving towards a job that is poorly paid, potentially hazardous, and time-consuming [9, 18].

African woman's struggle for survival was described as follows:

> *An African woman bent under the sun, weeding sorghum in an arid field with a hoe, a child strapped on her back—a vivid image of rural poverty. For her large family and millions like her, the meager bounty of subsistence farming is the only chance to survive." Against this background, many women work in potentially hazardous conditions that may affect their health and the environment [62], p. 1.*

While men and women may face pesticide risks, gender-related working conditions that are biased against women may place the latter at a distinct disadvantage [36]. Women are typically concentrated in poor working conditions, for example, employment in potentially hazardous jobs in the floriculture and horticulture sectors with little consideration of their promotion, access to information, and safety measures [5, 20]. Since women's paid work is an additional to domestic responsibility [63, 64], they may prefer temporary labor or seasonal jobs that are typically lower paid [3]. Among the 325 female flower farm workers in Ethiopia, 211 were temporarily employed [34] and are also heavily disadvantaged in terms of wage which was typically lower than for men [34] which may probably affect nutrition and personal hygiene. Because women are often not employed on a permanent basis, tasks that can be done with less training and skill are often allocated for them [18]. These tasks may include high-exposure activities such as weeding in recently sprayed fields. Working conditions in commercial farms is once again more hazardous for women due to the widespread use of different and multiple pesticides (see Table 1) with a potential long-term impacts for their health. As child care services are often not available, most women must take their children in the field [5], risking the health of future generations. Women casual and temporary workers are more likely to be targeted for sexual harassment by employers or immediate supervisors in the flower industry in most of Africa [65–67], increasing their susceptibility. Poor living and working conditions can be a distinctive source of exposure for farmers or farm workers as it causes malnutrition, general and occupational diseases, and complications from untreated diseases [1]. Although wage employment on women's empowerment is a considerable agenda globally in recent years [68], little has been done on their labor rights, reflecting their relative disadvantage for securing protection from pesticides or any other hazards and its subsequent outcomes.

Lack of personal protective clothing stands out another source of exposure for women. In a study carried out among 246 workers in the commercial farms of Zimbabwe, 130 males were seen wearing protective clothing as opposed to 44 females [32]. In Ethiopian flower farms, all re-entry female farm workers in the greenhouse were unprotected, as opposed to male applicators [6]. Female floriculture workers in Tanzania did not use any protective clothing because they perceive less pesticide risks [5]. Out of the 578 employed workers in the flower farms in Ethiopia, 343 were without protective clothing [4]. About 80% these workers were women. In this farm, protective clothing supply was either inadequate (60%) or not comfortable for work (40.2%). Though farm workers were provided with protective clothing in one of the flower farms in Ethiopia [7], where women constitute the majority of the employees, some workers removed their gloves while working due to less perceived risks. In another flower farms in Ethiopia [33], only men applicators received protective clothing. Whether it is either due to lack of protective clothing or other constraints, in Ethiopia's floriculture [4, 21, 44] and Kenya's [8] horticultural industry, respiratory as well as dermal contaminations of workers have been reported.

For women working in their own fields, personal protective clothing is neither affordable nor accessible in local shops. Instead of using protective clothing, most women in sub-Saharan Africa give priority to basic needs such as food [22]. In Uganda, where 80% of women apply pesticides on their subsistence farms, the high cost of protective clothing and inaccessibility in local shops were reasons for not to use [19]. In the same country, where 38% of women reported direct handling of pesticides, 65% of them did not use any protective clothing [17]. Women in sub-Saharan Africa also do not wear protective clothing for cultural reasons [9]. Respiratory as well as dermal contaminations have been reported among farmers in Ethiopia [39], Uganda [17, 19, 42], South Africa [23, 52] and Ghana [41], where women are similarly engaged with men in the farm either for weeding or other activities.

A further source of exposure for women is scarcity of water and lack of sanitary facilities. Female farm workers, who constitute 72% of the employees in the Ethiopian flower farms, suffer from the lack of sanitary facilities in the fields than men [34]. When washing facilities are available, women are not allowed to use them because their work is not considered hazardous [18]. Sexual violence also hinder women from walking long distances looking for water sources. In Ghana [16], women's fields are located far away from water sources than men's.

Lack of access to pesticide transportation can contribute to an increased risk of non-occupational exposure for women [16, 20]. While men use bicycles or motorcycles, women carry pesticides in a basket on their head walking from the market to their home or field. This may probably place them at a particular risk of exposure due to the possibility of pesticide spilling on their bodies. For these

women, financial constraints to buy the motors and lack of knowledge how to ride were mentioned as constraints.

Education and training

Another contributing factor for women's exposure against pesticide contaminations is the limited access to education, information or training. In studies carried out among horticulture farm workers in Tanzania [5], floriculture farm workers in Ethiopia [7, 21, 33], smallholder farmers in South Africa [22], Uganda [19], and Ghana and Mali [20], women were seen less able to read and understand pesticide labels than their male counterparts. In a study documenting gender differences in pesticide use, knowledge, practices and exposure among 293 and 120 farmers in Ghana and Mali, respectively, Christie et al. [20] illustrate lower literacy rates among women compared to men in both regions. According to Andersson and Isgren [19], 82% of female-headed households, as opposed to 57% of male-headed households in Uganda, cannot read and understand pesticide labels. Similar observation has been made in South Africa, where women had limited knowledge and risk perception to understand pesticide hazards [22]. This reflects that women are less likely to communicate risks, follow safety practices, handle properly even those pesticides that appear to be relatively safer [20].

Women appeared to be less informed on pesticide use and hazards. Trainings, in most cases, targeted male farmers or farm workers, supposed to be either pesticide applicators or supervisors [20]. As women mostly work in informal sectors, they are not invited for training [6, 34]. In a flower farm in Ethiopia, none of the 275 female workers received training on pesticide use because many of them were temporarily employed [6]. In Ghana and Mali, women were not invited for training on pesticide use because this task is traditionally perceived to be men's domain [20]. Further, extension packages in Ethiopia often focused on the heads of the household, assumed to be men [29–31]. Lack of training will eventually place an additional burden on women who are less literate.

There may be several reasons why women are apparently discriminated against receiving information or training on pesticide use. First, pesticide application is traditionally labeled as men's task and women's role and exposure is grossly underestimated [20]. Second, pesticide exposure for women from household work is not recognized as hazardous as exposure is associated only with crop spraying [9]. Third, the agricultural extension programs are mostly run by men as is the case in Ethiopia [30, 31] and Ghana and Mali [20]. The social norms appear to limit women's mobility outside their villages and contact with male extension workers, a major barrier for risk communication in most rural societies of sub-Saharan Africa [3, 69, 70]. Fourth, women are often busy in their triple roles; reproductive, productive and community and therefore may not have time to attend education or training [20]. These unfavorable employment conditions coupled with poverty and illiteracy aggravates women's susceptibility to pesticides risks. Figure 1 presents an overview of the socio-economic, institutional, and biological factors that affect women differently.

Discussion

Pesticide exposure and its adverse impacts are particularly alarming for women's health. The studies presented in this review shows that women are exposed to pesticides because they are increasingly involved in agriculture either in their own fields or commercial farms [1–3, 9] as pesticide applicators [16, 17, 19, 20, 22, 41] or through responsibility for weeding, harvesting, packaging or transportation [4, 7, 8, 21, 44, 52]. In addition to women's substantial contribution in their own fields, with commercialization of agriculture in many countries of sub-Saharan Africa, they are increasingly employed in the horticulture and floriculture sectors. As these sectors are high users of pesticides, opportunities of exposure for women may be increased [5, 18]. Pesticides that are suspected or possible endocrine disruptors or carcinogens, neurotoxicants, cholinesterase inhibitors, or other conditions [71] are intensively used in smallholder as well as commercial farming in sub-Saharan Africa, where women have little protection. For example, endosulfan, which is proposed for cotton, has been widely used in smallholder farms in Ethiopia [39] and Uganda [19], however this organochlorine insecticide is listed as a suspected endocrine disruptor [36]. Williamson [71] found serious ill health among 36 people as well as 37 fatalities in Benin, under poor spraying conditions of endosulfan. A report from Women in Europe for a Common Future [72] shows that many women exposed to endosulfan reported illnesses, miscarriages and birth defects. Likewise, use of DDT has been associated with endocrine disruption, probable carcinogens, and the ability to cause defects in a developing fetus as this insecticide persists in the environment, accumulates in the food chain and persists in human fatty tissues [27, 50]. In addition to the organochlorines, women face adverse consequences from organophosphates, carbamates or pyrethroids, which are used intensively in African agriculture (see Table 1).

With pesticide exposure in the field, women as well can be exposed domestically through responsibility for washing pesticide contaminated clothing and equipment and pesticide storage at home [16, 19, 20, 22], cleaning or re-using empty pesticide containers [5, 16, 20, 23, 24], domestic pest control [9, 16, 20], indoor DDT spraying

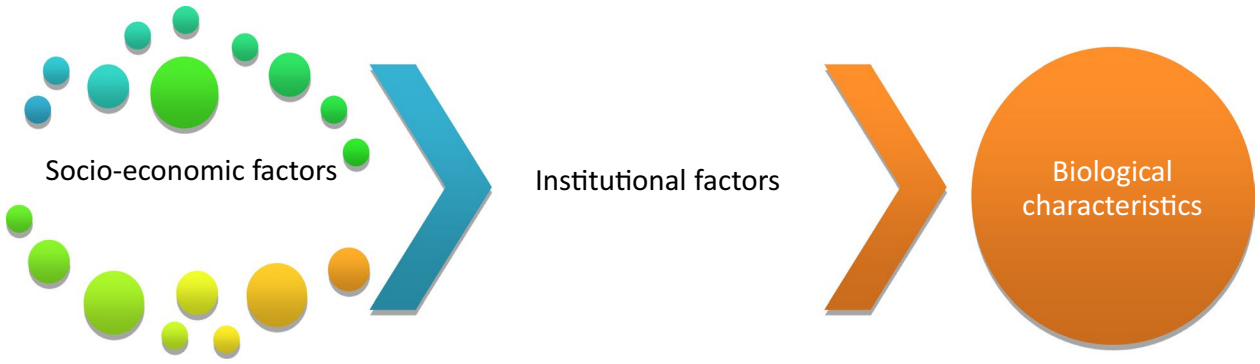

Fig. 1 An overview of factors for women's exposure (source: constructed by authors and adapted from the above literature)

[25–27] or spray drift while women work on a farm or drift reached their home [24, 28].

Pesticide usage is more problematic for women in sub-Saharan Africa, where access to pesticide education [5, 7, 19, 21] and information or training is largely gender discriminatory [6, 20, 22, 29–31] that may seriously affect risk perception and knowledge. The problem can be inevitable for women as they work in environments where protective clothing [6, 21, 22, 32] and washing facilities [24, 34] are often not available for them. When protective clothing is available, lower level of risk perception [5, 33] or social norms [9] matters. Lower wages [34] may also influence nutrition, thereby increases susceptibility to chronic diseases from pesticides [1].

From decades of scientific neglect, attempts have been made in the literature recognizing the importance of gender-based analysis in occupational and non-occupational exposure and the recognition of gender differences in living and working conditions [18]. However, still pesticide exposure and the possible adverse impacts for women's health remains grossly underestimated and under-reported despite the different sources of exposure for them and the social and biological conditions that often aggravate their exposure. This scientific neglect comes from the widely circulated notion that women are not at risk of pesticide exposure because their work is not hazardous for their health. This is clearly seen in the literature on pesticide exposure in Africa, where much of the occupational studies conducted to date [10–13] marginalize women in their research and have targeted male farmers or farm workers. Also in a well detailed review of literature in developing countries [9, 18] and Tanzania [5], the lack of literature on women's exposure and its adverse impacts are explicitly noted. Given this paucity of occupational research on women means that "we know little about the long-term effects of pesticide exposure on women's neurologic status, mental health, and well-being" [18], p. 53. In such circumstances, inattention to gender-specific exposure and outcomes may have substantial implication on policy and any intervention measures that particularly disadvantage women.

There is quite little scientific evidence on male–female differences in pesticide exposure and its impacts on their health. With regard to the studies presented in this review, few studies exclusively focus on women, some others focus on both and others are without any mention of participants' gender. That women who are working in hazardous environments may face additional risks from pesticides linked to their sex or gender, has been largely ignored. According to Garcia [36], "the potential for occupational and environmental exposure to pesticides in women is important, and it can be even higher than for men in some situations, as there are a substantial number of women working" in small-scale as well as commercial farming [36], p. 587. London et al. [18] added that the exposure patterns for men and women

differ substantially because women have higher proportions of adipose tissue, their biologic response to pesticide hazards and women's life events during pregnancy and menopause that affect the way in which pesticides are metabolized and excreted. Further, for social reasons (e.g., different lifestyles, behavior and occupations) among men and women, exposure patterns differ.

As only relatively occupational environments are considered hazardous, non-occupational exposure from the domestic setting remains inadequately addressed in scientific literature, although it can expose women to risks that often aggravate field exposure. As discussed earlier, that women are also at risk for particular exposure during other activities in the household. In light of this evidence, much more non-occupational exposure will come out for women in the near future.

As shown in Table 1, many of the studies presented here collected exposure information through surveys. These methods primarily assessed occupation of the target population and self-reported exposure through self-administered questionnaires. Some others used biological monitoring to measure pesticide residue levels of the target population primarily through sampling of blood, urine or breast milk. Few studies used fractional exhaled nitric oxide measurement for assessing inhalation exposure through sampling of the workers' breathing. While biological monitoring can be considered as an appropriate tool to document long-term exposure from a combination of occupational and non-occupational settings [18, 73], assessment through only quantitative approaches can be more challenging. A lot of factors that influence quantitative measurement are the different pesticides used, specific agricultural occupations, and the different sources of exposure, including those not related to occupation [73]. Qualitative methods such as field observations and focus group discussions with the target population provide useful insight on exposure. Quantitative measurements of exposure can enhance this approach [9]. Finally, many of the reviewed studies lack theoretical frameworks that offer our understanding of pesticide exposure pathways, as well as behavior (change), learning processes and cultural hindrances.

Responses

The topic of pesticide use and of women warrants far more focus than it currently receives. Women as well as their children are less able to protect themselves from pesticide hazards and silently experiencing the devastating consequences. Women and their children may have other serious risk factors like malnourishment or poor living and working conditions that may aggravate their exposure. It is either due to lack of information, ineffective enforcement of pesticide regulation, illiteracy, poverty or poor working conditions, it is clear that women and their children are not adequately protected, calling for an urgent need for immediate action to protect them against pesticide contamination.

The possible approaches that all together have the potential to change the practices in a sustainable manner are; first, further research addressing women's substantial occupational and non-occupational exposure to pesticides and its consequent adverse impacts on their health, considering biological factors, gender roles, socio-economic status, and working conditions, using participatory approaches [20, 36]. Second, enforcement of pesticide legislations that regulates not only pesticide imports, but also distribution, sale and use [51, 74–76]. Third, promotion and dissemination of alternative approaches [74, 77, 78] such as bio-pesticides, integrated pest management, organic farming, and agroecological methods. In this case, advisory services and science have to reset their focus towards communication of these alternative approaches to all farmers and should be more accessible to women. Fourth, educational and awareness creation programs are required for all stakeholders along the value chain; farmers, farm workers, extension workers, retailers, etc. Fifth, educating women about safe use of pesticides is not enough until they are empowered to secure greater protection for their own lives and their families through recognizing their labor rights, socio-economic rights, and gender rights [2]. Finally, as women assume huge responsibility in agriculture, interventions need to focus on reducing the time and work involved in domestic tasks. London et al. [18] underline that "until women in developing countries are empowered, pesticide usage and its health consequences for women will remain out of sight and out of mind for most of the world" p. 66. All these activities together might contribute to change gender discrimination and secure greater protection for women and their children from pesticide hazards and its adverse impacts on their health.

Author contributions

BAA developed the structure, conducted all the literature search, organized and wrote the first draft of the manuscript and organized in a structured way and also led revisions. BF and JB made critical points on the structure of the paper, draft writing, interpretation, discussion, comments on the revisions, proofread the manuscript including grammar and final remarks. All authors read and approved the final manuscript.

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