Evaluation of sustainable management options for the fallarmyworm*Spodopterafrugiperda*(Lepidoptera: Noctuidae) in maize production in Burkina Faso

Abstract

The fallarmyworm, *Spodopterafrugiperda*, attacks important cereals, such as corn, millet and sorghum, causingeconomic damage. It ishas been a new bioticconstraint to African agriculture sinceitinvaded the African continentin 2016.Reported in Burkina Faso in2017, itispresent in all regions of the country, causingsignificant damage to cerealcrops. Facedwiththisthreat, farmers have opposedseveral control methods, includingmainlysyntheticchemical pesticideswith all the consequencesthatthis entails. Withthis in mind, an evaluation of severalsustainable management options for thisinsectpestwasinitiated in Bama in western Burkina Faso during the consecutivedry and wetseasons of 2023. For thispurpose, a completelyrandomized block design was set up. It consisted of four treatments, T0=absolute control; T1=combination Push-pulltechnology-*Jatropha curcas*oil; T2=combination Push-pull technology-*Azadirachta indica*oil; T3=combination Push-pull technology-Emamectin benzoate. Four replicateswereused. Data werecollected by random sampling on twentymaize plants in eachelementary plot. Resultsshowedthat the different*S. frugiperda* management options reducedsignificantlypest damage rates: T3 (28% dry season, 34.50% wetseason), T1 (41.88% dry season, 47.64% wetseason) and T2 (37.88% dry season, 45.38% wetseason) comparedwith the control (66.38% dry season, 59.75% wetseason). The best yieldswerealsorecordedwith management options T1 (3.52t/ha), T2 (3.73t/ha), and T3 (3.57t/ha) for the dry season and T1 (2.91t/ha), T2 (3.26t/ha) and T3 (3.34t/ha) for the wetseason and were not significantlydifferent.

The Push-Pull-Emamectinoption isrecommended to Burkina Faso farmersfor the control of the FallArmyworm.

Key words: Burkina Faso, Maize, pesticides, *Spodopterafrugiperda*, Push-pull

Introduction

Cerealproductsplay a major role in human and animal nutrition worldwide. In 2019, maizerepresented the world's second most important cereal in terms of production, with 1,148,487,000 tons, or 12.27% of production, ahead of wheat (8.18%) and paddy rice (8.07%) (FAOSTAT, 2021). In Africa, maizemaintainsits second-place ranking in terms of quantityproducedamongcereals, with 81,891,000 tons out of a total of 946,111,000 tons, or 8.66% of the continent'scereal production (FAOSTAT, 2021). In 2021, South Africacontributed 1.34% to global maize production, according to a survey by the USDA Foreign Agricultural Service.

In Burkina Faso, maizeranked first (19.87%) in cereal production in 2019, ahead of paddy rice (4.38%) (FAOSTAT, 2021). Withcereal production estimated at 5,763,232 tons on an area of 4,275,072 ha in 2021, maizeranked second in terms of area (28%) aftersorghum (42%) (DGESS, 2021). This production satisfies a significant proportion of the country'smaizefoodrequirement, but stillneeds to beincreased to takeintoaccount the needs of industry and livestock (Dao et al., 2015). Unfortunately, maize production faces enormousdifficultiesincludingunfavorable agro-climatic conditions, insecure land tenure, difficulties in accessing finance,insufficient agricultural inputs and someherbivorouspestssuch as *Spodopterafrugiperda*Smith,whichcommonlyknown as the fallarmyworm (FAW). FAWis a polyphagousinsectknown for itswithgreatcapacity to spread, multiply and destroy cropswhich can feed on over 350 plant species (Montezano, 2018).

Of these host plant specieslisted by Montezano et al. (2018), 30% belong to the Poaceae. Despitethisbroad host range, the mostregularlyimpacted in Africa, Asia and nowAustraliaappears to bemaize (*Zeamays* L., 1753) (Day et al., 2017, Yan et al., 2021).*S.*

*frugiperda*attacks all aerial parts of corn, stems, leaves, flowers and ears (Prasanna et al., 2018;Yaméogo et al., 2024).A strongegg-layingpreference of *S. frugiperda*on*Z. mays* has been evidenced in the laboratory (Guo et al., 2021; He et al., 2021a; Sotelo-Cardona et al., 2021). This ovipositionpreferencecorrelateswithlarval performance, as *Z. mays*appears to behighlyconducive to the survival and development of *S. frugiperda*larvaecomparedwithothercultivatedspecies (Ali et al., 1990; Guo et al., 2021; He et al., 2021b). It threatens the food and nutritionalsecurity of thousands of farmers due to the extent of its damage to maize and othercerealcrops, resulting in significantyieldlosses and economicconsequences (Day et al., 2017; Prasanna et al., 2018; Yan et al. 2021).

To deal withthis situation, the Burkina Faso governmentsupportedgrowers as soon as the insectpestappeared, with 6,465 liters of chemical pesticides in addition to the quantitiesthatthemselvespurchased (DGESS, 2021). Using pesticides on traditionalcerealssuch as maize, sorghum and millet wasnot common in Burkina Faso before the arrival of *S. frugiperda*in2017 (Ahissou et al., 2021;Caniço et al., 2020). Henceforth, chemical control is the mostused control method by growers (Maïga et al., 2017;Yaméogo et al., 2023a). However, the increasing and uncontrolled use of chemical insecticides can destroy the biodiversity of naturalenemies and causing the emergence of resistantinsect populations (Tendeng et al., 2019;Sene et al., 2020). For thisreason, biological control islikely to become an important part of *S. frugiperda* management in Africa (Kenis et al., 2019;Ahissou et al., 2021). Habitat diversification strategies are attractingmuchinterest as pest control methods (Diatte et al., 2016). So, as part of one suchresearch initiative, the International InsectResearch Center (ICIPE) and itspartners have developed a new technologycalled push-pull technology to control Strigaweeds, improvingsoilfertility and pest management, the mostrecent of whichis FAW (Khan et al., 2006;Midega et al., 2018). It's a biologicalintegratedpest control technique using a repellent plant ("Push") and an attractive plant ("Pull") which traps pests. Push-Pull wasdevelopedin 1999 by Indian Professor Zeyaur Khan, a scientist at the International InsectResearch Center at Mbita station in Kenya, in collaboration with local farmers. Push-Pull technologyistherefore an association of cropsthatincreases plant biodiversity (Ogot et al., 2017). Plant biodiversityplays a majorrole in balancing insect populations, as itincreases the impact of naturalenemies in regulatingpest populations (Labou et al., 2016; Diatte et al., 2018). Push-Pull involvesintercroppingcerealswith a forage legume, *Desmodium*, and planting the poaceous*Brachiaria* as a border crop. *Desmodium* “pushes” stem borers and attractstheirnaturalenemies, while*Brachiaria* “pulls” theseinsectpeststowardsitselfin order to trap themwith substances itsecretesthatinhibit*S. frugiperda*larvaldevelopment (Khan et al., 2000; Khan et al., 2007). This technology has been tested in East African countries such as Kenya, Uganda, Ethiopia and Tanzania, and has raisedgreathopes for the ecological management of stem-boringpests and weedssuch as striga (Khan et al., 2008;Midega et al., 2010). By 2014, over 96,000 farmers in East Africahadadopted Push-pull strategy and theirmaizeyieldsincreased by an average of one to 3.5 tons per hectare, without the use of chemical insecticides and with minimal inputs (Khan et al., 2014). In addition to improvingmaizeyields, the strategyincreasedsmall-scalelivestock production, conservedsoilquality, controlledweeds, enhancedfunctionalbiodiversity and increased the income and empowerment of small-scalefarmers (Midega et al., 2017). It is in thiscontextthat the presentstudy,the first of its kind in Burkina Fasowasinitiatedusing Push-Pull technology in combination with insecticides (bothchemical and botanicals) aim to find an effective, ecological and sustainable management strategy for *S. frugiperda* in Burkina Faso.

1.Material and methods

1.1 Material

Study site

The studywasconducted at the Bama agricultural research station (Fig. 1) duringtwoconsecutive agricultural seasons, the 2023 dry season and the 2023 wetseason. The climate in the study area is South Sudanian, witha distinct rainyseasonfrom May to October and a dry seasonfromNovember to April. Rainfallfrequentlyexceeds 1000 mm (Guinko, 1984).

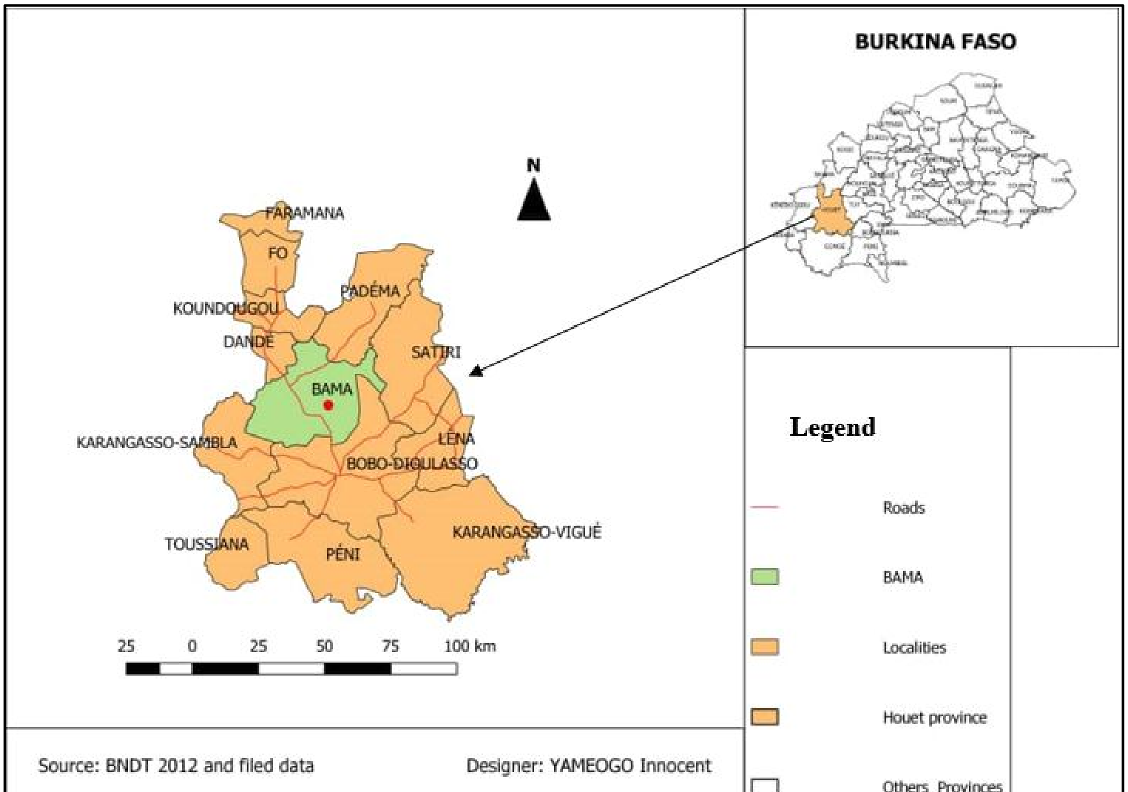

Fig. 1: Location of study area

Plant material:

It consisted of :

- The popularizedmaizevarietyKomsaya, medium-cycle, high-yielding and known to be not very susceptible to *Spodopterafrugiperda*attacksaccording to Yaméogo et al. (2023b);

- *Desmodiumuncinatum*(Jacq.), a perenniallegumethatcovers the soilbetween the rows of the main crop (maize);

- *Brachiariamullato* II (L.), a perennialpoaceae.

Insecticides: The insecticides used are shown in Table 1.

Table 1: Characteristics of insecticides used

Commercial names	Active ingredients	Doses	Crops	Targets
Emacot	Emamectine benzoate	0.5l/ha	Vegetablecrops, Subsistencecrops, Cotton	*Spodopterafrugiperda* *Helicoverpaarmigera*(Hübner), *Eariass*spp(Hübner), *Diparopsiswatersi*(Rothschild), *Spodopteralittoralis*(Boisduval), *Syleptaderogata*(Fabricius) *Plutella xylostella*(Linnaeus)
Neem oil	Azadirachtine	5l/ha	Vegetablecrops,S ubsistencecrops, Fruit and flowercrops	*Planococcus*spp. (Risso), *Iceryapurchasi*(Maskell), *Aonidiellaaurantii*(Maskell), *Ceroplasterusci* (Linnaeus) etc.
Jatropha curcas' oil		5l/ha	Vegetablecrops,S ubsistencecrops, Fruit and flowercrops	*Spodoptera.frugiperda*, *Busseolafusca*(Fuller), *Sesamiacalamistis*(Hampson), *Aphis gossypii*(Glover),*Callosobruchus maculatus*(Linnaeus).

1.2 Methods

1.2.1. Experimentalset-up

The experimentalset-upis a Fisher block with 4 treatments and 4 replicates, i.e. 16 elementary plots. Eachelementary plot is 8 m long and 5 m wide, i.e. a surface area of 40 m2. Spacingis 5 m between blocks and 5 m betweentreatments. The dimensions of the trial are 55 m long by 39 m wide, giving a total area of 2145 m². The differenttreatmentswerecomposed as follows:

T0= absolute control with no technology or insecticide application ;

T1= combination of Push-pull technology and *Jatropha curcas*(Linnaeus)oil;

T2= Push-pull technology - *Azadirachta indica*(A. Juss.) oil combination;

T3= Push-pull technology - Emamectin benzoate combination.

1.2.2. Setting up the experiment

1.2.2.1. Soilpreparation and crop establishment

The experimentwasconducted in the dry seasonfromJanuary to May 2023 and in the wetseasonfrom June to October 2023.

In order to provide the best conditions for the development of the maize plants, a 15 to 25 cm deepploughingwascarried out on wetsoil, followed by levelling to ensure a good distribution of inputs in the soil. The system was set up usingmetric tape, rope and stakes, in accordance with the experimental system, followed by a rack to mark out the sowinglines. Finally, the sub-plots werelabelled to facilitatetheir identification for data collection and processingoperations.

The twospeciesinvolved in the Push-Pull technologywereplanted 10 daysbeforemaizesowing, on January 09 and July 05, 2023 for the dry and wetseasonsrespectively. Maizewassown at a rate of 3 to 4 seeds per poquet at a depth of 2 to 6 cm, followed by resowing 9 daysafter the 1st sowing (JAS). Maizewassown at 80 cm betweenrows and 40 cm betweenrows. *Desmodiumuncinatum*issown in continuousrowsbetweentworows of maize and *B.mullato* II issown in rows of threebunches 20 cm apart.

Weedingwascarried out at 2 plants per bunchfrom the 9th day of the season. The first weedingwascarried out at 10 to 15 days. Mineralfertilization at a rate of 300 kg/ha of cottonfertilizer (14-23-14, 6S+1B) wasapplied on the same date. A second weedingwascarried out twoweekslater, between DAS 22 and 25, followed by the application of the first fraction of cover fertilizer at a rate of 100 kg/ha of urea (46%), i.e. 6.4 kg for the trial.

Ridgingwascarried out between the 38th and 40th DAS to reinforce plant vigor and cover the second fraction of ureaapplied at a rate of 50 kg/ha of urea (46%), i.e. 3.2 kg for the trial.

An irrigation system was set up in the dry season to supply water to the plants everythreedaysduringtheirdevelopment cycle. This wasgravity irrigation or surface irrigation whichconsists of circulating water without pressure on the surface of cultivated plots, by channeling it.

Whetheritis a flood or a furrow, in thismethod the water isdiverteddirectly onto the ground surface, withoutanyoutfall or component. This technique has a relativelylowcost and does not requireanytechnology.Irrigation began at the time of ploughing and ended one weekbeforeharvest.

1.2.2.2. Insecticide treatments

Insecticide treatmentswerecarried out once a weekfrommaizeemergence to plant maturity, as follows:

- For the neem oiltreatment, as for *Jatropha curcas*, weused 650 liters of water + 5 liters of neem or *Jatropha curcas*oil + 65 ml of liquid soap for an area of one hectare. So, to treat the 40 m² of the elementary plot, weused 2.6 liters of water + 20ml of neem or *Jatropha curcas*oil + 0.26 ml of liquid soap.

- The dose of Emamectin benzoate to beappliedis 0.5 liters of commercial product/ha, i.e. 2 ml and 1.28 liters of Emamectin benzoate water for 40 m² of elementary plot.

- Control plot: no insecticide or Push-Pull treatment.

1.2.2.3. Data collection

In each of the elementary plots, 20 maize plants wererandomlysampledeachweek, from JAS 13 to maizematurity. The followingparameterswerecollectedusing a data collection sheet:

- Plant size;
- Number of leaves/plant ;
- Number of whorls/plant;
- Number of whorlsattacked/plant;
- Number of attackedleaves/plant;
- Number of attacked spikes/plant;

- Presence or absence of larvae on observed plants.

The damage caused by *S. frugiperda*larvae in the whorls and on the leaves of each plant wasrecorded. Damage wasscoredusing the *S. frugiperda* damage assessmentscaledeveloped by Davis and Williams (1992).

The infestation rate wasdetermined, according to the formula proposed by FAO (2019):

Infestation rate = (Σ of infested plants) x 100 / Σ total of targeted plants.

At maturity, a 20 m² yield square was laid out in eachelementary plot, taking care to leave at least one border line on eachside of the plot. The earsharvestedfrom the variousyield squares weredried, shelled and their kernels weighed. The weight of the weighedsampleswascorrectedafteradjusting for a moisture content of 14%. The biomass of the yield squares wasalsoharvested and weighed.

- RDT (t/ha) = grain dry weight (kg) x 10000 (m2) / CR area (m2) x 1000
- RDT (14%) (t/ha) = (RDT at X% x (100-X)) / (100-14)

RDT = yield

X = grain moisture content.

CR= yield square

1.2.3. Data analysis

The data collectedwereentered and processed on a Microsoft Excel 2010 spreadsheet, thenimportedinto R software version 4. 2. 1. The data weresubjected to a Shapiro-Wilknormality test. Data following a normal distribution weresubjected to an analysis of variance. MeanswereseparatedusingTukey's test at the 5% threshold. Thosethatdid not follow a normal distribution weresubjected to the Kruskal Wallis test, and meanswereseparated by pgirmess at the 5% threshold.

2.Results and discussion

2.1. Results

Variation in parametersassociatedwith*S. frugiperda* as a function of factors

Table 2 presents the results of statisticalanalysis of mean infestation rates, mean*S.frugiperda*attack scores, and mean grain and haulmyields. Production season, treatment and phenological stages and their interaction significantlyaffectedmean infestation rates, meanattack scores and mean grain and haulmyields (P<0.0001).

In contrast, season and treatment interaction had no significant impact (P> 0.05) on mean grain attack scores and mean grain and haulmyields over the course of the study.

Table 2: Variation in parametersassociatedwith*S. frugiperda*

Sources of variation	Averageinfestations rates			Averagefoliar damage scores			Average grain damage scores			Average grain yield			Averagehaulmyield		
	df	F	P	df	F	P	df	F	P	df	F	P	df	F	P
Season	1	52.31	< 0.0001 ***	1	8.58	0.0034 **	1	20.99	0.0001 ***	1	15.90	0.0005***	1	59.61	0.0001 ***
Treatment (T)	3	457.35	< 0.0001 ***	3	38.00	< 0.0001 ***	3	9.62	0.0001 ***	3	14.63	0.0001***	3	5.95	0.0035 **
Stag	3	1741.30	< 0.0001 ***	3	197.12	< 0.0001 ***									
Season:stag	3	763.81	< 0.0001 ***	3	57.29	< 0.0001 ***									
Season: T	3	105.50	< 0.0001 ***	3	33.78	< 0.0001 ***	3	2.39	0.0690ns	3	0.57	0.6431ns	3	0.69ns	0.5680ns
Stag: T	9	116.16	< 0.0001 ***	9	7.06	0.0001 ***									
Season:Stag:T	9	68.61	< 0.0001 ***	9	27.70	< 0.0001 ***									

Df: degree of freedom; F: variance P: probability; ns: not significant; *: significant; **: highlysignificant; ***: veryhighlysignificant; Stag: stage.

Average*S. frugiperda* infestation rates in maizeaccording to treatments

During the twogrowingseasons of 2023, the push-pull- Emamectin benzoate treatmentsshowed the lowestaverage infestation rates, i.e. 28±20.07% for the dry season and 34.50±16.17% for the wetseason. The control treatments in bothgrowingseasonshad the highestaverage infestation rates (66.38±15.30%; 59.75±17.37% in the dry and wetseasonsrespectively). The Push-pull technology - *Jatropha curcas'*oil combination treatment (T1) showedaverage plant infestation rates of 41.88±16.43% for the 2023 dry season and 47.64 ±21.10% for the 2023 wetseason. The Push-pull technology - neem oil combination treatment (T2) recorded a mean infestation rate of 37.88±13.97% for the 2023 dry season and 45.38 ±15.84%, for the 2023 wetseason (Fig. 2). Production seasons (X2 = 1311.9, df = 3, p-value < 0.0001 in dry season; X2 = 635.33, df = 3, p-value < 0.0001 in wetseason) had a highlysignificant impact on the average*S. frugiperda*maize infestation rates of the treatments.

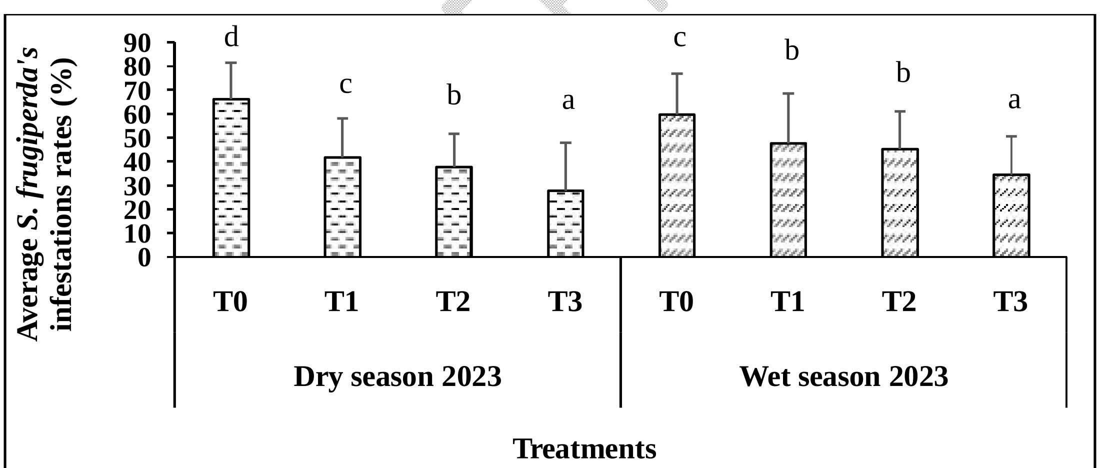

Fig. 2: Average rates of *S.frugiperda* infestation in maize as a function of treatment, Bama, Burkina Faso.

Meansassigned the sameletters are not significantlydifferentaccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control, T1= combination of Push-pull technology and *Jatropha curcas*oil

T2= Push-pull technology/neem oil combination

T3= Push-pull technology - Emamectin benzoate combination

Average*S. frugiperda* infestation rates in maize as a function of plant phenological stages

The curveillustratingaverage*S. frugiperda* infestation rates on maize in the dry seasonwasdecreasingfromemergence to plant maturity, whilethat for the wetseasonwasincreasingfromemergence to bolting and thendecreasingfrombolting to maizeheading. The highestaverage infestation rate in the dry seasonwasrecorded at emergencewith 59.90±16.92%, while in the wetseasonitwasrecorded at boltingwith 58.46 ± 19.46%. The lowestaverage infestation rates wererecorded at headingwith 34.21±16.15% in the dry season and 41.56 ± 19.64% in the wetseason (Fig. 3). A significantdifferencewasobservedbetweendevelopment stages (X2= 457.35; df = 3; p-value < 0.0001 in the dry season and X2= 412.71; df = 3; p-value < 0.0001 in the wetseason) with regard to average infestation rates.

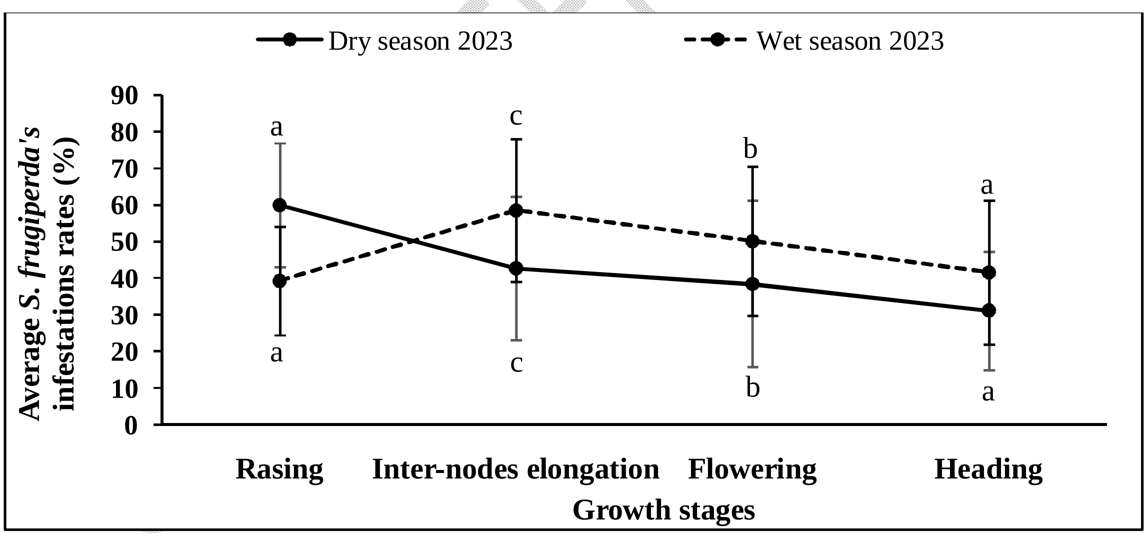

Fig. 3: Average rates of *S.frugiperda* infestation in maizeaccording to phenological stage, Bama, Burkina Faso.

Meansaffected by the sameletters are not significantlydifferentaccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

Severity of *S. frugiperda*damage on maizeleaves and kernels according to treatments

The averageseverity of *S. frugiperda*attacks on maizeleaves and kernels according to treatmentispresented in Table 3. During the vegetative phase of maize, the highestaverage infestation scores observedwere 2.59±1.36 and 1.89±0.97 in the dry and wetseasonsrespectively. Thesemean scores wererecorded in the control treatment (T0). The lowestmean infestation scores (1.50±0.83 and 1.55±0.74) recorded in the dry and wetseasonsrespectivelywereobservedwithtreatment T3 (Push-pull technology - Emamectin benzoate combination) and T2 (1.63±0.80) in the wetseason.

A significantdifferencewasobservedbetween the mean infestation scores on the vegetativeapparatusduring the dry season (X2= 197.12; df = 3; p-value <0.0001) and alsoduring the wetseason (X2= 137.75; df = 3; p-value <0.0001) depending on the treatments. Similarly, statisticalanalysis of mean grain scores revealed a significantdifference (X2=21.86; df = 3; p-value <0.0001 in the dry season and X2=9.46; df = 3; p-value = 0.0237 in the wetseason) betweentreatments at the 5% thresholdaccording to the Kruskal-Wallis test. The highestaverage infestation scores on grains wererecorded in the control (1.69±1.09 in the dry season and 1.89±0.97 in the wetseason), while the lowestaverageattack scores on grains wererecorded in treatments T1 (1, 26±0.65) (Push-pull-*Jatropha curcas*technology combination) and T2 (1.19 ±0.51) (Push-pull - neem oiltechnology combination) during the dry season, T2 (1.56 ±0.69) and T3 (1.43± 0.59) during the wetseason.

Table 3: Averageseverity of *S. frugiperda* damage on maize plants

Treatments	Dry season2023		Wetseason2023	
	Averagevegetative scores	Average grains scores	Averagevegetative scores	Average grains scores
T0	2.59±1.36c	1.69±1.09b	2.12±0.98c	1.89±0.97b
T1	1.82±1.01b	1.26±0.65a	1.92±1.03b	1.63±0.80ab
T2	1.78±1.03b	1.19±0.51a	1.90±1.04b	1.56±0.69a
T3	1.50±0.83a	1.11±0.36a	1.55±0.74a	1.43±0.59a
df	3	3	3	3
X²	336.89	21.866	137.75	9.4669
P	< 0.0000	0.0001	< 0.0000	0.0237

Meansassigned the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control, T1= Push-pull technology - *Jatropha curcas*oil combination

T2= Push-pull technology/neem oil combination

T3= Push-pull technology - Emamectin benzoate combination

Averageseverity of *S. frugiperda* damage as a function of the phenological stage of the maize plant

The averageseverity of *S. frugipera* damage to maize plants as a function of phenological stage over the twogrowingseasons of 2023 isshown in Fig. 4.

The mean score of maizeleavesdamaged by *S. frugiperda*washighest at emergence (2.27±1.09) in the 2023 dry season and at bolting (2.10 ± 1.03) in the 2023 wetseason. The lowestmean scores wererecorded at heading (1.60±0.93) and emergence (1.72±0.86) in the dry and wetseasonsrespectively. The effect of seasonshad a significant impact (X2= 194.5; df = 3; p-value < 0.0001 in the dry season and X2= 58.47; df = 3; p-value < 0.0001 in the wetseason) on the meanvegetative scores according to the phenological stages of the maize plant.

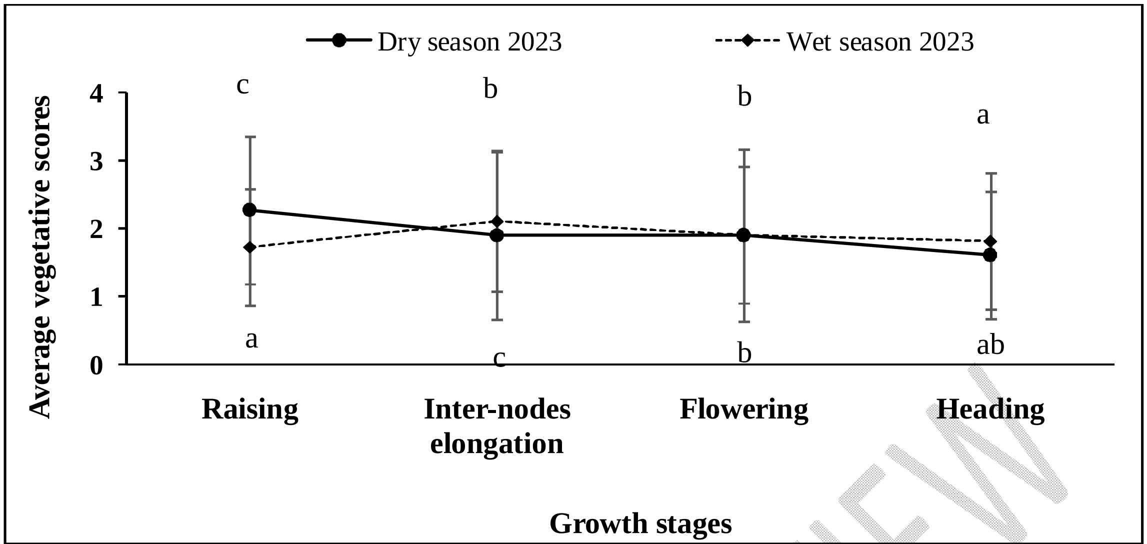

Fig. 4: Meanvegetative scores for damage inflicted on maize by *S.frugiperda* as a function of plant phenological stages, Bama, Burkina Faso.

Meansaffected by the sameletters are not significantlydifferentaccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

Larvalpresence of *S.frugiperda*

Generallyspeaking, treatmentsthatreceived insecticide applications combinedwithPush-Pull technologyshowedloweraveragelarvalpresence rates than control plots. The highestaveragelarvalpresence rate (31.88 ± 0.47% for the 2023 dry season and 38.63 ± 0.49% for the 2023 wetseason) wasobserved in treatment T0 (control), while the lowestaveragelarvalpresence rate (4.25 ± 0.20% for the dry season and 8.13 ± 0.27% for the wetseason) wasrecorded in treatment T3 (Push-Pull technology - Emamectin benzoate combination) (Table 4). Treatmentshad a significanteffect (X2= 298.87; df = 3; p-value < 0.0001 in the dry season and X2= 314.39; df = 3; p-value < 0.0001 in the wetseason) on the presence rate of the FAW larvae

Table 4: Average rates of larvalpresence of *S. frugiperda* on maize plants

Meansassigned the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control, T1= Push-pull technology - *Jatropha curcas*oil combination

T2= Push-pull technology/neem oil combination

T3= Push-pull technology - Emamectin benzoate combination

Average*S. frugiperda*larvalpresence rates according to maizephenological stages

The presence rate of *S. frugiperda*larvaeduring the two 2023 growingseasonsrangedfrom 3.54 ± 0.18% to 25.94 ± 0.44%, depending on maizedevelopment stage (Fig. 5).

The highestaveragelarvalpresence rate wasobserved at the bolting stage (23.75 ± 0.43% for the dry season and 25.94 ± 0.44% for the wetseason), followed by the emergence stage (18.65 ± 0.39% for the dry season 21.77 ± 0.41% for the wetseason). The averagelarvalpresence rate was 12.81 ± 0.33% for the dry season and 13.54 ± 0.34% for the wetseason at the flowering stage. The lowestaveragelarvalpresence rates (3.54 ± 0.18% for the dry season and 11.41 ± 0.32% for the wetseason) wererecorded at heading (Figure 5). Phenological stages had a significant influence (X2= 155.94; df = 3; p-value < 0.0001 in the dry season and X2= 68.13; df = 3; p-value < 0.0001 in the wetseason) on the larvalpresence rate of the pest.

Average*S. frugiperda*'slarvalpresence rate (%)		
	Dry season 2023	Wetseason 2023
T0	31.88±0.47c	38.63±0.49c
T1	10.38±0.31b	14.13±0.35b
T2	9.38±0.29b	11.32±0.32ab
T3	4.25±0.20a	8.13±0.27a
df	3	3
X^2	298.87	314.39
P	< 0.0001	<0.0001

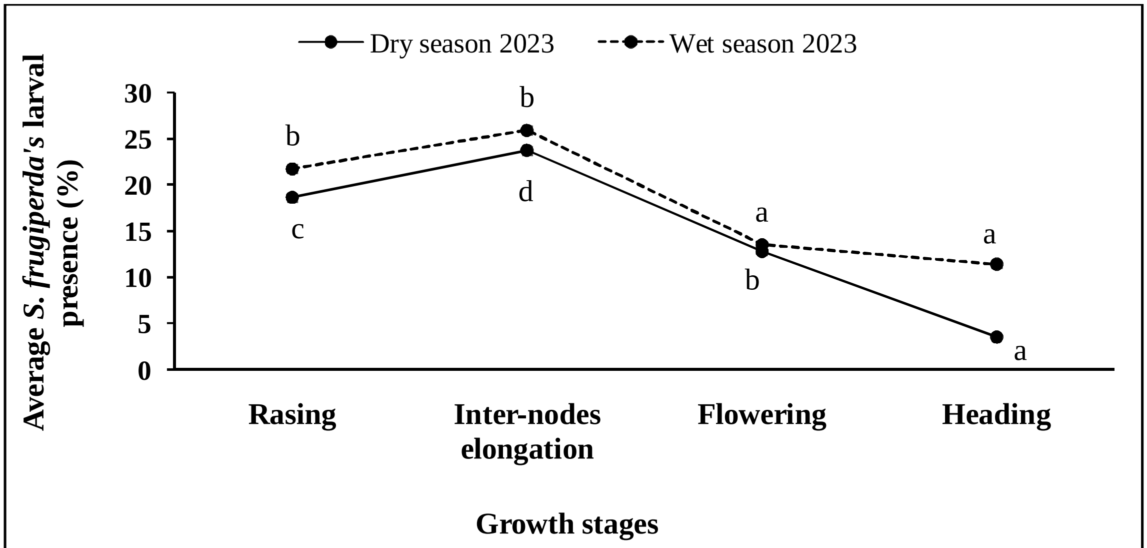

Fig. 5: Meanlarvalpresence rates of *S. frugiperda* as a function of phenological stages of the maize plant, Bama, Burkina Faso.

Meansassigned the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

Averagemaize plant height by treatment

The analysis of variance of meanmaize plant heightsaccording to the differenttreatmentsduring the twogrowingseasonsrevealed a significantdifference ($F = 13.63$; $df = 3$; $p < 0.0001$ in the dry season and $F = 9.05$; $df = 3$; $p < 0.0001$ in the wetseason) betweentreatments at the 5% thresholdaccording to Tukey's test. Treatment T1 recorded the maize plants with the highestmeanheightswhatever the growingseason (203.11±17.46 for the dry season and 201.49 ± 23.20 for the wetseason). The lowestmeanheights (186.74±17.36 and 183.41 ± 20.11 for the dry and wetseasonsrespectively) wereobservedwithtreatment T0 (control) (Fig. 6).

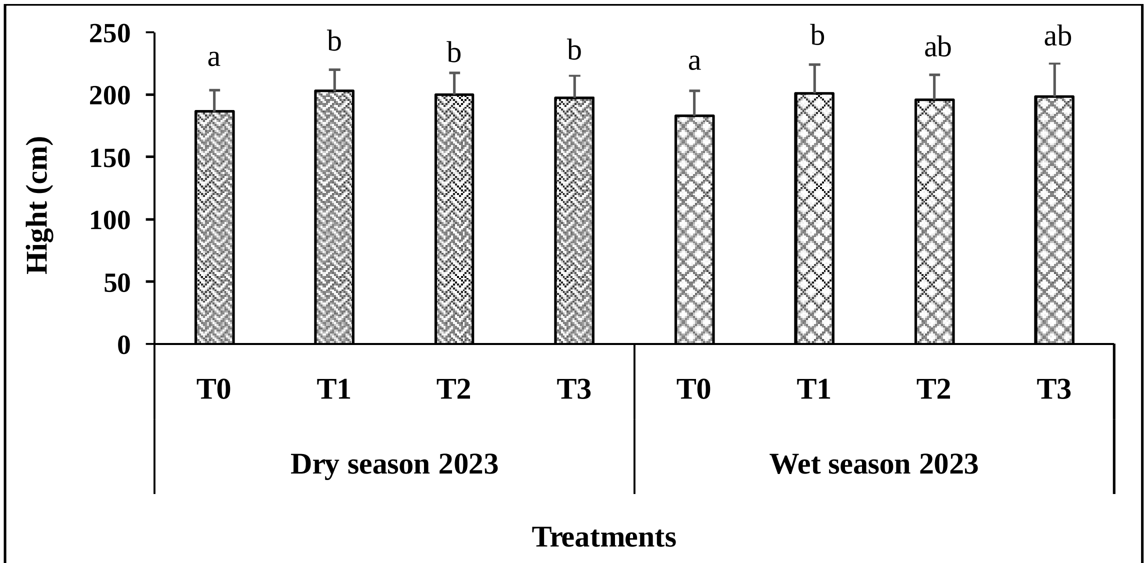

Fig. 6: Averagemaize plant heights, Bama, Burkina Faso

Meansassigned the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control, T1= combination of Push-pull technology and *Jatropha curcas*'oil

T2= Push-pull technology/neem oil combination

T3= Push-pull technology combination - Emamectin benzoate

Averagemaize grain yields by treatment

An analysis of variance of the averagemaize grain yieldsobtainedduring the twoconsecutivegrowingseasonsrevealed a significantdifference (F=7.82; df = 3, p= 0.0037 in the dry season and F = 7.40; df = 3; p = 0.0046 in the wetseason) betweentreatments at the 5% thresholdaccording to Tukey's test. The lowestaverageyieldswereobtainedwith the T0 treatments, at 2.81 t/ha for the 2023 dry season and 2.43 t/ha for the 2023 wetseason (Fig.7). The meanyieldsrecorded in treatments T1 (3.52± 0.30), T2 (3.73± 0.32), and T3 (3.57± 0.24) during the dry season and T2 (3.26± 0.18) and T3 (3.34± 0.43) during the wetseason, were not significantlydifferentfromeachother (Fig. 7).

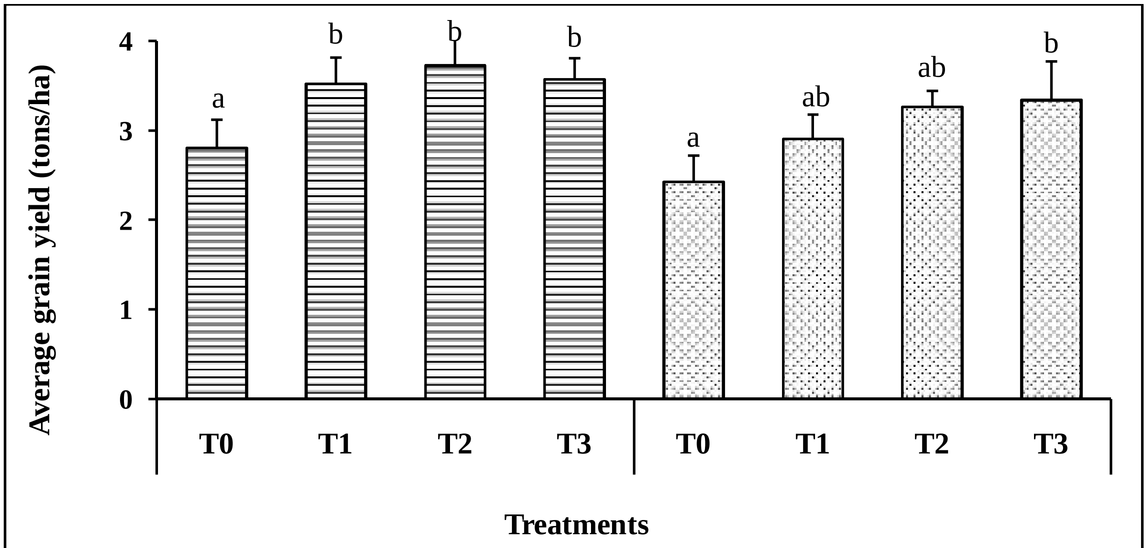

Fig. 7: Average grain yield (t/ha), Bama, Burkina Faso.

Meansassigned the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control, T1= Push-pull technology - *Jatropha curcas*oil combination

T2= Push-pull technology/neem oil combination

T3= Push-pull technology combination - Emamectin benzoate

Averagehaulmyields (t/ha) by treatment

The effect of the differenttreatmentssignificantlyinfluencedaveragemaizehaulmyields (F= 4.51; df = 3; p = 0.0243 in the dry season and F= 4.31; df = 3; p = 0.0279 in the wetseason) at the 5% thresholdaccording to Tukey's test, as shown in figure 8. The lowestaveragemaizebiomassyields (4.26±0.37 obtained in the dry season and 2.94 ± 0.39 recorded in the wetseason) wereobserved in plot T0 (control). Next came treatment T3 (Push-Pull technology - Emamectin benzoate combination) with 5.28±0.52 (dry season) and 3.37±0.69 (wetseason) of maizebiomass. Then T2 (Push-Pull technology - neem oil combination) with 5.60±0.55 (dry season) and 3.80±0.66 (wetseason) and finally T1 (Push-Pull technology - *Jatropha curcas* combination) which records the highestbiomasswith 5.73±0.93 (dry season) and 4.25±0.35 (wetseason).

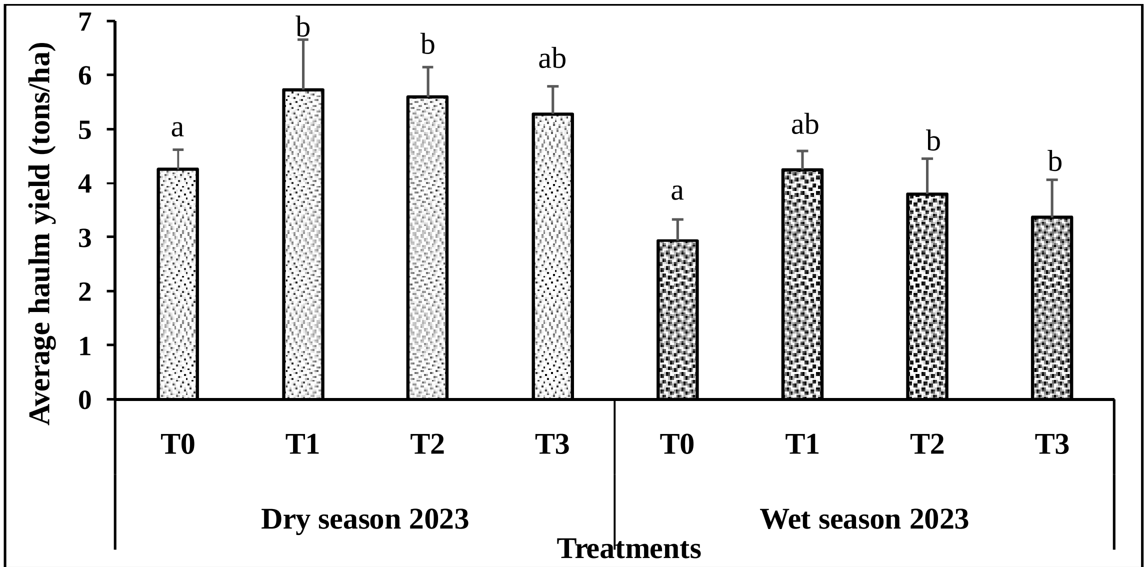

Fig. 8: Averagemaizehaulmyield by treatment

Meansmarkedwith the sameletters are not significantlydifferentfromeachotheraccording to the Kruskall-Wallis (K-W) test at the 5% threshold.

T0= control,

T1= Push-Pull-oil and *Jatropha curcas*technology combination

T2= Push-Pull technology -neem oil combination

T3= Push-Pull technology- Emamectin benzoate combination

2.2.Discussion

The results of the presentstudy, carried out during the twoconsecutivegrowingseasons of 2023, showedthataverage infestation rates, averageattackseverity and averagepresence rates of *S. frugiperda*larvae on maize plants variedaccording to treatments and plant phenological stages. Attacks by *S. frugiperda*weregreatest at maizeemergence in the dry season of 2023 and at bolting in the wetseason of 2023. Theseattackswereassociatedwith a high averagelarvalpresence rate. The lowestattackswereobserved at heading, with a lowaveragelarvalpresencerate in both 2023 growingseasons. In fact, at the emergence and bolting stages, maizeleaves are tender and thereforeideal for feedingarmywormlarvae (FAO and CABI, 2019). Afterbolting, maize plants stop producing new leaves and make do with the activity of acquiredleaves for the rest of their life cycle. Theylengthenthrough the internodes to reachtheir final size. Thus, leafspacingcoupledwithleafagingwithoutrenewalcontribute to a scarcity of food for larvae, exposingthem to predators and otherclimatichazards (winds, storms, extremeheat, etc.). This explains the high foliarattack rates of the pestobservedduring the earlydevelopmental stages of maize plants, particularly at bolting, and the lowfoliarattack rates recordedduring the laterdevelopmental stages of the plant, particularly at apiaison. Theseresultscorroboratethose of Tindo et al. (2017), whoreportedthat the early stages of maize plant development are the mostattacked by the armyworm. Also, in the case of treatmentsdesigned to control the pest, such a resultcouldbeexplained by the factthatwhenBrachiariamullato II and *D. uncinatum* plants are stillsmall, theywould not have enough influence on the pest to reduceits infestations, and thereforeits damage. As thesetwo plants develop, theyproduce more volatile chemical compounds thatattract, or repel, S. frugiperda, thusreducing the pest's infestation rate (Lofinda et al., 2018). Pest damage wasgreater in the control plots than in the othertreatmentsduring the twoconsecutiveseasons of 2023. The relativelylowlevel of pestattacks in treatmentsaimed at controlling*S. frugiperda*couldbeexplained by the combined action of push-pull and insecticide applications. According to Lofinda et al (2018), stimuli emitted by intercropping or marginal plants certainlymodify the behavior of insects and plants in the field. As a result, trap plants are not adapted to the survival of pestlarval stages, leading to high mortality rates and delayedlarvaldevelopment (Khan et al., 2006;Midega et al., 2011).

Among IPM combinations, the Push-pull - Emamectin benzoate technology combination recorded the lowestaverage rates of larvalpresence, infestations and averageattackseverityduring the two 2023 growingseasons.Theseresults are in line withthose of Koffi et al. (2020), whoshowedthat the application of chemical insecticides is effective in protectingmaize and cottonagainst the armyworm. According to Fandriàka (2018), Emamectin benzoate producesimmediate action thanks to anti-appetanttoxic substances against*S. frugiperda*larvae. Indeed, the active ingredient, Emamectin benzoate causes paralysis of lepidopteranlarvae due to activation of the chloridechannel in the nerves (Fandriàka, 2018). The biological pesticides used in the presentstudy, namely Azadirachta indicaoil and Jatropha curcasoil, alsoconsiderablyreduced*S. frugiperda* damage. In fact, Azadirachtin, the active ingredient in A. indicaoil, acts by slowing down the insect'sfeeding rate, causingparalysis and dieback of targetorganisms (Andreu et al., 2000;Senthil-Nathan et al., 2004). Gnago et al. (2010) have alsoreportedthat*A. indica*oilreduces the fecundity of FAWfemales, whichisjustified by the considerablereduction in the number of egg clusters of thiscaterpillar and its damage. Habou et al (2013) have alsoshownthat J. curcasoilis effective in regulatingLepidoptera populations. Our resultsalsocorroboratethose of Adebowale and Adedire (2006), whoshowedthat*J. curcas*oilcaused the total death of eggs and larvae of the bruchidbeetle, *Callosobruchus maculatus*(Fabricius).During the 2023 growingseason, maize plants developedbetter in plots thathadreceived a push-pull combination with pesticides than in control plots. Similarly, average grain and haulmyieldswerehigher in the push-pull plots than in the control plots. This resultcouldbeexplained by the presence of *D. uncinatum* in the push-pull plot, whichwould have contributed to the increase in biomassavailable in the maize plot. Legumesharborsymbioticnitrogen-fixing bacteria in their root nodules (Lamy, 2016). Most plants needavailablenitrogen for vegetativegrowth. Leguminous plants in association withseedlingsprovidethemwith the nitrogentheyneed for growth and improvetheirproductivity (Khan et al., 2000;Midega et al., 2009). *Desmodiumuncinatum*is a legumethatimprovessoilfertility and moisture (Corre-Hellou et al., 2013).

Indeed, foliar damage inflicted by *S. frugiperda* on maizeresults in a reduction in the plant'sphotosyntheticactivity, which in turn can lead to a reduction in maizegrowth. Our results do not agreewiththose of Tiendrébéogo (2020), whoobserved normal maize plant growthdespite*S. furgiperda* infestations. Soilfertilizationwith*D. uncinatum*could help provide the nutrientsneeded for good grain and cob formation. As a result, average grain yieldswerehigherthanthoseobtainedwith the control. Our resultscorroboratethosereported by Balde et al (2022), whoshowedthat the greatervegetativedevelopment and number of earsobserved in the push-pull plot can beexplained by a combination of factors: increasedsoilfertility and moisturepreservation due to the presence of *D. uncinatum*. Similarly, ICIPE (2010) showedthatsomefarmersusing Push-Pull technologywereharvestingfive tons of maize per ha in fieldswhereyieldshadpreviously been belowone ton. Theseresultsdemonstrate the effectiveness of push-pull technology in combination with certain pesticides in managing*S. frugiperda* in Burkina Faso.

Conclusion

The FAW is a seriousthreat to maize production in Burkina Faso. The aim of thisstudy, carried out in western Burkina Faso, specifically in Bama, was to evaluatesome management options for *S. frugiperda* in Burkina Faso. The activitiescarried out within the framework of thisstudyenabled us to estimate the average rates of infestation of maize plants by *S. frugiperda* as a function of treatments and phenological stages of the plant, and to assignaveragevegetative scores for the sameparameters. The results of thisstudyshowedthat the Push-Pull technology - Emamectin benzoate combination provideda better protection of maize plants against*S. frugiperda*larvaethan the othertwo IPM combinations, whichwerehowever more effective than the control.

The combination of Push-Pull technology and Emamectin benzoate thereforeappears to be the best combination for managing*S. frugiperda*. However, combinations of Push-Pull technologyand biological pesticides showedsomeeffectiveness in reducing damage caused by the FAWlarvae. Push-Pull technologymaythereforebe an interesting avenue for managing*S. frugiperda*, whileprovidingotherbenefits to growers.

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Details of the AI usage are given below:

1.

2.

3.

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