Location and Planting Date Influenced Fall Armyworm Infestation and Maize Yield in the Guinea and Sudan Savanna Zones of Ghana

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ABSTRACT

Maize production in Ghana faces significant yield losses due to fall armyworm (FAW) infestations. This study evaluated the impact of planting dates and location on FAW infestation and maize yields in the Guinea and Sudan savanna zones of Ghana. Using a split-plot design, the effects of location and Planting date were evaluated across three locations, namely Damongo, Nyankpala, and Manga, under both early and late planting dates during the 2023 season. There were significant differences observed due to the interaction between location and Planting date on Larvae count, Leaf damage, plant and ear height, and grain yield. The interaction effect of location and Planting date revealed that early planting recorded the highest FAW infestation and damage in Nyankpala and the lowest in Damango. The low pest pressure in Damongo supported vigorous plant growth and the highest yields (4,252 kg/ha), while heavy FAW infestation and damage in Nyankpala resulted in stunted growth and poor yields (2,235 kg/ha) in the early planting date. During the late planting date, observations indicated that pest infestation and damage were reduced in Damongo and Manga, but infestation persisted in Nyankpala. Despite this, Nyankpala achieved the highest late-planting yield (3,372 kg/ha), while Damongo saw reduced yields (1,304 kg/ha). The superior yield performance in Nyankpala can be attributed to an interaction between the crop's growth stage at the time of the pest attack, its inherent physiological resilience, and the favorable environmental conditions that supported recovery and grain filling. The significant difference in FAW infestation and grain yield observed across planting dates and locations demonstrates that agroecological conditions and seasonal stress factors strongly influenced yield. These results emphasize the need for location-specific planting schedules to mitigate fall armyworm damage and improve maize yields.

Keywords: Fall Armyworm, Location, Planting Date, Maize Yield in Ghana, Guinea and Sudan Savanna Zones

INTRODUCTION

In Ghana, the maize crop has over one million hectares under cultivation and contributes 50-60% of the nation's overall cereal yield (Adu *et al*., 2023). Its importance to Ghana's economy is clear, as it significantly boosts food security and alleviates poverty, especially in rural communities. With Ghana's expanding population, maize plays a crucial role in meeting the country's food security needs. Despite the economic advantages of maize cultivation, the farms in Ghana produce some of the lowest yields in the world (MOFA, 2021). Although Ghana has the potential to produce an average of 5.50 Mt/ha of maize per hectare, the country has only achieved 46% (2.53 Mt/ha) of this capacity (Agriculture in Ghana, 2022). This is also far below the potential yield of 4-6 Mt/ha achieved in on-station trials (Uzun *et al*., 2021). The primary challenge for maize cultivation in the country is the invasive pest known as the fall armyworm (*Spodoptera frugiperda*) (Banson *et al*., 2020). In 2017, it was projected that the FAW outbreak could potentially lead to a 45% yield reduction in Ghana's maize production, resulting in a revenue loss of approximately US$284.4 million (Rwomushana *et al*., 2018). Since the emergence of the fall armyworm in 2016, Ghana has relied heavily on chemical pesticides as the primary approach to managing it (Tambo *et al*., 2023). However, continuous chemical spraying can

have negative environmental consequences, including soil and water pollution. Pesticide use may also harm non-target beneficial insects and disrupt local ecosystems (Abrahams *et al.*, 2017). Unintended consequences of pesticides in the air, soil, and water can negatively impact soil and aquatic life and non-target organisms, such as natural enemies, ultimately disrupting ecosystem function (Aktar *et al.*, 2009). Various environmental factors are significant in determining the population of pests and the extent of damage caused by them. Therefore, knowledge about the influence of weather on the seasonal incidence and population dynamics of pests in varied tropical ecological zones is important in developing a suitable, sustainable pathway to manage the pest. Considering the above facts, the present study sought to investigate the effects of planting dates and location on fall armyworm infestation and yield.

MATERIALS AND METHODS

2.1 The study locations

The study was conducted in 2023 at three experimental stations of CSIR-SARI, namely, Nyankpala, Damongo, and Manga. Nyankpala is located in the Tolon district of Northern Ghana with latitudes 9°15′–10°02′ N, and longitudes 0°53′–1°25′ W. The area has a tropical climate with maximum temperatures during the day of approximately 45°C (March-April) and a minimum of 12°C at night (December-January). Humidity ranges from 95% during the night to 70% during the day. Rainfall is unimodal, from April/May to October, averaging 1,157 mm per annum (Akrofuom District Assembly, 2021).

Damongo is located in the West Gonja district, it is the regional capital of the Savanna Region, with geographical coordinates of 9° 5′ 0″ N, 1° 49′ 0″ W. The district's yearly temperature is 31.12ºC (88.02ºF) and typically receives an average annual precipitation of 1144mm, beginning in late April to late October. The peak of rainfall is in June/July, with a prolonged dry spell in August (Ghana Statisical Service (GSS), 2014).

Manga is located in the Binduri District of the Upper East region with geographical coordinates of latitude11°01'00.2"N (11.0167300°) and longitude 0°16'01.5"W (-0.2670800°). The mean rainfall ranges between 950mm to 1,200mm per year. The highest day temperatures are generally recorded in March and April and can go up to 45°C, while tnhe lowest night temperatures of around 12°C have been observed in December and January. The humidity levels between April and October are generally high at night and fall during the day (G.S.S, 2014).

2.2 Land Preparation and Planting

For each planting date, each genotype was planted in two rows per plot, with each row measuring 5 meters. An inter-row spacing of 75cm and an intra-row spacing of 50cm were used. The same plot size and planting spacing were maintained across all locations. The first and second planting was done on 13/07/2023 and 27/07/2023, respectively. A maximum of 3 seeds were planted per hill and later thinned to 2 plants per stand at two weeks after emergence.

2.3 Experimental design and treatments

The experiment was conducted under natural fall armyworm infestation conditions at the three study locations, employing a split-plot design (SPD) that incorporated two experimental factors: location (Nyankpala, Manga and Damongo) and planting date (Early and Late). Location was considered the main plot factor whiles planting date was the subplot factor. There were three replications or blocks in a trial.

2.4 Data collection

Data collection commenced two weeks after planting. 20 plants were randomly selected from each plot and tagged for observation and data collection in all trial fields. Data was collected on plant stand, plant height, flowering, plant and ear height, stem and root lodging, husk cover, plant and ear aspect, ear rot, foliar damage, number of plants infested by FAW, FAW adult moths, FAW larvae count, FAW egg masses, and yield-related data such as field weight, grain weight, grain moisture, and kennel damage by FAW (Adu *et al.*, 2021; Nboyine *et al.*, 2022).

2.5 Data analysis

Data was analysed using GenStat statistical software (12th edition) for ANOVA. Data parameters such as Larvae count, Adult moth population, egg masses, Plant and Ear height were transformed using Logarithmic (Log 10) Transformation method. The least significant difference (LSD) and Standard error of means (SEM) at 5% were used to separate treatment means that were significantly different (Lü *et al*., 2024; Nboyine *et al*., 2022). Correlation analysis was performed using GenStat statistical software (12th edition) to assess the relationships between fall armyworm damage, grain yield, and selected parameters such as anthesis, silking, plant height, ear height, leaf damage, egg mass, larval count, and adult moth.

RESULTS AND DISCUSSION

3.1 Egg masses

The interaction between planting date and location had a highly significant effect (P < 0.001) on the number of fall armyworm egg masses observed at 4 and 6 weeks after planting (WAP) in the three study locations. At 4 WAP, egg masses were most abundant in Nyankpala during early planting, while Manga recorded the highest numbers under late planting. In contrast, Damongo had no egg masses at either planting date. However, by 6 WAP, Damongo experienced a sharp increase in egg masses, whereas Nyankpala and Manga recorded lower counts across both planting dates (Table 1).

Table 1: Variation in Egg mass due to the interaction effect of planting date and location at 4WAP and 6WAP

Planting date	Location	4WAP	6WAP
Early Planting	Damongo	0.00	0.952
	Manga	0.095	0.690
	Nyankpala	1.548	0.190
Late Planting	Damongo	0.00	1.286
	Manga	0.476	0.262
	Nyankpala	0.095	0.167
P-value		**<0.001**	**<0.001**
LSD		**0.270**	**0.277**

3.2 Larvae count

The interaction between location and planting date had a significant effect on fall armyworm larval population. The interaction revealed that Nyankpala experienced early and persistent larval infestation from 2 to 6 weeks after planting under both planting dates. In contrast, Damongo and Manga recorded delayed infestations, with larval numbers increasing at 4 WAP and 6 WAP, respectively (Table 2).

Table 2: Variation in larvae count due to the interaction effect of location and planting date at week 2, 4 and 6 WAP

Location	2WAP		4WAP		6WAP	
	Planting dates					
	EP	LP	EP	LP	EP	LP
Damongo	0.00	0.00	0.00	0.57	1.67	3.12
Manga	0.00	0.00	0.00	0.00	10.74	6.17
Nyankpala	2.86	8.67	11.69	0.45	2.07	0.31
P-value	**0.001**		**0.001**		**0.001**	
LSD	**0.71**		**0.97**		**0.99**	

NB: WAP=weeks after planting, EP= Early Planting, LP= Late Planting

3.3 Adult moth

The interaction between location and planting date was highly significant at both 4 and 6 WAP (P < 0.001). At 4WAP, adult moth populations were notably higher in Nyankpala during the early planting date, but lower during the late planting date. However, at 6WAP, early planting in Nyankpala witnessed a sharp increase in adult moth numbers, but were not observed during the late planting regime. In Damongo, adult moths were predominantly observed at 6 WAP in both planting dates, while in Manga, they appeared at 4 WAP under both planting regimes. These results suggest that the timing and intensity of adult FAW moth presence vary across locations and are influenced by planting date (Table 3)

Table 3: Variation in the number of FAW adult moths at 4, and 6 WAP due to the interaction effects of location and planting date.

Location	Planting dates			
	4WAP		6WAP	
	EP	LP	EP	LP
Damongo	0.00	0.00	0.69	1.524
Manga	0.429	0.452	0.00	0.00
Nyankpala	1.143	0.286	1.786	0.00
P – value	**<0.001**		**<0.001**	
LSD	**0.278**		**0.445**	

NB: WAP=weeks after planting, EP= Early Planting, LP= Late Planting

3.4 Leaf damage

The interaction between location and planting date had a highly significant impact on fall armyworm leaf damage (P<0.001). The location x planting date interaction revealed that leaf damage was highest in Nyankpala, followed by Manga, with Damongo recording the lowest leaf damage in both planting dates. Early planting in Damongo and Manga resulted in higher leaf damage compared to the late planting date. Comparatively, Nyankpala recorded higher leaf damage ratings compared to Damongo and Manga; however, there were no significant differences in leaf damage scores observed in Nyankpala between the early and late planting dates (Table 4).

Table 4: Variation in FAW damage on leaf due to the interaction effect of Location and Planting date at 2, 4, 6 and 8 WAP

FAW damage score								
Location	2WAP		4WAP		6WAP		8WAP	
	Planting dates							
	EP	LP	EP	LP	EP	LP	EP	LP
Damongo	0.00	0.00	0.05	0.00	0.21	0.07	2.048	1.548
Manga	0.4	0.02	0.41	0.10	0.42	0.24	2.595	2.262
Nyankpala	0.33	0.47	0.50	0.53	0.51	0.55	3.452	3.595
P-value	**0.001**		**0.001**		**0.001**		**0.010**	
LSD	**0.02**		**0.03**		**0.06**		**0.302**	

NB: WAP=weeks after planting, EP= Early Planting, LP= Late Planting

The fall armyworm infestation was observed early in Nyankpala at 2, 4, and 6 WAP, indicating the presence of favorable environmental conditions that supported the early growth and spread of the FAW pest, potentially leading to a significant number of egg masses laid on plant leaves. Fall armyworm damage was consistently higher in Nyankpala as a result of the early presence of adult FAW moths and early egg masses on leaves, resulting in early heavy infestation, suggesting that higher larval infestation in the early growth stage could result in higher damage to leaves. In a related study, Mbaidiro *et al*., (2023) found that increased FAW

infestation led to significant leaf damage, which negatively impacted maize growth and yield. In contrast, larval infestation in Damongo emerged at week 4 and Manga at week 6, suggesting that conditions during the early season in these areas were unsuitable for early infestation. Damongo and Manga experienced lower leaf damage scores as a result of the late infestations. These results agree with the findings of Harrison *et al.,* (1984), who reported that maize infested early with FAW suffered more damage compared with those infested at a later phenological stage. Severe defoliation frequently delays the plant's developmental timeline, as resources are redirected towards the recovery and regeneration of damaged tissues, delaying the transition to reproductive stages. Van Antwerpen, (2019) reported significant damage to maize during the vegetative stage caused by FAW, as the early growth phases were more appealing and suitable for FAW larvae feeding.

Larvae numbers were observed to be high in Nyankpala in the early planted maize, probably because early planted maize appears to be the only food source available for the first generation of FAW (Mbaidiro *et al*., 2023). However, early-planted maize experienced poor yields in Nyankpala, where FAW infestation and damage were observed to be high. This finding aligns with Kandel and Poudel, (2020), who reported higher FAW damage due to high infestation at the early planting resulting in lower yields. But differs from Sowmiya *et al*., (2022), who reported that earlier maize planting resulted in lower FAW damage and higher grain yield. Similarly, research by Nyabanga *et al*., (2021) showed that early planting reduces FAW infestations in maize crops in Zimbabwe.

The late planting regime witnessed a reduction in larval numbers across all trial fields. This had subsequently led to reduced leaf damage in Damango and Manga in the late planting date. However, there was no significant difference in damage ratings in Nyankpala for both early and late planting dates. Reduction in larvae numbers at the late planting date could have been influenced by the availability of abundant food from other sources for the FAW in the later part of the season (Mbaidiro *et al*., 2023). Reduced larva numbers and infestations could also be influenced by the different environmental conditions that are unfavorable to the pest populations in the three locations. Factors such as temperature, rainfall, and humidity can influence pest population dynamics in the environment. Temperature results from the three experimental sites showed a drop in average minimum and maximum temperatures in the month of August in all three locations, which may have influenced larval numbers in the fields to drop. In a related study, it was reported that Cooler temperatures affect FAW reproductive processes, while warmer temperatures can accelerate FAW development, leading to more rapid population increases (Barfield *et al*., 1978). Suggesting that the low larval population in the late planting date may have been influenced by lower temperatures in the study areas. The month of August was also the peak month of heavy rainfalls across all locations of the experiment. This may have a negative influence on larval numbers, considering the higher quantum precipitation and higher rain days that were recorded within the month of August. Harrison *et al*., (2022) reported that delaying planting may result in pest population buildup coinciding with periods of heavy rainfall, which can reduce infestation levels by naturally washing away larvae or causing egg mortality. Similarly, the presence of natural enemies such as parasitoid wasps, tachinid flies, and ants may have contributed to the reduction in egg masses and larval populations in the maize fields, as these organisms are natural enemies of the fall armyworm (Koffi *et al.,* 2020). These findings indicate that the effects of location and planting dates on FAW infestation and leaf damage may be geographically dependent, reflecting how local environmental conditions influence the severity of attack. By adjusting planting schedules to align with local conditions and avoid peak FAW activity, farmers can minimize crop damage and optimize yields across different planting dates and locations

3.5 Days to 50% Anthesis and Silking

The interaction between location and planting date on days to 50% anthesis was highly significant (P < 0.001) (Table 5). In the early planting date, days to 50% anthesis occurred earlier in Damongo and later in Manga. Similarly, during the late planting date, anthesis occurred earlier in Nyankpala and Damongo but was delayed in Manga. Across locations, anthesis was earliest in Damongo, followed by Nyankpala, and Manga with the latest. A similar trend was observed for days to 50% silking, where the interaction between location and planting date was also highly significant (P < 0.001) (Table 5). During the late planting date, silking occurred earlier in Nyankpala and later in Manga, whereas in the early planting date, it occurred earlier in Damongo and was delayed in Manga. Among the locations, silking occurred earliest in Damongo, followed by Nyankpala, with Manga recording late silking.

Table 5: Variation in the number of days to 50% Anthesis and Silking due to Location and Planting date interaction effect

| Location | Planting dates | | | |
| | Days to 50% anthesis | | Days to 50% silking | |
	Early Planting	Late Planting	Early Planting	Late Planting
Damongo	47.90	46.33	49.64	48.88
Manga	58.19	59	62.81	61.98
Nyankpala	54.95	46.12	56.88	48.60
P-value	<.001		<.001	
LSD	1.59		1.79	

3.5.1 Anthesis

Silking and anthesis are two crucial stages in the reproductive cycle of many plants, particularly in crops like maize, whose yield is significantly influenced by silking and anthesis. Days to 50% anthesis were influenced significantly by the interaction effect of Location and Planting date.

Early planting date resulted in early days to anthesis in Damongo. These findings contradict that of Sangoi *et al*., (2002) who observed that early-planted maize required an additional 5-10 days to achieve 50% anthesis compared to late-planted maize, primarily due to reduced thermal accumulation. The early days to 50% anthesis in Damongo may have influenced the high grain yield produced in Damongo whiles late anthesis influenced lower yields in Nyankpala and Manga during the early planting date. Edmeades *et al*., (1999) found that early anthesis genotypes had 10-15% higher yields under drought conditions due to earlier maturity. Kamara *et al*., (2003) noted that early-flowering maize in West Africa produced more stable yields because it benefited from optimal water availability during the grain-filling stage.

Late planting in Nyankpala resulted in Early days to 50% Anthesis, taking approximately 46 days in Nyankpala. Suggesting that Late planting of maize in Nyankpala may accelerate growth and hasten the transition to reproduction, enabling the plant to complete its life cycle within a shortened growing season. This adaptation helps the plant mature before facing unfavorable conditions, such as drought or cooler temperatures (Zhao *et al*., 2016). In some cases, stress from late planting, such as limited water availability, higher temperatures, or reduced light duration, can trigger the plant to flower early. Early planting, however, led to a delayed number of days to reach 50% anthesis in Nyankpala. These findings align with the study by Nielsen *et al*., (2018), who reported that the number of days to flowering decreases with delayed planting but increases with early planting.

3.5.2 Silking

Days to 50% silking were influenced by the interaction effect of Planting date and Location. Early planting date resulted in early days to 50% silking in Damongo and more days to silking in Manga and Nyankpala. Days to silking were consistent with days to 50% anthesis in Damongo, suggesting that there is a higher chance of successful pollen and silk receptivity, thereby reducing kennel abortion and increasing yields. Early silking and anthesis allow maize to complete grain filling before late-season drought, minimizing yield loss (Cairns *et al*., 2013).

Early planting in Manga and Nyankpala resulted in a higher number of days to 50% silking. Late silking consistently reduces maize yield due to pollination failures, stress susceptibility, and disease risks (Li & Xu, 2025). Late silking also increases the anthesis-silking interval (ASI), leading to pollen scarcity when silks are receptive, causing kernel abortion (Bolaños and Edmeades, 1996). Pollination failures and other abiotic stressors may have influenced the lower yields in Nyankpala and Manga in the early planting date. Late planting date, on the other hand, recorded earlier days to 50% silking in Nyankpala and Damango, and later days in Manga. This has significantly influenced higher yields in Nyankpala, but do not significantly influenced yields in Damongo during the late planting date.

3.6 Plant height, Ear height, and Ear rot

A significant interaction (P<0.001) was observed between location and planting date on plant height. The interaction between planting date and location revealed that early planting resulted in the tallest plants, with an average height of 192 cm in Damongo, followed by 153 cm in Manga. However, Nyankpala recorded the lowest plant height (136 cm) in early planting dates (Table 6). A similar trend was observed in the late planting date, where Damongo produced the highest plant height and Nyankpala the lowest. During the early planting date, the tallest ear heights were observed in Damongo, while Nyankpala recorded the shortest. Similarly, in the late planting period, Damongo produced the tallest ear heights, with Nyankpala again recording the shortest (Table 6). Overall, ear height was consistently higher in Damongo and lower in Nyankpala across both early and late planting dates. Additionally, the highest ear rot scores were recorded for plants planted during the late planting period across all three locations, while the lowest scores were observed in the early planting date (Table 7).

Table 6: Variation in plant and ear height due to the Interaction effect of location and planting date

Location	Planting dates			
	Plant height (cm)		Ear height (cm)	
	Early Planting	Late Planting	Early Planting	Late Planting
Damongo	192	172	87.95	67.33
Manga	153	138	64.52	58.9
Nyankpala	136	137	55.45	54.43
P-value	<0.001		<0.001	
LSD	8.12		5.15	

Table 7: Variation in ear rot in maize due to the interaction effect of Planting date and location.

Planting dates	Location		
	Damongo	Manga	Nyankpala
Early Planting	0.09	0.12	0.01
Late planting	0.38	0.16	0.18
P-value	<0.001		
LSD	0.07		

3.6.1 Plant height

The interaction effect of location and planting date was observed to have a significant influence on plant height. Comparatively, plants in Damongo and Manga recorded taller plants, and Nyankpala with the shortest plants in both planting dates. The shortest plants in Nyankpala may be attributed to early and sustained fall armyworm (FAW) infestation during the plant's vegetative stages in Nyankpala for both planting dates, resulting in severe defoliation of leaves affecting plant photosynthesis and limited soil nutrient uptake, ultimately hindering plant growth. Abang et al.,(2024) reported that plants exhibit more vigorous growth in the absence of lepidopteran feeding on plant leaves; however, leaves damaged by fall armyworm during the vegetative growth stage can lead to stunted plant growth. Fall armyworm infestation and damage occurred later in Damango and Manga for both early and late planting dates. This delay likely allowed for rapid growth during the vegetative stages in these locations. Furthermore, adequate soil moisture, plant nutrient uptake, and efficient sunlight capture may have supported robust growth and development, resulting in taller plants in Damango and Manga.

In a related study, it was observed that early planting increases plant growth while delayed planting reduces crop growth and development, as the plants captured less solar radiation from emergence to the silking stage during the late planting period (Cirilo & Andrade, 1994). Several other factors such as rainfall and temperature, may also have influenced plant height. Damongo recorded the highest quantum and number of rain days during the experimental year, which could also be a factor for higher plant height. Anandhi et al., (2020) reported that high frequency of rainfall reduces larval infestation and leaf defoliation, leading to rapid plant growth and

development. Balla *et al*., (2020) reported that sufficient rainfall during the vegetative growth period can result in robust plant growth and higher yields.

3.6.2 Ear heights

Ears positioned higher above the ground are less exposed to soil moisture, lowering the risk of fungal infections like ear rot. Additionally, they are less accessible to pests such as rodents and ground-dwelling insects, which can cause damage to the ears. Ear heights in the early planting window were the tallest, reaching 87.95 cm in Damango, 64.52 cm in Manga, and 55.45 cm in Nyankpala. In contrast, the late planting window recorded lower average ear heights of 67.33 cm, 58.90 cm, and 54.43 cm in Damango, Manga, and Nyankpala, respectively. These results show that the early planting produced taller ears than the late planting in all three locations. In a similar study, it was reported that maize planted early benefits from extended daylight hours, enhancing photosynthetic activity and vegetative growth, which results in taller plants and higher ear placement (Tollenaar and Aguilera, 2015). However, late-planted maize frequently faces elevated temperatures and water stress, which can inhibit growth and limit internode elongation, resulting in shorter plants with lower ear placement (Zhang *et al*., 2019).

3.7 Grain yield

The interaction between location and planting date had a significant effect on grain yield (P < 0.001). In Damongo, early planting led to higher grain yields, whereas Nyankpala achieved maximum yields under late planting. In contrast, Nyankpala recorded the lowest yield during early planting, while Damongo had the poorest performance under late planting. However, no significant yield difference was observed in Manga between early and late planting dates (Table 8).

Table 8: Variation in grain yield due to the interaction effect of Planting date and location.

Location	Grain yield (kg/ ha)	
	Planting dates	
	Early planting	**Late planting**
Damongo	4252	1304
Manga	2697	2071
Nyankpala	2235	3372
P-value	**<0.001**	
LSD	**385.8**	

The interaction between location and planting date had a significant effect on grain yield. The highest yield was recorded in Damongo under early planting (4252 kg/ha), outperforming Manga (2697 kg/ha) and Nyankpala (2235 kg/ha) under the same planting date. In contrast, under late planting, the highest yield was observed in Nyankpala (3372 kg/ha), followed by Manga (2071 kg/ha), while Damongo recorded the lowest yield (1304 kg/ha). This suggests that the L x PD interaction favored Nyankpala under late planting conditions and Damongo under early planting date. Early planting in Damongo resulted in higher yields, possibly because larval infestation occurred later and leaf damage was minimal. These results align with Darshan and Prasanna, (2024) study, where early-sown maize yielded more grain due to reduced FAW damage. Sowmiya *et al*., (2022) also observed that early planting led to lower FAW infestation and better yields than late planting.

The late infestation and larval damage may have allowed for uninterrupted vegetative and reproductive growth, resulting in taller plants and higher yields in Damongo. Early silking and anthesis in Damongo further supported timely pollination, contributing to improved grain yield. Additionally, abundant rainfall and frequent rain days in Damongo (Supplementary figure 1) provided adequate water for plant growth and kernel formation, while continuous rainfall likely reduced pest populations. Conversely, the reduced yield observed in Nyankpala with early planting may be attributed to the intense larval infestation and significant leaf damage experienced during the early growth stages. These stress factors likely disrupted both vegetative and reproductive development, resulting in shorter plants and lower yields. Additionally, the delayed anthesis and silking recorded in the early planting window may have led to pollination challenges, further reducing kernel

development and overall productivity. The late planting date yielded higher grain production in Nyankpala but produced the lowest yield in Damongo. Despite substantial leaf damage in Nyankpala during late planting, its grain yields surpassed those in Damongo and Manga, where infestation and damage were comparatively lower. The high yields recorded from the late-planted maize in Nyankpala, despite severe FAW-induced leaf damage, can be attributed to the interaction between the crop's growth stage, its physiological resilience, and favorable environmental conditions. Several studies indicate that yield loss from Fall Armyworm damage is largely determined by the crop's developmental stage at the time of attack, with the greatest losses occurring when larvae feed on maize during its early, sensitive growth stages (Prasanna *et al*., 2018). In this regard, the peak damage for the late-planted crop in Nyankpala was at 8 weeks after planting, a time when the plants were well-established and closer to tasseling. This indicates that late infestations may coincide with the reproductive stage (silking or grain filling) of maize, during which time leaf damage has limited impact on yield (Chisonga *et al*., 2023). Moreover, the shorter anthesis-silking interval in late-planted maize supports efficient pollination even in the face of leaf damage, reducing the associated yield losses compared to early-planted maize that often experiences heat or drought stress (Edreira *et al*., 2018). A similar study conducted by Baudron *et al*., (2019) in Zimbabwe determined that the effect of FAW on grain yield is strongly dependent on rainfall and noted that the highest losses were experienced in fields characterized by both FAW infestation and drought conditions. To this end, late-season rains in Nyankpala may have furnished the essential water and nutrients required to realize the potential benefits of metabolic repair processes in the plant. Baudron *et al*., (2019) further confirmed that yield loss due to FAW is not directly proportional to the visually assessed leaf damage, especially in the case of late-season attacks during the late vegetative growth stages and when plants have ample resources to support their recovery processes. These findings further suggest that an effective FAW management strategy must ensure optimal growing conditions, which can reduce the impact of late-season FAW attacks on grain yield.

CORRELATION ANALYSIS

Significant negative correlations were observed between FAW damage and yield across both early and late planting dates in Nyankpala (r = -0.60), Damongo (r = -0.64), and Manga (r = -0.64), negative correlations were also observed between FAW damage and plant height, ear height, and number of adult moth population across all locations of the experiment. Conversely, there were significant positive correlations between FAW damage and larva count in Nyankpala (r= 0.69), Damongo (r= 0.70), and Manga (r= 0.70). Other parameters, such as Days to 50% anthesis and silking, also showed significant but lower positive correlations with FAW damage (Table 9).

Table 9: Correlation analysis between FAW damage and other parameters measured in the study

| Parameters | Fall armyworm Damage in EP and LP of the three Locations | | | | | | | | |
| | Damongo | | | Manga | | | Nyankpala | | |
	Early planting	Late planting	Across EP and LP	Early planting	Late planting	Across EP and LP	Early planting	Late planting	Across EP and LP
Egg mass	0.31***	0.29**	0.30***	0.28**	0.31***	0.29***	-0.12	-0.10	-0.11
Larvae count	0.71***	0.69***	0.70***	0.69***	0.72***	0.70***	0.68***	0.71***	0.69***
No. of adult moth	-0.06	-0.04	-0.05	-0.07	-0.04	-0.06	-0.05	-0.03	-0.04
Plant height	-0.42***	-0.39***	-0.40***	-0.38***	-0.41***	-0.39***	-0.35***	-0.37***	-0.36***
Ear height	-0.84***	-0.81***	-0.82***	-0.81***	-0.83***	-0.82***	-0.77***	-0.76***	-0.75***
Anthesis	0.27***	0.24**	0.26***	0.24**	0.27***	0.25***	0.26**	0.29***	0.28***
Silking	0.25**	0.22*	0.23***	0.22*	0.25**	0.23***	0.24**	0.26**	0.25***
Grain yield	-0.66***	-0.63***	-0.64***	-0.63***	-0.65***	-0.64***	-0.60***	-0.61***	-0.60***

EP =Early planting LP =Late planting, * = significant at 5% probability level, ** = significant at 1% probability level, and ***=significant at 0.1% probability level

Strong positive correlation was observed between fall armyworm damage and larvae count across all three locations and planting dates. Suggesting that higher larval numbers have a strong positive influence on the rate of leaf damage on maize. The correlation matrix also revealed a strong negative correlation between FAW

damage and grain yield in Nyankpala (r = -0.60), Damongo (r = -0.64), and Manga (r = -0.64). This suggests that as fall armyworm damage increases, grain yield decreases significantly. These findings are in line with Baudron *et al*., (2019), who emphasized that pest pressure, particularly at the larval stage, negatively affects resource allocation to grain formation, which ultimately affects overall yield potential. Across locations, FAW damage exhibited a negative correlation with plant height and ear height, indicating an inverse relationship between FAW damage and plant and ear height. As FAW damage increases, plant height and ear height growth decrease, suggesting that fall armyworm larvae damage interrupts normal vegetative and reproductive growth patterns of maize in all the study locations. A study by Lima *et al*., (2010) reported that fall armyworm feeding affects plants' vigor and development, most especially during vegetative and reproductive growth stages. Comparatively, ear heights recorded a stronger and highly negative correlation with FAW damage in all locations than plant height.

Anthesis and silking timing also exhibited lower correlation with FAW damage in Damongo, Manga, and Nyankpala locations. This implies that delayed flowering may be associated with increased FAW damage, which may be a result of prolonged vegetative phases, leading to an increasing vulnerability of maize plants (Nielsen *et al*., 2018) . Adult moth counts in the three locations are consistently not correlated or weakly negatively correlated with fall armyworm damage, which is likely because adults do not cause leaf damage directly to plants, and their presence may not accurately reflect larval presence. Egg mass exhibited a moderate positive correlation with FAW damage in Damongo (r = 0.30) and Manga (r = 0.29) but with a weak negative correlation in Nyankpala (r = -0.11). Moderate positive correlation suggests that high egg masses count resulted in an increased FAW leaf damage in Damongo and Manga. However, since the correlation is not strong (r < 0.5), other factors such as plant resistance, natural enemies, or environmental conditions may have an impact on damage levels. In contrary, Hruska, (2019) revealed that egg masses on leaves are not always a reliable predictor of leaf damage by fall armyworm. Additionally, the weak negative correlation in Nyankpala implies that higher egg masses were weakly associated with less FAW damage, which is contrary to expectations.

CONCLUSION

The study assessed how location and planting date affect fall armyworm infestation, damage, and maize yield. The study concludes that location-specific planting schedules, such as early planting (Early July) for Damongo and late planting (Late July) for Nyankpala, are crucial for reducing FAW impact and improving maize yield in the Guinea and Sudan zones of Ghana. This strategy can be combined with other FAW control measures to further reduce FAW damage and enhance maize productivity.

LIMITATIONS OF THE STUDY

This study was undertaken in a single cropping season in just three locations within Guinea and Sudan savanna zones of Ghana. Given this, the results may not provide an accurate representation of the seasonal differences or the general ecological heterogeneity over maize-producing regions of Ghana, especially over the Guinea and Sudan savanna zones of northern Ghana. Furthermore, the focus of data collection was at the plot level, which could fail to reflect situations in farm-managed plots in which input usage variation, pest and disease control strategies, and resource availability could affect outcomes.

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