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REVIEW ARTICLE

A REVIEW ON INVASION AND MANAGEMENT OF FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*) IN NEPALKushal Naharki^a, Sabina Regmi^b, Niruta Shrestha^a^a Institute of Agriculture and Animal Science, Lamjung Campus, Tribhuvan University, Nepal.^b Institute of Agriculture and Animal Science, Paklihawa Campus, Tribhuvan University, Nepal*Corresponding Author Email: kushalnaharki@gmail.com

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ABSTRACT

Nepal faces a significant risk of invasive species posing a direct threat to food security and native biodiversity. With the potentiality of causing a considerable loss in yield and quality, invasive pest species can lead to significant damage in the Nepalese agricultural sector. Fall armyworm is a polyphagous, transboundary invasive pest that invaded Nepal in August 2019. They have a wide host range, the potentiality to establish rapidly and are highly migratory. Maize is the major host of fall armyworm which comes second in terms of production and area cultivated in Nepal. Spread and establishment of this pest are enhanced during the monsoon season of the country with favorable climate and temperature. This review presents an introductory pathway of the invasive pest, biology, lifecycle, status, and management of fall armyworm in Nepal. Integrated pest management can be the best approach for the management of this pest. Control of this invasive pest requires early monitoring, scientific research, and management strategy with awareness, knowledge, and technical support to Nepalese farmers.

KEYWORDS

Fall armyworm, invasive pest, introductory pathway, integrated pest management, Nepal.

1. INTRODUCTION

Invasive Alien Species (IAS) is the non-native organisms introduced knowingly or accidentally which affects ecology, economy, and health (Meyerson and Reaser, 2003). They can result in yield loss affecting food security. IAS causes a decline in local species, biodiversity, and distinctiveness (Kohli et al., 2004; Abrol and Shankar, 2012). They are intensified with climate change and other human activities like travel, international trade, and pollution (CBD, 2007; Howard, 2019). Invasive species are considered the second greatest threat to local species after the destruction of habitat (Park, 2004). Increasing global trade, change in land-use patterns, and climate change have enhanced the invasion of IAS in developing nations like Nepal (Thapa et al., 2018).

Fall Armyworm (FAW), *Spodoptera frugiperda* is a lepidopteran insect native to tropical and subtropical regions of the Americas (Bateman et al., 2018). It was reported as an invasive pest in West Africa in early 2016 and is cosmopolitan in distribution by now. The invasion of FAW predominantly occurs in the warmer region with its presence regulated by climate, temperature, and precipitation (Goergen et al., 2016; Early et al., 2018). Maize strain and rice strain are the two different genetic strains of FAW with maize strain being more prevalent (Frerot et al., 2017). FAW is a migratory polyphagous pest with a wide range of hosts. It feeds on leaves and stems of more than 350 plant species belonging to 76 plant families including maize, rice, millet, and vegetable crops causing severe damage (Pogue, 2002; CABI, 2020). It can quickly multiply, spread, and establish itself in new regions. FAW moth can fly 100 km per night and has several generations per year (Rice, 2017).

Invasion of IAS in Nepal is a challenging problem in biodiversity conservation, agriculture production, and food security. Among countries threatened by IAS, the agriculture sector of Nepal is ranked third as Nepal is highly reliant on the import of agricultural products, seeds, and goods (MoFSC, 2014; Paini et al., 2016). The risk of invasive pests like FAW can result in a considerable loss in agricultural production and its damage is further increased by a lack of awareness of the severity of the pest problem. FAW was reported in August 2019 in Nepal after it invaded India during the mid-year of 2018 (NPPPO, 2019). The environmental condition in Nepal is favorable for its establishment and spread. Maize is the most preferred host crop of FAW which is in the second position in terms of production and area in Nepal (MoALD, 2018).

The rapid invasion of the FAW in Nepal has resulted in a serious threat to Nepalese food security with considerable yield losses in maize and other key staple cereal crops. FAW is a voracious pest that can cause significant damage to the crops and their yield by feeding on both vegetative and reproductive structures. It can cause a 100 percent loss of maize crops in Nepal when lacked proper management (Beshir et al., 2019). Prevention of introduction, control, or eradication of IAS with appropriate measures is necessary. Integrated pest management (IPM) is considered as the best approach for the management of FAW (Day et al., 2017). IPM strategy includes combinations of various control methods available locally with cultural control, biological control, and safer use of pesticides to manage the pest. Entomopathogens and biopesticides are also getting popular as management options these days.

Knowledgebase, research activities, and management strategy on Invasive pests in Nepal are scanty and limited (Shahi, 2016). FAW can cause severe

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effects on developing countries like Nepal which lacks awareness, study and research work, expertise, insufficient resources, and technical support for their management (Shrestha, 2016). This review has been conducted to understand the invasion of FAW in Nepal. It focuses on the introduction pathway, current status, biology, lifecycle, threat, and damage of FAW. Control and prevention measures to minimize the loss by FAW with sustainable management options have also been identified.

2. MATERIALS AND METHODS

A thorough search of the literature and data for relevant works was performed. The relevant information related to the pathway of invasion, current status, biology, lifecycle, and management of FAW were obtained from the thorough study of journal articles, research papers, reports, and books. The data for the invasion of FAW in Nepal were acquired from FAW reports of Centre for Agriculture and Bioscience International (CABI), Food and Agriculture Organization (FAO), Ministry of Agriculture and Livestock Development (MoALD) Nepal and Plant Quarantine and Pesticide Management Centre (PQPMC) Nepal. An extensive study was carried out to assess the threat of FAW in Nepal and management for Nepalese farmers.

3. RESULT AND DISCUSSION

3.1 Invasion of Pest

3.1.1 Invasive pests in Nepal

Nepal has great diversity in geography, temperature, and climate which makes it a suitable habitat for organisms from different parts of the world. The biological invasion has raised problems in biodiversity conservation, agricultural production, and ecosystem services in Nepal (PQPMC, 2019). Invasive pests can result in reduced production and income which increases risk in the economy, food security, and native biodiversity. It possesses a huge threat but is among the neglected topics in the country (Shrestha, 2016). There is a need to conduct detailed study and research activities about the status and impacts of invasive pests with the increasing threat of invasive species like FAW in Nepal. From a survey of invasion of pests and pathogens in 124 countries, Nepal was found to be among the top 10 nations in the world threatened by IAS to the agriculture sector in proportion to its gross development product (Paini et al., 2016). A total of 69 alien species of fauna have been reported in Nepal among which 20 species are of insects (Budha, 2014).

Table 1: List of important invasive pests introduced in Nepal

Common Name	Scientific Name	Year of Introduction
African Giant Land Snail	<i>Achatina fulica</i>	1930-1940
San Jose Scale	<i>Quadraspidiotus perniciosus</i>	1962
Potato tuber moth	<i>Phthorimaea operculella</i>	1966
Chinese citrus fly	<i>Bactrocera minax</i>	2014
Tomato Leaf Miner	<i>Tuta absoluta</i>	2016
Fall armyworm	<i>Spodoptera frugiperda</i>	2019

Source: Plant Quarantine and Pesticide Management Center (PQPMC), 2019

3.1.2 Pathway of invasive pest introduction

The main phases of invasion of IAS include an introduction, establishment, and spread (Darrigran et al., 2015). IAS may be introduced intentionally as biological control insects or maybe unintentional which is driven by global trade, tourism, and travel, also known as '3T' which results in movement of pests across different regions (McNeely et al., 2001). IAS may lack natural predators and control measures in new environments making a suitable environment for their establishment, abundance, and spread. IAS are known to compete, prey, and infect local species after the introduction which results in loss of food, income, and disturbs the local ecological process. The introduced species should be able to establish, reproduce, and spread under the favorable condition in the new environment. Invasion of alien species will be harder to control or reverse as they are likely to enhance with an increase in climate change, human activities, and trade (Howard, 2019). Open border with India, increasing global trade, and high import makes Nepal more susceptible to the introduction of IAS. Nepal has an extremely higher rate of import with an import-export ratio of 11 (Shrestha et al., 2017). Article 8(h) of the Convention on Biological Diversity (2007) calls the nation to thoroughly prevent, control, and eradicate IAS with potential threats and damage.

Figure 1: Stages of Invasion of species (Source: Adopted from Stages in the invasion process of a nonnative species - Darrigran et al., 2015)

First confirmed reports of FAW invasion were from West Africa in early 2016 and the presence of FAW was rapidly followed by spread throughout sub-Saharan Africa and recently southeastern Asia (Goergen et al., 2016; Nagoshi et al., 2020). It has now reached above 109 countries globally. FAW has already been reported in Bangladesh, India, Nepal, and Sri Lanka in southern Asia. It was first detected in India in 2018 with causing significant loss to farmers in Karnataka and other Southern Indian states in the month of May 2018 (Sharanabasappa et al., 2018). With the morphological and molecular diagnosis of the pest, reported the detection of FAW from the Nawalpur district of Nepal in May 2019 (Bajracharya et al., 2019). FAW is known as 'American FaujiKira' and 'Michaha Faujikira' in the Nepali language.

Figure 2: Geographic distribution of FAW by year of introduction (Source: Food and Agriculture Organization (FAO), 2020)

3.2 Biology of FAW

The lifecycle of FAW consists of egg, six to seven larval instars, pupa, and adult. It can complete its lifecycle in about 30 days which can extend up to 60 to 90 days when the temperature drops down (CABI and FAO, 2019). Biology of FAW first reported in Nepal were similar to the findings and resembled with FAW molecular analysis from various part of parts (Sharanabasappa et al., 2018; Bajracharya, 2019). The identification features of FAW according (Prasanna et al., 2018; Sharanabasappa et al., 2018; CABI, 2020):

Egg: Eggs are creamy white, dome-shaped, and have a flattened base. They have a diameter of 0.4 mm and a height of 0.3 mm. The color of the egg changes to dark up to the stage of hatching. The favorable temperature is 20-30 °C. FAW lays its eggs in clusters on the underside of the leaf typically near the base of the plant, close to the junction of the leaf and the stem. They are covered with protective scales rubbed off from the moths' abdomen. FAW moth can lay over 1500 eggs in her lifetime.

Larvae: Larvae is the destructive stage of the FAW. Larval development occurs between 28- 30 °C. They have a biting mouthpart that damages the crop. FAW larvae pass through six different instars, with each instar differing to some extent in physical form. The mature caterpillar is about 1.5-2.0 inches in length. Newly hatched larvae are greenish during the first two instars. They turn brown to black from third to the sixth instar. Dark head with an inverted Y-shaped mark is observed in the sixth instar stage. A distinct pattern of four “dots” is also seen on the eighth abdominal segment.

Pupa: Pupa is an oval-shaped reddish-brown in color with a size of 14 to 18 mm in length and 4.5 mm in width inside 20-30 mm in length cocoon. FAW pupates underground soil up to 2-8 cm deep with the formation of a cocoon under a suitable temperature of 13-16 °C. Cocoon is formed by tying together particles of soil with silk. If soil is hard for penetration, the caterpillar will cover itself in leaf debris.

Adult: They possess two antennae in their head. They have forewings which are grey and brown in color. The female moths are larger than the male. Distinct triangular white spots can be observed in male moths at the tip and center of the forewings. They have a wingspan of 32-40 mm and can travel long distances being mostly active in the evening. Female moths can fly and migrate 500 km before oviposition.

Figure 3: Lifecycle of FAW (Source: Adopted from CABI, 2020)

3.3 Damage of FAW in Nepal

FAW has a high preference for the plants belonging to the Poaceae family with feeding being more active during the night (Bessin, 2004). *Agrostis spp.*, *Digitaria spp.*, *Cyperus spp.*, *Amaranthus spp.* are the major weed hosts of FAW (Prasanna et al., 2018). A group researchers reported that FAW can attack in every developmental stage of Maize if proper precautions and control measures aren't applied (Tambo et al., 2020). FAW causes severe leaf feeding damage as well as direct injury to the ear. Serious damage is observed when the leaf whorl is destroyed. At the later phase of development stages, FAW larvae also can feed on the tassels, burrow into the cobs and destroy the kernels.

Information on climate and temperature thresholds of pests is important for predicting their distribution and damage. A group researcher also predicted that Southeast Asia has a good climate for the invasion of FAW (Early et al., 2018). A group researcher observed the growth of FAW at different temperature ranges and found that the optimal temperature range for the development of FAW from egg to adult was found to be between 26 °C and 30 °C (Du Plessis et al., 2020).

The minimum temperature was recorded at 13.01 °C for egg development, 12.12 °C for larvae, and 13.06 °C for pupae below which growth and development of the insect stop. Pogue (2002) found FAW to be more destructive from June to August when the minimum average temperature exceeds 10 °C. FAW usually appears in the areas with forest cover, the annual temperature of 18-26 °C, and rainfall of 500-700mm (Early et al., 2018). The average temperature of the hilly region of Nepal is 28 °C in the summer and late spring with 80% of the rainfall occurring from June to September (Baral, 2020). Maize is mainly grown in the summer season in Nepal. Thus, temperature and climate during pre-monsoon, monsoon, and post-monsoon are more suitable for FAW development in Nepal.

Figure 4: Environmental Suitability of FAW in Nepal (Source: Fall armyworm environmental suitability maps, CABI, 2018)

FAO has placed Nepal under an immediate threat to food security due to the loss caused by FAW (FAO, 2020). The most preferable host of FAW is maize which is the major crop grown in the mid-hill of the country where there can be a high rate of food insecurity due to its invasion. Maize is cultivated in the 900,288-ha area of Nepal with the production of 1,300,121 MT and is the second most important crop of Nepal after Rice (MoALD, 2018). Hybrid varieties of maize like Rampur hybrid-4, Rampur hybrid-6, Arun 3, 4, and 6 are recommended for different parts of Nepal. Bessin found that late-planted and hybrid varieties are more susceptible to infestation by FAW (Bessin, 2004). The location-specific study is required to study the impacts of FAW in different parts due to variable climate, geography, and crops of Nepal (GC et al., 2019).

90 tonnes of maize grown on 30 hectares of land is destroyed in Kumakh Rural Municipality-1 and its surrounding villages with a total of 2,450 hectares of maize field in Banke district being destroyed by FAW this year (Maharjan, 2020). The severity of damage is more likely to increase in different mid-hill districts of Nepal with the spread of this invasive pest. A group researcher estimated that FAW can cause a loss of about one-third of maize crops to farmers (Groote et al., 2020). FAW causes serious damage by feeding on the ears of maize and also causes a dead heart by feeding the maize plants through whorl. Larvae feed on the maize whorl, ears, and tassel reducing the yield and quality (Capinera, 2017). It can also cause exposure to cob which can cause infection by other microorganisms which can result in total damage of the maize and loss of the yield. Such damage also can increase the mycotoxin risk like aflatoxin with the infestation through mycotoxin producing fungi (FAO, 2020). A group researchers estimated a 21 to 53 % loss in the annual production of maize (Abrahams et al., 2017). In case of minimal damage too, the estimated loss of maize will be more than 460,024 MT productions with 180,057 ha of area field affected in the case of Nepal.

3.4 Management of FAW

The management of IAS can be challenged by knowledge, political and cultural barriers (Mack et al., 2000). Resistance varieties, intercropping, plant diversity, and integrated pest management should be promoted to control the pest (Day et al., 2017). National Biodiversity Strategy and Action Plan 2014-2020 has targeted for impact assessment and biological control of IAS to address its emerging threat in Nepal (MoFSC, 2014). The maize production system in Nepal is diverse varying with geography, climate, season among small landholding farmers which requires an integrated approach of pest management. Pesticides used in pest management result in pollution, health hazards, and impacts non-target organisms (FAO, 2018). Management options that are ecofriendly, sustainable with lower risks should be preferred (Bateman et al., 2018). IPM includes effectiveness, ecofriendly, less health hazardous, and economical ways for crop protection.

Identification, monitoring, and prevention play an important role in the control of the FAW population. IPM approach to control FAW includes an integrated approach including host plant resistance, biological methods, cultural methods, suitable doses of pesticides which reduces the negative impacts on non-target organisms and controls the pest effectively (Prasanna et al., 2018). Using the combination of various control activities, IPM is suitable and eco-friendly approach to manage FAW. Regular monitoring, early warning, and preparation with scouting and application of IPM measure early help to reduce the loss and outbreak of the pest.

3.4.1 Monitoring and Prevention Methods

Monitoring and prevention of pests is an effective method to control the spread and establishment of FAW. Prediction of infestation time and assessing the severity helps in the timely management of the invasive pests. Monitoring, surveillance, and scouting is an important step in implementing IPM strategy (Prasanna et al., 2018). Light traps and pheromone traps can be used for the monitoring and collection of moths (Gebreziher, H. and Gebreziher, J., 2020). Constant surveillance and scouting can be done killing larvae and moth manually in the field. A group researchers suggested seed treatment with Imidacloprid 48% F.S. 4 m.l. per kg of seed and selection of varieties with husk covering the full maize cob for the prevention of FAW in Maize in Nepal (Rajbhandari et al., 2019).

3.4.2 Cultural Methods

Cultural practices help in reducing pest population and preventing damage encouraging healthy growth of plants and appropriate agronomic practices. Timely sowing or early of the crop helps in reducing FAW infestation. Pupae harboring in soil can be destroyed with deep plowing and exposure to the sun. Monocropping increases the pest problem which can be decreased with intercropping with leguminous crops. Maize should be intercropped with black gram and mung (Rajbhandari et al., 2019). Improved agronomic practices with quality seed, recommended doses of fertilizer application, mixed and intercropping rather than sole cropping, crop rotation and mulching helps reduce the infestation of the pest (Harrison et al., 2019).

Push and pull strategy are getting popular as the cultural method of FAW control. Napier grass (*Pennisetum purpureum*) or Brachiaria grass can be planted as attractant trap crops and Desmodium grass (*Desmodium spp.*) as repellent plants (Khan et al., 2018). FAW collected in the trap crops can be killed spraying insecticides. A group researchers found a higher yield of 2.7 times with reductions of 82.7% of larvae per plant and 86.7% in plant damage per plot adopting climate-adapted push and pull strategy (Midega et al., 2018).

3.4.3 Biological Methods

Natural Enemy: Natural enemies of the pest are available in the field or can be imported to control the invasion of the pest. Predators, parasitoids, and pathogens can be used as a natural enemy for the biological control of the pest. Predators eat pests as their prey. Ladybird beetles, earwigs, predatory bugs, soil surface beetles, and ants can be used as Predators for the control of FAW (FAO, 2018). Parasitoids kill its host by feeding them. A group researchers suggested using *Telenomus remus* for the augmentation of parasitoids against FAW (Kenis et al., 2019). Pathogens like viruses, fungi, bacteria, nematodes, and protozoa act as biological control agents by causing the infection.

Table 2: Biological control agents used for FAW management		
Type	Life Stage	Natural Enemy
Predators	Larvae	<i>Calleida decora</i> , <i>Calosoma alternans</i> , <i>Calosoma sayi</i>
	-	<i>Carabidae</i> , <i>Doru luteipes</i> , <i>Doru taeniatum</i> , <i>Ectatomma ruidum</i> , <i>Geocoris punctipes</i> , <i>Steopolybia pallipes</i> , <i>Podisus maculiventris</i>
Parasitoid	Egg	<i>Telenomus remus</i> , <i>Trichogramma achaeae</i> , <i>Trichogramma chilotraeae</i> , <i>Trichogramma pretiosum</i> , <i>Trichogramma rojasi</i>
	Larvae	<i>Archytus incertus</i> , <i>Campoletis flavicincta</i> , <i>Cotesia marginiventris</i> , <i>Cotesia ruficrus</i> , <i>Euplectrus platypenae</i> , <i>Glyptapanteles creatonoti</i> , <i>Lespesia archippivora</i>
	Eggs/Larvae	<i>Chelonus curvimaculatus</i> , <i>Chelonus insularis</i> , <i>Microchelonus heliopaie</i>
	Larvae/Pupa	<i>Archytus marmoratus</i>
Pathogens	Larvae	<i>Bacillus cereus</i> , <i>Bacillus thuringiensis</i> , <i>Bacillus thuringiensis alesti</i> , <i>Bacillus thuringiensis darmstadiensis</i> , <i>Bacillus thuringiensis thuringiensis</i> , <i>Bacillus thuringiensis kurstaki</i> , <i>Granulosis virus</i> , <i>Nucleopolyhedrosis virus</i>
	Egg/Larvae	<i>Beauveria bassiana</i> , <i>Metarhizium anisopliae</i>

Source: Natural enemies of FAW, CABI (2020)

Biopesticides: Biopesticides based on bacteria *Bacillus thuringiensis* (Bt), fungi, and baculovirus are found to be effective against FAW (FAO, 2018). Virus based insecticides *S. frugiperda* multiple nucleopolyhedrovirus (SfMNPV) is specific to FAW only (CABI, 2020). Neem based pesticides are also found to be highly effective against FAW (Constanski et al., 2016). Many botanicals like Neem are locally available in Nepal which has high efficacy against pest. A group researcher reviewed potential biopesticides for the management of FAW where biopesticides containing Pyrethrins, Bt, spinosad, and neem were found to be used mostly (Bateman et al., 2018). There are 12 registered biopesticides in Nepal among which found neem-based pesticides and Bt to be most effective for FAW management (GC et al., 2020).

3.4.4 Chemical Control

Chemical control methods are used as the last option during IPM when there is severe damage by the pest or have been infested by a large population. Alternated application of contact/systemic insecticides based on pyrethroids, carbamates, or organophosphates is recommended for the chemical control of the pest (Evans, 2017). A group researcher in their extension pamphlet on American Fall Armyworm management in the Nepalese maize field suggested the measures for direct control for the FAW (Rajbhandari et al., 2019). Organic insecticides like *Bacillus thuringiensis* (Bt) can be used at 2 gm per liter water to control the pest. Spinetoram (11.7% SC) 0.5 ml or Chlorantraniliprole (18.5% SC) 0.4 ml or Spinosad (45% SC) 0.5 ml or Emamectin Benzoate (5%SC) 0.4 gm per liter water can be spread on the infested maize field to manage the FAW using chemicals. According to WHO, Bt, Spinetoram, and Chlorantraniliprole fall under U group which are not hazardous in normal use and Spinosad fall under III group which are less hazardous. Thiamethoxam (12.6% SC) with lambda cephalothin (9.5% SC) 0.5 ml per liter can be spread in severe conditions. Emamectin Benzoate, Thiamethoxam with lambda cephalothin falls in group II by WHO which are moderately hazardous with a wetting period of 7 to 10 days.

3.4.5 Management Efforts in Nepal

FAW is likely spread across different parts of Nepal affecting many farmers cultivating maize which requires a coordinated effort of farmers, extension agencies, researchers, and government. Identification, early detection, and eradication with strengthening the capacity of farmers, availability of technical support and resources, assessment of impact, and management is necessary for regions with a higher possibility of spread. Cost-effective and eco-friendly management of the pest should be encouraged. Research activities for effective management of the pest in the country are required. Information, awareness, and control strategies should also be made available at farmers level for the management of the pest.

National Plant Protection Organization (NPPO) is coordinating the initiative to manage FAW under MoALD. MoALD Nepal has formed a special task force to fight against the FAW invasion and spread. Scientists at the International Maize and Wheat Improvement Center Nepal have been working with public and private partners before and after the invasion of the FAW in Nepal (Pradhan, 2020). It is also evaluating IPM strategies and the efficacy of push-pull cropping systems to control FAW in Nepal. Awareness pamphlets and leaflets of photo guide, lifecycle, and management strategies of FAW has been developed by CABI in Nepali language (CABI, 2020).

4. CONCLUSION

FAW are migratory pests with a wide host range and can complete their lifecycle in 30 days in favorable conditions. It has invaded Nepal in August 2019 and is likely spread and establish in different parts of Nepal upon favorable climatic conditions and temperature in monsoon season. Nepal is highly susceptible to invasive pests due to high import, international trade, and lack of proper policy for monitoring and its management. Invasive pests like FAW can be devastating and create a considerable loss in the quality and quantity of agricultural production threatening the food security of the nation. The government should implement policies related to pest quarantine, research activities, education, and management practices for farmers. FAW has a high potential to cause damage to maize production in different districts of Nepal. Scouting, effective monitoring, and preventive measures of the pest in the potential risk areas with immediate preparedness and actions are essential. Capacity building of farmers with awareness, technical support is necessary with a coordinated approach of the local government, extension agencies, and farmers. IPM strategy is considered as the best option to manage this pest. IPM approach combining various control measures available locally should be adopted by the farmers to sustainably manage FAW.

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