ENTOMOLOGY | RESEARCH ARTICLE

Militia feruginaea solvent extracts on maize weevils and red flour beetles repellency; an implication to use them in storage pest management in Ethiopia

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Abstract: Milletia ferruginea leaf solvent extracts were tested for repellency against the most important pests of stored maize; the maize weevils and the red flour beetles. 2.5%, 5%, and 10% dosages were applied in 9 cm Whatman number 1 filter paper, with dividing it into three parts. The untreated portion was used as a control, while the neutral was served as the insect release portion. Significantly (P < 0.05) higher percentage weevils and beetles (>55%) repellency was recorded in all M. ferruginea leaf polar solvent extracts applied at rates of 5% and 10%, at 2 days after treatment than nonpolar and partial polar solvent extract treatments, and the untreated check. One hundred percent weevils and beetles repellency were recorded in all M. ferruginea leaf polar extract treatments applied at rates of 10%, at 3 days after treatment. Therefore, the M. ferruginea leaf polar solvent extracts were potent, and they could be used in the management of the maize weevils and the red flour beetles in stored maize, at 5% and 10% dosages, under farmers' storage conditions in Ethiopia. However, the crude extracts effect on a human beings,

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PUBLIC INTEREST STATEMENT

The search for alternative management strategies such as botanicals has been recommended for storage pests' management, due to their adverse effects on the environment, human, and nontarget organisms, among others. Botanicals have been reflected to be harmless, as they pose a negligible influence on the environment and human health, and as they reduce unwanted chemical remains on food grains from insecticides use. Accordingly, recently the species in the genus Milletia, in general, and M. ferruginea, in particular, have been attracting great attention in search of new biologically active phytochemicals against pests. However, a study on the repellency effect of feruginaeMilletia ferruginea on storage weevils and beetles control is lacking in Ethiopia and the potency of this botanical in stored grain protection is yet to be justified. Therefore, this finding confirmed the efficacy of feruginaeMilletia ferruginea leaves solvent extracts in maize weevils and red flour beetles repellency under lab conditions in Ethiopia.
natural enemies, and the cost-effectiveness under farmers' storage conditions needs further study.

**Subjects:** Nutrition; Toxicology; Biology; Entomology

**Keywords:** Botanical; red flour beetles; maize weevils; Millettia ferruginea; repellency; stored maize

1. Introduction

Cereal grains have been playing an imperative role in the diet of resource-poor farmers of Ethiopia (Abebe et al., 2009; Worku et al., 2012). Maize, sorghum, teff, barley, and wheat have been aiding in filling the main nutrient requirement of the country. Among these cereals, maize accounts for the greatest share of the production and productivity nationally. It has unlimited adaption to a wide range of climatic conditions across the country (Abate et al., 2015). It is the cheapest diet source, of the major cereal. Its calorie unit charge per US dollar is two times and one-and-a half lesser than teff and wheat, respectively. It is also a cheap source of protein among cereals, as it delivers 0.2 kg per USD than 0.1 kg of from teff, and 0.2 kg of protein from wheat and sorghum per USD (Rashid et al., 2010). Accordingly, maize has been considered as a vital crop for sustaining the national food security (Abate et al., 2015).

Nevertheless, loss of food grains, including maize due to insect pests during storage has been one of the critical impediments that affects subsistence farmer food security in Ethiopia (Abebe et al., 2009; Hiruy & Getu, 2018; Manandhar et al., 2018; Worku et al., 2012). The maize weevil, Sitophilus zeamais, and the red flour beetle, Tribolium castaneum, respectively, are among the most destructive primary and secondary pests that are responsible for food insecurity rural poor (Hiruy & Getu, 2018; Srivastava & Subramanian, 2016).

Farmers in Ethiopia have been using an array of management practices such as cultural methods, botanicals, and synthetic insecticides, among others, against the storage of insect pests. But, there has been a large dependence upon the use of synthetic insecticides and fumigants. These conventional synthetic chemicals have been often associated with adverse effects such as toxicity on nontarget organisms, environmental pollution, and health risk on man (Karakas, 2016). These conditions of synthetic insecticides have encouraged the search for relatively benign, ecologically sound, and hopeful pest management alternatives such as botanicals (Dubey et al., 2008; Karunarathne & Karunarathne, 2015; Nikkon et al., 2009).

Repellency against insect pests is among the main motives that botanicals have been used traditionally by the farmers under their grain storage. Repellents represent the plants biochemical that push away the insect pests from materials treated against them through motivating the olfactory or other receptors of the insect pests while causing less effect on the environment (Jahromi et al., 2012; Karunarathne & Karunarathne, 2015). Botanicals have been reflected to be harmless, as they pose a negligible influence on the environment, and human health, and as they reduce unwanted chemical remains on food grains that could be resulted from the use of synthetic insecticides (Rajashekar et al., 2012; Talukder, 2006; Talukder et al., 2004). Besides, the various plant part extracts have been used as stored grains insect pest repellant and protectants in diverse areas of the world (Ishii et al., 2010; Karunarathne & Karunarathne, 2015).

Accordingly, phytochemical screening studies associated with the species of Millettia, including *M. ferruginea* have shown that they are a rich source of flavonoids (isoflavonoids, rotenoids, chalcones, and pterocarpons) (Deyou et al., 2015; Deyou & Jang, 2018; Wang et al., 2020) and rotenoids (deguelin, rotenone, and tephrosin) (Choudhury et al., 2015). As a result, former studies have confirmed wide-ranging biological activities of the species of Millettia, such as pesticidal, anti-inflammatory antiviral, bactericidal, and antitumoral activities. Thus, recently the species in the...
genus *Millettia*, in general, and *M. ferruginea*, in particular, have been attracting great attention in traditional medicine and search of new biologically active phytochemicals against pests and disease agents (Mollel & Adema, 2006; Wang et al., 2020). However, a study on the repellency effect of *Millettia ferruginea* on maize weevils and flour beetle management is lacking in Ethiopia and the potency of this botanical in stored grain protection from pests is yet to be justified. Therefore, this study has determined the percent repellency of six solvent extracts *Millettia ferruginea* leaves against the two most vital storage insect pests; *Sitophilus zeamais* and *Tribolium castaneum* under laboratory conditions in Ethiopia.

2. Materials and methods

2.1. The study period
The study was done in between 1 October 2016 to 30 June 2017 in the Insect Science Laboratory of the Zoological Science Department, Addis Ababa University of Ethiopia.

2.2. Mass rearing of the test insects
The maize weevils and the red flour beetle adults were collected from various farmers’ traditional storage facilities of stored maize of the study site (Figure 1) and taken to the laboratory of Addis Ababa University insect science insectary of Zoological science department of Faculty of Life Sciences.

Figure 1. Map of the study site in Hadiya and Silte zones in Southern Ethiopia.
Science, of Ethiopia. Then, the test insects were cultured at 27 ± 3°C and 55–70% RH (Jembere et al., 1995; Zewde & Jembere, 2010). Shone variety of maize grains, the most frequently grown variety of the area, and considered to be susceptible to insect infestation were also acquired from farmers’ storages of the survey site. The grains were kept at −20 ± 2°C for 2 weeks to kill any infesting insects. As adopted by Gemechu et al. (2013) broken grains and rubbishes were removed and the grains were graded manually, where similar-sized grains were selected for the experiment. Fifteen pairs of the adult of the test insects were placed in 12, 1 l glass jars containing 200 g of maize grains as adopted by Zewde and Jembere (2010). The plastic jars were then enclosed with a nylon net and fasten with rubber bands to permit aeration and to avoid the escape of the test insects. After 13 days of oviposition time, the parental insects were sieved out. Then, the jars containing grains and the experimental insects were set aside until the F1 progeny rises under the aforementioned experimental condition. After 30 days, the emerged F1 progeny was sieved out and used for the experiment.

2.3. Identification of the test plant
Plant materials (that are the leaves) (Figure 2) used for the study was collected from natural habitats of the Hadiya Zone of Southern Ethiopia (Figure 1) and the identification of the plant into M. ferruginea (Birbira) species was done at the national herbarium of Life Science Faculty of Addis Ababa University.

2.4. Description of the test plant
According to Jembere et al. (2005) & Getu (2014), Millettia ferruginea (Hochst) Baker (commonly called Birbira in Amharic) (Figure 2) is a large shady tree, which grows up to a length of 35 m, is an endemic to Ethiopia, which broadly grown in between 1000 and 2500 m above sea level elevation. In other words, most parts of Kola and the whole woinadega of Ethiopia are potential areas for M. ferruginea growth. The tree is also commonly named as Sotallo, Katalu, Sari, Yego (in Afan Oromo), Zaghia (in Wolaita), Enghediksho (in Sidama), Dhadhato (in Gedamma) languages (Getahun, 1976), and Belawheka (in Hadiya) languages. Therefore, the habitat of M. ferruginea is rather diverse, as it has an advanced mechanism of minimizing water loss, which enabled it to utilize water in a very conservative manner as demonstrated by Gindaba et al. (2004). As reported by previous researchers, two sub-species of it were known to occur in Ethiopia, and these are M. f. ferruginea which is confined to the northern part of the country, and M. f. darasana which occurs in southern provinces, particularly Sidamo Zone (Getu, 2014; Jembere et al., 2005). The mixtures of the two species are shown in trees from central to western Ethiopia (Jembere et al., 2005). It was also reported that in south-central Ethiopia, including Hadiya Zone M. ferruginea is frequently found in association with some useful annual and perennial crops like maize, sorghum, barley, and coffee, which indicates the usefulness of it in the conservation and improvement of soil fertility and the productivity of traditional farming systems (Negash, 2002).
As demonstrated by Jembere et al. (2005), *M. ferruginea* is the tree with a numerous purposes and is used as tool handles, local construction, firewood, household utensils, and aids as a shade tree in coffee-growing areas. Its yields were applied ere for fish poison, where mature husks and seeds were powdered, and spread on the water surface (Siegenthaler, 1980). It is also used as decorative plants that are planted along roads and in agroforestry. It has a traditional medicinal value in different parts of Ethiopia in different forms to treat some diseases, and skin infections (Mesfin et al., 2009). The roots and seeds of this plant are used as insecticides and pesticides in many parts of the world, and rotenone is responsible for the toxicity (MacLachlan, 2001 as cited in Ameha, 2004). As a result, recently different parts of it have been extracted and the active chemical components have also been screened against different insect pests, including storage insect pests, and have been also indicated potent in their control (Gebre-Selase & Getu, 2009; Getu, 2014; Jembere, 2002; Zewde & Jembere, 2010). However, confirmation of its potency to use in storage pest management under farmers’ storage conditions nationally needs more research effort by concerned bodies.

2.5. Drying and preparation of the experimental plant powder
For two to 3 weeks, the fresh plant leaves were kept under shade in a well-ventilated room and dried (Gebre-Selase & Getu, 2009). The dried leaves were powdered to fine texture using mortar and pestles and sieved to eliminate bigger material (Figure 2) (Jembere, 2002; Tekie, 1999).

2.6. Repellency bio-assay
Repellency test was conducted following the procedures adopted by previous researchers (Talukder & Howse, 1995; Obeng-Ofori & Reichmuth, 1997; Jahromi et al., 2012) using the area preference (A choice bioassay) method. The fine-dried powder of the test plant was diluted with respective solvents (ethanol, acetone, methanol, distilled water) (polar solvents), N-hexane (partial polar solvent), and chloroform (nonpolar solvent) to prepare 2.5%, 5.0%, and 10.0% solutions (Figures 3 and 4). Petridis was divided into three parts, treated portion and untreated portion (3.5 cm each) and neutral center portion (2 cm) as adopted by Amin (2013). In other words, the test procedure consisted of 9 cm Whatman number 1 filter paper that was divided into three halves (Figure 5). Three gram of maize grains were placed in each untreated and treated portion of
Petridis leaving neutral center portion free. With the help of a pipette, 1 ml solution of each plant extract was applied to one-half of the grains, and the other side was left untreated as a control side (Figure 5). The entire-treated halves were then air-dried to allow evaporation of the solvent completely for 30 min. Ten insects were released at the central portion of each Petridis, and then the Petridis were subsequently covered, and they were kept at 25–30°C, temperature, and 65–70%, relative humidity (Jembere et al., 1995; Zewde & Jembere, 2010). The experiment was set up in a
completely randomized design (CRD) in three replications in a factorial arrangement. The insect pests that occurred on the treated (NT) and the control (NC) portion of the discs were quantified after 12, 24, 48, and 72 h, respectively. Percent repellency (PR) was calculated by the formula shown below (Obeng-Ofori & Reichmuth, 1997; Nerio et al., 2009; Jahromi et al., 2012).

\[
PR = \frac{\text{INC-NT}}{\text{INC+NT}} \times 100
\]

where NT was the number of insect pests on the treated portion and NC was the number of insects on the untreated area after the treatment application.

2.7. Data management and analysis

Data on the percentage repellency of the tested plant on the experimental insects were summarized and managed with the Microsoft Excel version 2010. The repellency of M. ferruginea leaves extracts treatments on the test insects were compared using analysis of variance (ANOVA) of the Statistical Program for Social Sciences (SPSS) software version 16.0, followed by Turkey’s studentized (HSD) test for multiple-comparison (P < 0.05). The repellency effect of different treatments of M. ferruginea leaf solvent extracts on the test insects was analyzed using an appropriate statistical method, two-way analysis of variance (ANOVA), and means were compared using Turkey’s studentized (HSD) test at P < 0.05 through SPSS version 16.0 software package in Microsoft Windows 10 operating system. Correlation between the different treatments of the solvent extracts of M.
leaves and the mean percent repellency was determined using Pearson’s correlation of SPSS program of version 16.

3. Result

Percent repellency of the maize weevils and red flour beetles was proportionally increased with an increase in dosage, polarity, and time of exposure of polar solvent extract treatments. *M. ferruginea* leaves. All polar solvent extract (distilled water, methanol, ethanol, and acetone extracts) treatments of *M. ferruginea* leaves applied at all rates had a significant (P < 0.05) effect on percent repellency of the maize weevils and flour beetles in comparison to nonpolar and partial polar solvent extract treatments and the untreated control, at all days after treatment application (Figures 6 and 7). Significantly (P < 0.05) higher percentage repellency of weevils and beetles (>76%) was recorded in all polar *M. ferruginea* leaves solvent extract treatments (distilled water, methanol, ethanol, and acetone extracts) applied at a dosage of 10% at 1 day (24 h) after treatment application than those applied at lower rates (2.5% and 5%). Significantly (P < 0.05) high percentage repellency of weevils and beetles (>55% and >76%, respectively) were also recorded from all polar solvent extracts of *M. ferruginea* leaves applied at a dosage of 5%, at 2 days (48 h) and 3 days (72 h) after treatment application, respectively, than those applied at 2.5% rate. Of which, the higher percentage repellency of weevils and beetles occurred 3 days after treatment application (>60%) than 2 days after treatment application (>55) (Figures 6 and 7).

However, significantly (P < 0.05) higher percentage repellency of the maize weevils and flour beetles (>65%) was recorded from all polar solvent extract treatments of *M. ferruginea* leaves applied at a dosage of 10% at 12 h (half-day) after treatment application as compared to polar

![Figure 7. Percent repellency of red flour beetles due to different solvent extract treatments *M. ferruginea* leaves at 2.5%, 5%, and 10% rates at different hours after treatment.](https://example.com/figure7.png)
solvent extract treatments of M. ferruginea leaves applied at 5%, in which higher percent repellency of weevils and beetles was observed 2 days after treatment. Furthermore, it was also noted that significantly (P < 0.05) higher (>56%) percentage repellency of maize weevils and red flour beetles was recorded from the aqueous extract treatment M. ferruginea leaves applied at a rate 5% and 10% 2 days (48 h) after treatment application in comparison with nonpolar and partial polar solvent extract treatments and the untreated control (Figures 6 and 7).

The efficacy of the tested plant leaves solvent extract treatments applied at different rates on different days after treatment exposure on weevils and beetles percentage repellency was also varied (P < 0.05) significantly within the polar of solvent used for extraction. Significantly (P < 0.05) the highest percentage of repellency maize weevils and flour beetles (>89%) was recorded from all polar extracts of the tested botanical leaves applied at 10% dosages, at 48 h (2 days) after treatment application than at 5% and 2.5% rate. Of which, the maximum percentage repellency of maize weevils and flour beetles was recorded from treatment ethanol extract (>96%), followed by extracts in acetone (>93%) methanol (>92%), and distilled water (>89%) in general. Furthermore, 100% repellency of maize weevils and flour beetles was recorded in all polar extract treatments of M. ferruginea leaves applied at rates of 10%, at 3 days (72 h) after treatment (Figures 6 and 7).

The correlation among the treatments of solvent extracts of the tested plant leaves, and the percentage repellency of maize weevils were found to be highly significant (P < 0.01) and strongly negative. The correlation among the treatments the tested plant leaves applied at different rates, and percent repellencies of red flour beetles was also found to be highly significant and strongly negative (Tables 1 and 2).

4. Discussion
The present study revealed that all polar solvent extracts of the tested botanical leaves applied at all rates had caused significant (P < 0.05) effect on percent repellency of maize weevils and red flour beetles at all dates after treatment application in comparison to nonpolar and partial polar solvent extract treatments and the untreated control. This suggests the presence of more polar solvent-soluble volatile phytochemicals in leaves of M. ferruginea, which are responsible for higher percentage repellency of weevils and beetles, and as most of them might probably be polar, i.e., polar flavonoids and rotenoids, among others. Accordingly, phytochemical screening studies associated with the species of Millettia, including M. ferruginea have shown that they are a rich source of flavonoids (isoflavonoids, rotenoids, chalcones, and pterocarps) (Deyou et al., 2015; Deyou & Jang, 2018; Wang et al., 2020) as well as rotenoids (deguelin, rotenone, and tephrosin) (Choudhury et al., 2015). Besides, former studies have confirmed wide-ranging biological activities of the species of Millettia, such as pesticidal, anti-inflammatory antiviral, bactericidal, and antitumoral activities. (Mollel & Adema, 2006; Wang et al., 2020). The extractive capability of phenolic and

| Table 1. Correlation among percent repellency efficacy determining parameters of M. ferruginea leaves solvent extracts on maize weevils |
| Solvent extracts | Rates | Time after treatment | Repellency |
|------------------|-------|----------------------|------------|
| Solvent extracts | 1     | 0.00                 | 0.00       | -0.62** |
| Rates            | 0.00  | 1                    | 0.00       | 0.52** |
| Time after treatment | 0.00 | 0.00                 | 1          | 0.24** |
| Repellency       | -0.64** | 0.58**      | 0.24**     | 1        |

Correlation coefficients with two asterisks (**) represent highly significant association at P values < 0.01 (2-tailed) and those without asterisk are nonsignificant.
flavonoid components from plant materials was also reported to be significantly dependent on the type of solvent used and the extracts gotten by great polarity solvents were shown to be substantially extra effective fundamental scavengers than those via less polarity solvents, in a study done in two varieties of young ginger (Ghasemzadeh et al., 2011). And consequently, these scholars suggested that active compounds with different polarities might be found in plant material parts (Ghasemzadeh et al., 2011).

In similar manner, it was suggested that the active ingredients in the leaf extract of the plant reside in the polar fractions indicating that the active principals are polar in nature after studying castor bean plant against ectoparasites of animals (Amante, 2016). It was also indicated that high Z. subfasciatus mortality was caused by M. ferruginea water extract that probably might be due to the presence of high water-soluble chemicals in the seeds of it (Jembere et al., 2005). It was also shown that the strongest repellent effect of methanol and acetone solvent extract treatments of M. viridis and O. gratissimum on C. maculatus suggests that solvents methanol and acetone appeared to be more effective in extracting bio-active compound/s the two plants out of four tested plants (Karunaratne & Karunaratne, 2015). It was also indicated that methanol, an aqueous, and ethanol extracts all the botanicals leave tested (Euphoria balsamifera, Lawsonia inermis, Mitracarpus hirtus, and Sena obtusifolia) had repellent potential against adult Sitophilus zeamais in stored sorghum (Suleiman et al., 2018). It was indicated that the Milletia genus alone contains more than 25 flavonoids, 50 isoflavonoids, 12 chalcones, and various compounds and rotenone are one of the foremost active biochemical found in M. ferruginea (Jembere, 2002).

According to the current study, significantly (P < 0.05) higher percentage repellency of weevils and beetles (>76% and >55%, respectively) was recorded from all polar M. ferruginea leaves solvent extract treatments (distilled water, methanol, ethanol, and acetone extracts) applied at a dosage of 10% and 5% at 1 day and 2 days after treatment application, respectively. Similarly, Karunaratne and Karunaratne (2015) also indicated a significantly higher percent repellency of methanol, acetone, and ethanol extracts of M. viridis and O. gratissimum against C. maculatus. Several previous researchers have also been reported the repellent, insecticidal, or antifeedant, and development inhibiting effects of various plant parts, and their products on S. zeamais and T. castaneum with varying degrees of success (Amoh-Amoah, 2010; Arannilewa et al., 2006; Asawalam et al., 2006; Jahromi et al., 2012; Katamssadan, 2016; Lale, 2002; Muchiri, 2017; Nukenine et al., 2011; Tripathi et al., 2009; Udo, 2005).

In the present study, the percentage repellency of maize weevils and red flour beetles was increased proportionally with the increase in dosage, polarity, and time of exposure of polar solvent extract treatments. In line with this finding, different earlier researchers also indicated that percent repellency increase with increased dosage, after testing solvent crude extracts of different botanicals against storage pests such as S. zemains, T. castaneum, and C. maculatus.
According to the present study, the percent repellency of the tested botanical leaves crude extract treatments on maize weevils and red flour beetles was also varied (P < 0.05) significantly within the type of solvent used for extraction; the highest being in ethanol extracts, followed by extracts in acetone, methanol, and distilled water. Consistently, Jembere (2002) also indicated that water extracts of M. ferruginea were the third effective, following acetone and ethanol extracts on maize weevils at 3 days after treatment application. Congruently, it was also indicated that the toxic effects of the plant extracts against the maize weevils, among other storage pests, varied with the kind of solvent extract-treated (Fredrick, 2012).

The highest repellency of botanical leaves solvent extracts in ethanol in the present study might also be probably due to its broad solubility properties of organic compounds of the tested botanical in it. Similarly, Koffi et al. (2010) also shown that ethanol extracts were found to be more effective than aqueous extracts of the same plant in general, as a result of the higher solubility of organic compounds in ethanol. It was also reported that ethanol is an accepted solvent for contact application, as a result of its wide-ranging solubility properties, among the different solvents (water, acetone, and petroleum ether, among others) that were used for plant part extract preparation (Amoh-Amoah, 2010).

The great repellent potential of M. ferruginea leaves polar solvent extracts applied at rates of 5% and 10% on maize weevils and red flour beetles at 2 days after treatment application in the current study might probably be the result of the synergism of some or all of these active volatile plant phytochemicals on olfaction of the experimental insects that forced them to repel away from the different treatments. Nevertheless, screening of the most contributors for such a repellency requires more investigation. Consistently, phytochemical screening studies have shown that M. ferruginea is a rich source of flavonoids (isoflavonoids, rotenoids, chalcones, and pterocarpans) (Deyou et al., 2015; Deyou & Jang, 2018; Wang et al., 2020) as well as rotenoids (deguelin, rotenone, and tephrosin) (Choudhury et al., 2015). Formerly studies have also confirmed wide-ranging biological activities of the species of Millettia, including M. ferruginea such as pesticidal, anti-inflammatory antiviral, bactericidal, and antitumoral activities (Mollel & Adema, 2006; Wang et al., 2020). It was also indicated that plant essential oils and/or solvent extracts contain several phytochemicals, and the repellency to insects is typically enhanced by the synergistic effects of the individual components on them (Zhang et al., 2013). Likewise, plants were revealed to be a principal basis of bioactive phytochemicals, with an exhibition of repellent, toxicant, and antifeedant effects on a variety of field and storage insects (Jahromi et al., 2012). And therefore, their extracted produces have been considered as alternative options for controlling insect pests (Tripathi et al., 2009).

The great repellency of M. ferruginea leaves polar solvent extracts (especially aqueous extracts which are cheap and safe) applied at rates of 5% and 10% on maize weevils and red flour beetles at 2 days after treatment application was observed in the present study. This might have vital implications to use them on the management of storage insect pests of stored maize, particularly the maize weevils and red flour beetles in Ethiopia. Accordingly, previous studies have shown that M. ferruginea is a rich source of flavonoids (isoflavonoids, rotenoids, chalcones, and pterocarpans) (Deyou et al., 2015; Deyou & Jang, 2018; Wang et al., 2020) as well as rotenoids (deguelin, rotenone, and tephrosin) (Choudhury et al., 2015), and it has been confirmed to play wide-range of biological activities, such as pesticidal, anti-inflammatory antiviral, bactericidal and antitumoral activities (Mollel & Adema, 2006; Wang et al., 2020). Similarly, many of the plant crude extracts and their constituents have been proven to be less toxic, biodegradable, noneco-pollutant, safe, and selective pest management options (Aryani & Auamcharoen, 2016; Erdogan et al., 2012; Pugazhvendan et al., 2009). It was also indicated that sustainable use of botanicals with pesticide property will lead to enhancement the food security, especially in areas where the use of synthetic pesticides for pest control is
risk full and uneconomic (Ogendo et al., 2003; Qwarse, 2015). Similarly, it has been indicated that plant crude extracts and essential oils are potent for use in the protection of field and storage pests, as they possess various secondary metabolites such as monoterpenoids, diterpenoids, and sesquiterpenoids among others, which displayed repellent, feeding, and oviposition deterrent, ovicidal, larvicidal, adulticidal antifeedant, and toxicant effects (Aryani & Auamcharoen, 2016; Ishii et al., 2010; Isman, 2006; Kedia et al., 2015; Masika et al., 2008; Rozman et al., 2007).

The susceptibility of insect pests to repellency of crude solvent extracts of botanicals depends on the chemical nature of the plant’s secondary phytochemicals found on them. Consequently, the repellency and/or toxicity effect of one crude solvent extract in a given insect pest can be less visible upon the other (Regnault-Roger et al., 1993; Weaver et al., 1991). Such differences in insect pest’s reactions to plant defense phytochemicals have directed to a general concept of insect-plant interaction and the associated co-evolution between them (Feehery, 1990; Fredrick, 2012). Accordingly, the vulnerability of the maize weevils, and the red flour beetles to the volatile secondary metabolites of a crude solvent extract of the tested plant leaves in the current study, might probably be due to the absence of co-evolutionary interaction of the tested insect pests with the repellent components of the crude plant leaves solvent extract. As both the maize weevils and the red flour beetles have been mostly restricted to the stores since the time of man started storing food grains, which is also consistent with reports of previous scientists (Fredrick, 2012; Ryan & Byrne, 1988).

5. Conclusion
Among different the tested plant leaves solvent extracts for repellency against maize weevils and red flour beetles in the current study, ethanol extracts were the first effective, acetone extracts were the second effective, methanol extracts were the third effective and water extracts were the fourth effective. This suggests the likelihood of applying these solvents in plant extract preparation for evaluating repellency, toxicity, and screening phytochemicals, among others on the maize weevils and flour beetles, among others. Besides, the effectiveness of water extracts also ensured that the water extracts of the tested plants leaves at 5% and 10% rates could be used by resource-poor farmers for the management of the maize weevils and the red flour beetles under traditional storage condition in Ethiopia. Since the preparation of crude extract by water is cheap and easy, safe, and environmentally sound.

The current study also justified that the vulnerability of the maize weevils and the red flour beetles to the volatile secondary metabolites of a crude solvent extract of the tested plant leaves could probably be due to the absence of co-evolutionary interaction of the tested insect pests with the tested plant, as both the maize weevils, and the red flour beetles have been mostly restricted to the stores.

The great repellent potential of *M. ferruginea* leaves polar solvent extracts at a rate 5% and 10% on the experimental insects, at 2 days after treatment in the current study also assured that the presence great possibility for utilizing of this plant specie as grain protectant against storage insects under resource-poor farmers traditional storage condition in sub-Sahara Africa, in general, and Ethiopia, in particular. Thus, the solvent extracts at the aforementioned dosages can be recommended for managing the tested weevils and beetles on stored maize grain under farmers’ storage conditions in Ethiopia and elsewhere with similar environmental conditions. Nonetheless, the effect of these crude extracts on human beings, natural enemies, and cost-effectiveness under farmers’ storage conditions need further study before the extensive implementation of the outcomes of this study.

**Acknowledgements**
We authors sincerely thank Arba Minch University and Zoology Department of Addis Ababa University for their financial support to conduct the study.

**Funding**
The authors received funding from Arba Minch University and Zoology Department of Addis Ababa University for this research.
Hiruy & Getu, Cogent Food & Agriculture (2021), 6: 1860562
https://doi.org/10.1080/23311932.2020.1860562

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Data availability statement
Data is available within the article on its last pages.

Competing interests
The authors declare no competing interests.

Author statement
This manuscript describes original work that has not been published elsewhere and is not under consideration by any other journal.

Authors’ contributions
The first author was responsible for searching literature reviews, planning, writing up preparation, and standardization of the paper. The second author also contributed to the preparation and standardization of the manuscript. Both authors contributed equally to the preparation of the manuscript and approved the final manuscript for publication.

Ethical statement
This study does not involve any human or animal testing.

Citation information
Cite this article as: Milletia ferruginea extracts on maize weevil and red flour beetles repellency; an implication to use them in storage pest management in Ethiopia, Berhanu Hiruy & Emano Getu, Cogent Food & Agriculture (2021), 6: 1860562.

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