

1 Comparative Effects of *Piper guineense* Emulsion and Cabbage-Tomato
2 Intercropping for Mitigating Cabbage Pest Infestation and Improving Performance

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26 **Authors' contributions**

27 This work was carried out in collaboration between all authors. CBT designed and
28 established the field trial, prepared organic input and managed the field site,
29 conducted harvest and data collection, data processing and analyses, performed
30 literature searches and wrote the first manuscript draft. CN contributed in the
31 experimental design, processed the data and performed statistical analyses,
32 conducted literature searches and coordinated preparation of the first manuscript
33 draft. NNN contributed in the experimental design, coordinated the field
34 experimentation and data collection, and supervised the study. All authors read
35 and approved the final manuscript.

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51 **ABSTRACT**

52 **AIM:** To improve cabbage production by mitigating cabbage pests via locally
53 produced organic pesticide and cabbage-tomato intercropping.

54 **METHODOLOGY:** The impact of four treatments (control, cabbage-tomato
55 intercropping, organic and synthetic pesticides) was evaluated on cabbage
56 performance and pest infestations.

57 **RESULTS:** Pest infestation correlated negatively with treatments ($r = -0.95$),
58 ranging from 2–23 infested cabbage plants per treatment and varied across
59 treatments ($P = .001$), with highest infestation in control compared to the others (P
60 $= .05$). Mean DBM larvae ranged from 1–10 per plant and varied across
61 treatments ($P = .001$), with highest in control compared to the others ($P = .05$).
62 Looper correlated negatively with treatments ($r = -0.62$), ranging from 0–8 larvae
63 per plant and varied across treatments ($P = .05$), with highest in control compared
64 to the others ($P = .05$). Mean snail population ranged from 34–91 per treatment
65 and varied across treatments ($P = .001$), with highest in control and lowest in
66 organic treatment compared to the others ($P = .05$). Mean number of sprouted
67 cabbage plants ranged from 0–5 per treatment and varied across treatments ($P =$
68 $.001$) with the highest in control compared to the others ($P = .05$). The number of
69 sprouted cabbage correlated negatively with treatments ($r = -0.93$), but correlated
70 positively with pest infestation ($r = 0.81$), DMB ($r = 0.71$) and looper ($r = 0.58$).
71 Cabbage yield ranged from 3.2–6.0 t ha⁻¹ and varied across treatments with the
72 lowest in control and the highest in intercropping ($P = .05$). Meanwhile, a negative
73 correlation occurred between cabbage yield and DBM ($r = -0.62$), looper ($r =$
74 -0.63) or sprouting ($r = -0.62$).

75 **CONCLUSION:** The **piper** emulsion botanical pesticide effectively mitigated
76 cabbage pest populations below economic injury threshold, **which represents an**
77 **important alternative for synthetic pesticides.**

78

79 **Keywords:** *Diamondback Moth, Looper, Piper emulsion, Snails, Webworm*

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81 **1. INTRODUCTION**

82 Cabbage (*Brassica oleracea*, **Linnaeus**) is an exotic nutrient rich leafy vegetable
83 with variable forms of consumption [1,2]. Cabbage cultivation is an important
84 source of food and nutrient security, income and livelihood in Cameroon [3].
85 Cabbage consumption limits micronutrient deficiency that is a major cause of poor
86 health and high mortality in Africa [4]. With **about** 40% malnutrition in SSA,
87 vegetable diets represent the most affordable and accessible source of
88 micronutrients, vitamins and health-promoting secondary metabolites [5,6].
89 However, cabbage is a nutritious succulent leafy vegetable that attracts many
90 insect pests that bore leaves and destroy growing buds and mature heads.
91 Hence, cabbage production is affected by field pests, which are mitigated by
92 various farm management practices including intercropping, synthetic pesticides
93 and botanicals.

94 Cabbage yield loss caused by diamondback moth – DBM (*Plutella*
95 **xylostella**, Linnaeus) can reach up to 90% during severe field infestation [7].
96 Looper (*Trichoplusia ni*, **Hübner**) is **another** major pest of cabbage that feeds on
97 leaves and kills young plants or cause sprouting, while feeding on cabbage heads
98 causes contamination with frass [8]. Webworm (*Helulla undalis*, **Fabricius**) is **also**
99 an important cabbage pest that accounts for huge field losses [8]. Snails facilitate

100 decomposition of plant material and serve as biological indicators of soil quality,
101 but they represent major pests of tropical and subtropical regions and most
102 damaging during wet seasons [9,10]. Meanwhile, resistance to conventional
103 pesticides has increased the need for alternative sustainable control measures for
104 snails that include the use of plant products [11].

105 Globally, the use of commercial synthetic pesticide has exacerbated reliance
106 on chemical controls and increased pest resistance, leading to higher production
107 cost with negative externalities [12,13]. Commercial synthetic chemicals are
108 commonly used to manage field pests and diseases [14-17]. However, pest
109 evolution and resistance, environmental effects and high cost of synthetic
110 chemicals often limit their use in smallholder farming systems [13]. Moreover, the
111 evolution of pest resistance to synthetic pesticides requires the use of more
112 powerful pesticides at higher doses, which increases insecticide dependency
113 [18,19]. Hence, this has necessitated alternative sustainable management
114 strategies involving the use of botanicals that are effective and affordable without
115 negative externalities [20-22]. However, both synthetic pesticides and botanicals
116 have demonstrated variable responses to field pests and diseases [18,23,24].

117 The PAMS model (prevention, avoidance, monitoring, and suppression) was
118 used to evaluate various pest management practices [25]. The preventive tactics
119 included treatments or crop rotation and planting of pest-resistant cultivars, while
120 the avoidance tactics included altering planting dates and managing irrigation
121 schedules [25]. Further avoidance tactics involves intercropping cabbage with a
122 repellent crop like tomato (*Lycopersicon esculentum*, Miller), and cabbage-tomato
123 intercropping reportedly reduced DBM infestation in cabbage fields [3,26]. The
124 odour from the tomato intercrop repels DBM [3] or has an oviposition deterrent

effect on DBM [27]. This similar to onion (*Allium cepa*, Linnaeus) and garlic (*Allium sativum*, Linnaeus) that also demonstrated repellent effects on DBM [26,28].

This study was intended to improve cabbage production by incorporating the concepts of integrated pest management and integrated soil fertility management via a combination of planting time, intercropping, and organic or inorganic inputs [29]. It was hypothesized that (i) the locally produced organic pesticide will effectively mitigate field pests, (ii) Cabbage-tomato intercropping will reduce pest infestation, and (iii) Cabbage-tomato intercropping will improve cabbage performance.

2. MATERIALS AND METHODS

2.1 Experimental Site and Setup

The study was conducted at the teaching and research farm of the Faculty of Agriculture and Veterinary Medicine of the University of Buea, located at the foot of mount Cameroon, Southwest Region. It is situated between latitudes 4°3'N and 4°12'N of the equator and longitudes 9°12'E and 9°20'E. The soil was derived from weathered volcanic rocks dominated by silt, clay and sand [30,31]. Buea has a mono-modal rainfall regime with less pronounced dry season and 85–90% relative humidity. Heavy rainfall occurs between June and October while the dry season starts from November to May, with rainfall ranging from 2085 mm to 9086 mm between March and November [32]. Mean monthly air temperature ranges from 19°C to 30°C, while soil temperature at 10 cm depth decreases from 25°C to 15°C with increasing elevation from 200 m to 2200 m above sea level [31,33,34].

The experiment was setup as a randomized complete block design with four

150 replicates per treatment. The field was cleared manually with a cutlass and tilled
151 with a hoe and partitioned into 16 plots measuring 3x4 m each. The experimental
152 setup comprised four treatments including a control (control – sole cabbage and
153 sole tomato, synthetic pesticides, organic pesticide, tomato intercrop). Each plot
154 contained 8 rows and 6 columns of cabbage with 50×50 cm planting distance,
155 leading to 48 plants per plot. The intercropped plots had 24 cabbage plants and
156 24 tomato plants, planted at 50×50 cm, in one alternating row crop. Meanwhile,
157 the experimental plots were separated from each other by a 50 cm buffer zone.

158

159 **2.2 Locally Produced Organic Pesticide**

160 The locally produced organic amendment comprised the West African black
161 pepper *Piper guineense* Schum. and Thonn, harvested from a primary forest at
162 Inokun-Eyumojock, Southwest Cameroon. The fresh piper seeds were sun-dried
163 for one week and blended into fine powder using a kitchen blender. 250 g piper
164 powder was dissolved in 1 L vegetable oil (KING'S®, Lagos-Nigeria) that is
165 commonly sold in the local market. The mixture was thoroughly stirred and 10 g of
166 commercial detergent (SABA®, Douala-Cameroon) added to produce a slightly
167 sticky emulsion for easy absorption by plants. The organic emulsion pesticide was
168 stored at room temperature in a plastic container. Prior to field application of the
169 organic pesticide, a laboratory evaluation trial was conducted to determine the
170 effective application dose for best field results. For this, ten DBM larvae were
171 randomly collected in the morning from the field and placed in five petri dishes
172 with two larvae each. A piece of cabbage leaf was introduced into the petri dish as
173 food substrate for the larvae. Five concentrations were prepared from the stock
174 organic emulsion; 0.007 (100:15), 0.005 (80:15), 0.004 (60:15), 0.003 (50:15) and

0.013 (20:15) product:water (ml:L) ratio and applied in five respective petri dishes containing insects using a syringe. Based on performance evaluations, the 0.003 concentration (50:15 ml:L) was chosen for field applications. The field application of organic amendment was performed during cold dry periods, often in early mornings with minimal drift. For field applications, 50 ml of organic product was filtered using a double 169-folded muslin cloth to remove sediments, diluted in 15 L water and stirred vigorously to achieve homogeneity. The homogenized mixture was poured into a knapsack sprayer and used to uniformly spray both sides of the cabbage leaves, including folded leaves for all 192 plants in the respective four experimental plots, and at two weeks intervals.

185

186 **2.3 Plant Cultivation**

187 **2.3.1 Cabbage**

188 Hybrid cabbage seeds (*Brassica oleraceae* L. var. *capitata* F1 Green Coronet; 189 STARKE AYRES®, France) were purchased from an agro-shop in Buea 190 Cameroon and pre-germinated on a 2.5×1 m nursery bed beside the experimental 191 plots. The nursery bed was prepared by clearing the site with a cutlass and the 192 soil tilled manually using hoes. Cabbage seeds were sown at an inter-row spacing 193 of 15×15 cm. Vigorous seedlings were transplanted from the nursery to the 194 experimental plots on the 10th of March 2016 following the usual planting season 195 in this region. The cabbage seedlings were field-planted at 50×50 cm spacing on 196 3×4 m (12 m²) experimental plots of manually raised soil beds of approximately 30 197 cm height, with one plant per stand and 48 plants per sole cabbage plot or 24 198 cabbage plants per intercropped plot.

199

200 **2.3.2 Tomato**

201 Hybrid tomato seeds (*Lycopersicon esculentum* L.; F1 Cobra 26; TECHNISEM®
202 France) were purchased from an agro-shop in Buea Cameroon and pre-
203 germinated on nearby 2×1 m nursery bed at 15x15 cm inter-row spacing. The
204 nursery seedlings were amended with 0.5 kg of NPK fertilizers (20:10:10) and
205 treated with 35 ml synthetic insecticide (K-Optimal; SCPA SIVEX International®
206 France; comprising active components Lambda – cyhalothrine 15 g/l +
207 Acetamipride 20 g/L) and 100 g fungicide (Mancozan super; SCPA SIVEX
208 International® France; comprising active components 640 g/kg Mancozebe + 80
209 g/kg Metalaxyl) in 15 L of water, and applied with knapsack sprayer. After 3
210 weeks, vigorous seedlings were transferred from nursery to experimental plots.
211 The tomato seedlings were field-planted on the raised beds at 50×50 cm spacing
212 on 3×4 m plots (12 m²), with one plant per stand and 24 tomato plants per plot.

213

214 **2.4 Field Management**

215 **2.4.1 Fertilizers**

216 All treatment plots received the same type and amount of fertilizer inputs as soil
217 amendments. Poultry droppings and urea fertilizer were applied to experimental
218 plots at the rate of 5 g per plant, 7 days before transplanting and 30 days after
219 transplanting.

220

221 **2.4.2 Pesticides**

222 Organic plots were only treated with the locally produced piper emulsion pesticide
223 while the inorganic plots received a combination of synthetic pesticide (K-Optimal;
224 SCPA SIVEX International® France) and fungicide (Mancozan super; SCPA

225 SIVEX International® France). The intercropped plots only had tomato plants that
226 served as pest repellent or attractant, with no pesticide application. Meanwhile,
227 there were no organic or synthetic pesticide application in the sole cabbage or
228 sole tomato control plots.

229

230 **2.4.3 Tillage**

231 Before transplanting, the experimental field was tilled manually to produce raised
232 soil beds of approximately 30 cm height, with a non-raised bed of 50 cm buffer
233 zone between the experimental plots.

234

235 **2.4.4 Irrigation and Weeds**

236 The experimental site was irrigated manually to improve soil moisture before
237 seedlings were transplanted. After transplanting, the experimental plots were
238 supplemented every two days by manual irrigation to maintain soil moisture for
239 optimal plant growth. Meanwhile, weed emergence was monitored regularly after
240 transplanting and plots were weeded manually using hoes.

241

242 **2.5 Cabbage Yield and Sprouted Plants**

243 Harvest was conducted manually and data for cabbage yield was obtained as the
244 crop attained maturity. At harvesting stage, 10 cabbage plants were incised above
245 the soil level per experimental unit and weighed individually using a top loading
246 balance (Brand MK-01, China). Before weighing, all damaged leaves were
247 removed using a cutter. The mean weight of harvested cabbage heads per
248 treatment was recorded as a yield and considered as marketable yield, and
249 presented in t ha^{-1} .

250 Meanwhile, the number of sprouted cabbage plants was assessed as the
251 total number of plants with multiple shoots (sprouts) per experimental plot, and
252 reported as the mean ($\pm$ SD) number of sprouted cabbage plant per treatment.

253

254 **2.6 Pest Infestation**

255 Plants were observed for pest infestation before and after heading, with regular
256 monitoring of the wrapper leaves for observable signs of pest damage. Data on
257 pest infestation was collected as the total number of infested cabbage plants per
258 plot based on the occurrence of major field pests such as DBM, looper and
259 webworm larvae. Plants were identified as infested based on the observation of
260 insect larvae or their damage.

261

262 **2.6.1 Diamondback Moth**

263 DBM was observed as small round holes or scratching off the leaf tissue leaving
264 the epidermis on one side untouched giving a window appearance. Five plants
265 with DBM damage were randomly selected per plot and assessed for the number
266 of DBM larvae on the wrapper leaves per plant. Data were presented as mean
267 number (Mean $\pm$ SD) of DBM larvae per cabbage plant.

268

269 **2.6.2 Looper**

270 Looper was assessed and presented as the mean number (Mean $\pm$ SD) of looper
271 larvae per cabbage plant. The assessment of looper larvae was also performed
272 on five randomly selected plants per experimental plot.

273

274 **2.6.3 Webworm**

275 Plant damage by webworm (i.e. leaves held together with silk) was also assessed
276 via five randomly selected cabbage plants for the occurrence of webworm larvae.
277 Data were presented as the mean number (Mean $\pm$ SD) of webworm larvae per
278 cabbage plant.

279

280 **2.6.4 Snails**

281 Snails were assessed as the total number of snails per experimental plot and
282 presented as mean number (Mean $\pm$ SD) of snails per treatment. However, snails
283 were considered as minor pests because their damage was concentrated on the
284 lower leaves that are often not harvested alongside cabbage heads for marketing,
285 and therefore they did not account for the calculation of pest infestation. But at
286 high snail infestation, damages can be significant to producers as they could feed
287 on the tender wrapper leaves and disrupt head formation.

288

289 **2.7. Statistical Analyses**

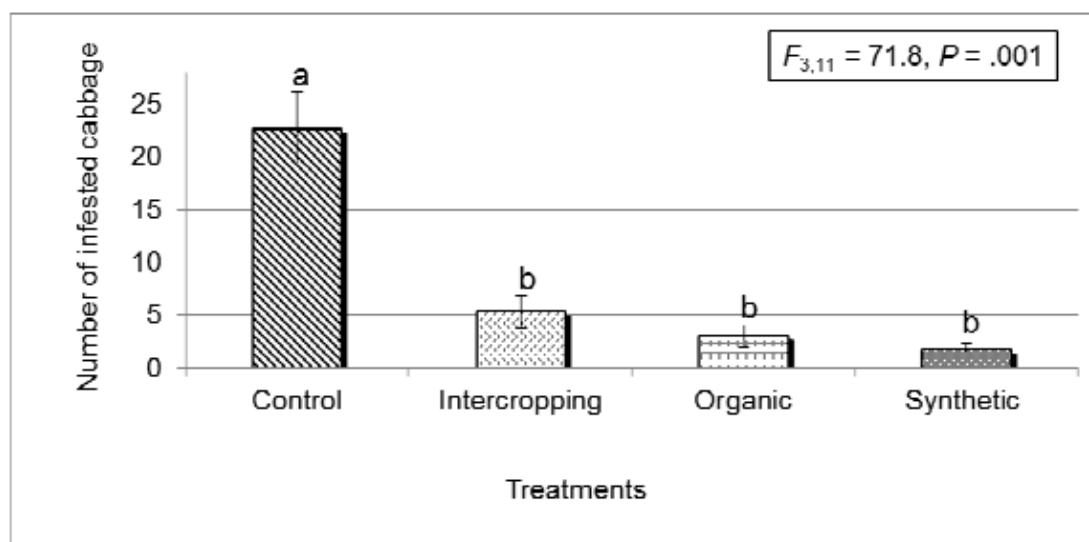
290 All data sets were subjected to statistical analyses using STATISTICA 9.1 for
291 Windows [35]. The response design variables such as insect pests (i.e. DBM,
292 looper, webworm and snail) and cabbage performance (i.e. yield and sprouting)
293 were subjected to univariate analysis of variance (ANOVA, $P = .05$) to test effect
294 of treatments ($n=4$) as categorical predictors. Significant means were compared
295 by posthoc Tukey's HSD test ($P = .05$). Where applicable, Spearman Rank
296 Correlation ($P = .05$) was performed to determine the degree of association
297 between treatments as the categorical predictors and pest infestation or cabbage
298 performance as the dependent variables.

299

300 3. RESULTS

301 3.1 Effect of Treatment on Cabbage Pests

302 Four major pests were identified during the different growth stages of cabbage,
 303 with Diamondback Moth being the most and webworm the least. The number of
 304 infested cabbage plants ranged from 2 to 23 plants per treatment and differed
 305 (ANOVA: $F_{3,11} = 71.8$, $P = .001$; Fig. 1) significantly across treatments. The
 306 highest pest infestation was recorded in the control plots that differed (Tukey's
 307 HSD, $P = .05$; Fig. 1) significantly from all the other treatments. However, the
 308 synthetic pesticide was neither significantly different from intercropping nor from
 309 the organic piper emulsion pesticide treatment. Overall, the number of infested
 310 cabbage plants decreased with treatments as corroborated by the negative
 311 correlation between treatments and the number of infested cabbage plants ($r =$
 312 -0.95 , $P = .05$). Meanwhile, the different treatments demonstrated a similar effect
 313 and correlation for the individual pests (i.e. DBM, loopers, webworm and snails).



314
 315 Fig. 1. Effect of treatments (i.e. control, intercropping, organic or synthetic
 316 pesticides) on the number of infested plants per treatment (Mean ± SD) due to

317 Diamondback moth, **loopers** and **webworms**; Values with different letters are
318 significantly different according to Tukey's HSD, $P = .05$.

319

320 **3.1.1 Diamondback Moth**

321 The **mean** number of DBM larvae on cabbage plants ranged from 1 **larvae per**
322 **plant** in **the piper emulsion pesticide** to 10 **larvae per plant** in the control, which
323 differed (**ANOVA: $F_{3,11} = 20.7$, $P = .001$; Table 1**) significantly across treatments.
324 The highest DBM infestation was recorded in the control, which differed (**Tukey's**
325 **HSD, $P = .05$; Table 1**) significantly from all the other treatments. However, the
326 synthetic pesticide was neither significantly different from intercropping nor from
327 the organic **piper emulsion pesticide** treatment. Overall, the number of DBM
328 larvae decreased with treatments but there was no correlation between
329 treatments and number of larvae ($r = -0.54$, $P = .05$).

330

331 Table 1. Impact of treatments (i.e. control, intercropping, organic or synthetic
332 pesticides) on the **mean** population density of field pests **per plant** (i.e. Mean $\pm$ SD
333 number of DBM, **loopers, webworms**); Values with different letters are significantly
334 different according to Tukey's HSD, $P = .05$.

Treatments	Diamondback Moth	Looper	Webworm
Control	10.3 $\pm$ 2.1a	8.3 $\pm$ 0.6a	4.0 $\pm$ 1.0a
Intercropping	1.3 $\pm$ 2.3b	0.3 $\pm$ 0.6b	3.7 $\pm$ 3.5a
Organic pesticides	1.0 $\pm$ 1.0b	0.7 $\pm$ 0.6b	1.3 $\pm$ 1.2a
Synthetic pesticides	1.3 $\pm$ 1.2b	0.3 $\pm$ 0.6b	0.0 $\pm$ 0.0a

335

336

337 **3.1.2 Looper**

338 The mean number of looper larvae on cabbage plants ranged from 0 to 8 larvae
339 per plant and differed (ANOVA: $F_{3,11} = 140.2$, $P = .05$; Table 1) significantly across
340 treatments. The highest looper infestation was recorded in the control, which
341 differed (Tukey's HSD, $P = .05$; Table 1) significantly from all the other treatments.
342 Meanwhile, the synthetic pesticide was neither significantly different from
343 intercropping nor from the organic piper emulsion pesticide treatment. Meanwhile,
344 the number of looper larvae on cabbage plants decreased with treatments as
345 corroborated by the negative correlation between treatments and the number of
346 looper larvae on cabbage plants ($r = -0.62$, $P = .05$).

347

348 **3.1.3 Webworm**

349 The mean number of webworm larvae on cabbage plants ranged from 0 to 4 per
350 plant, with no significant difference across treatments (ANOVA: $F_{3,11} = 2.9$, $P =$
351 $.09$; Table 1). Similarly, the synthetic pesticide was neither significantly different
352 from intercropping nor from the organic piper emulsion pesticide treatment.
353 Meanwhile, the number of webworm larvae on cabbage plants was negatively
354 correlated with treatments ($r = -0.75$, $P = .05$).

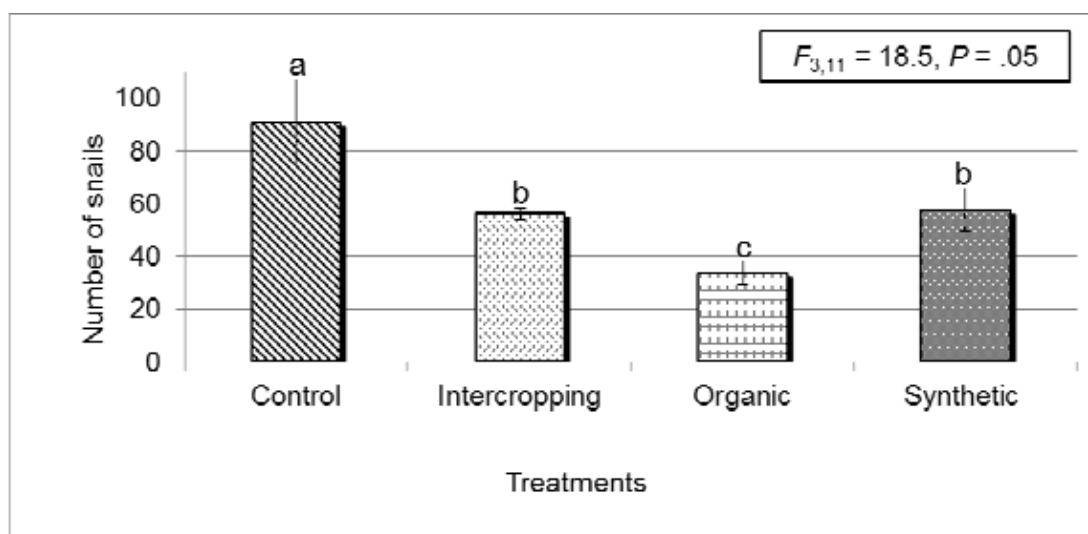
355

356 **3.1.4 Snails**

357 Although snails were not identified to species level, various snail species were
358 observed in the field (*Limicolaria numidica*, *Limicolaria aurora*, *Limicolaria*
359 *flammea*, *Limicolaria martensiana* and *Limicolaria zebra*). Amongst them,
360 *Limicolaria aurora* and *Limicolaria zebra* were often found feeding towards
361 cabbage wrapper leaves with potential to cause significant damage to crops at

362 higher densities. The mean number of snails ranged from 34 in the organic piper
 363 emulsion pesticide treatment to 91 snails in the control, which differed (ANOVA:
 364 $F_{3,11} = 18.5$ $P = .001$; Fig. 2) significantly across treatments. The highest snail
 365 infestation was recorded in the control treatment that differed (Tukey's HSD, $P =$
 366 $.05$; Fig. 2) significantly from all the other treatments. The organic piper emulsion
 367 pesticide treatment was significantly (Tukey's HSD, $P = .05$; Fig. 2) different from
 368 the synthetic and intercropping treatments, but there was no significant difference
 369 between the synthetic pesticide and intercropping treatments. Overall, the mean
 370 number of snails decreased with treatments but there was no correlation between
 371 the treatments and number of snails ($r = -0.51$, $P = .05$).

372



373

374 Fig. 2. Effect of treatments (i.e. control, intercropping, organic or synthetic
 375 pesticides) on the mean number of snails per treatment (Mean $\pm$ SD); Values with
 376 different letters are significantly different according to Tukey's HSD, $P = .05$

377

378 3.2 Impact of Treatment on Cabbage Performance

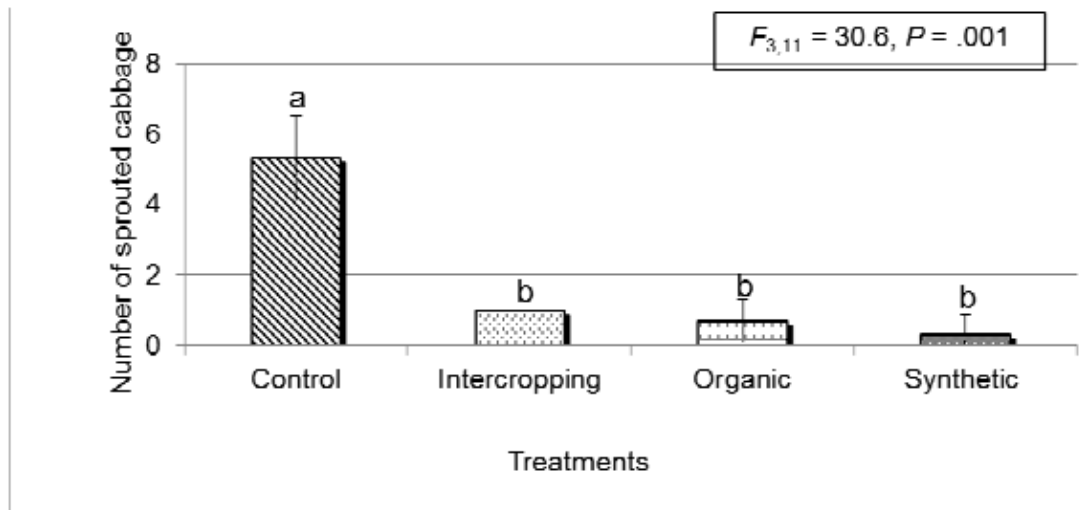
379 Crop data are only presented for cabbage as the main crop since tomato was
380 mainly introduced as a comparable treatment to the synthetic and organic
381 pesticides. Interestingly, tomato plants in the sole tomato control and cabbage-
382 tomato intercrop treatments were completely damaged by pest infestation, which
383 indicates a strong ability of tomato to attract the cabbage pests.

384

385 **3.2.1 Sprouted Plants**

386 The number of sprouted cabbage ranged from 0 to 5 plants per treatment and
387 differed (ANOVA: $F_{3,11} = 30.6$, $P = .001$; Fig. 3) significantly across treatments.
388 The highest number of sprouted cabbage plants was recorded in the control plots,
389 which differed (Tukey's HSD, $P = .05$; Fig. 3) significantly from the other
390 treatments. Meanwhile, the synthetic pesticide was neither significantly different
391 from the intercropping nor organic treatments. Overall, there was a positive
392 correlation between pest infestation and the number of sprouted cabbage plants (r
393 $= 0.81$, $P = .05$). However, a strong negative correlation occurred between the
394 number of sprouted cabbage plants and treatments ($r = -0.93$, $P = .05$), while
395 positive correlations occurred between the number of sprouted cabbage plants
396 and DBM ($r = -0.71$, $P = .05$) or loopers ($r = 0.58$, $P = .05$).

397



398

399 Fig. 3. Impact of treatments (i.e. control, intercropping, organic or synthetic
 400 pesticides) mean number of sprouted cabbage plants per treatment (Mean $\pm$ SD);
 401 Values with different letters are significantly different according to Tukey's HSD, P
 402 = .05.

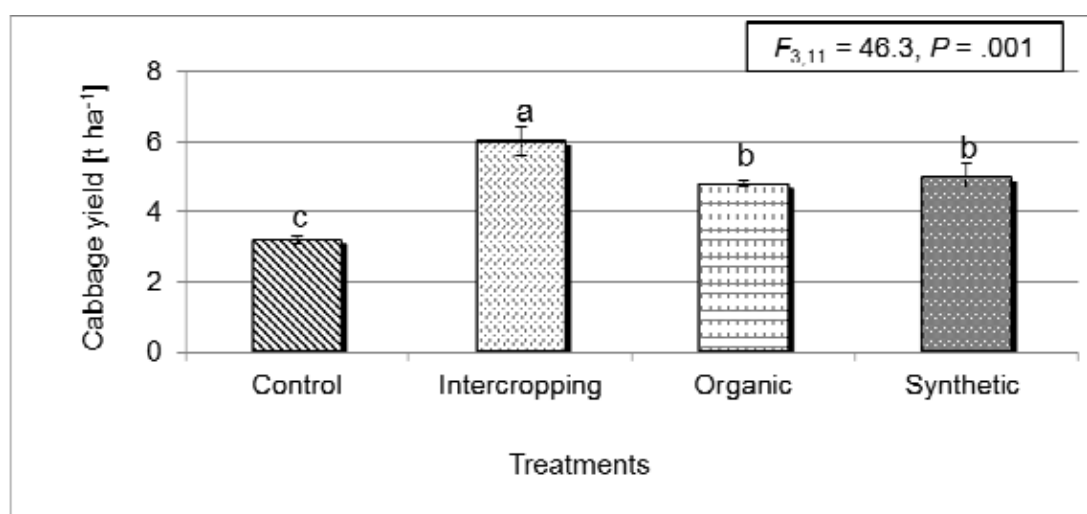
403

404 **3.2.2 Cabbage Yield**

405 The cabbage yield ranged from 3.2 to 6.0 t ha^{-1} and differed (ANOVA: $F_{3,11} = 46.3$
 406 $P = .05$; Fig. 4) significantly across treatments. The lowest cabbage yield was
 407 recorded in the control, which differed (Tukey's HSD, $P = .05$; Fig. 4) significantly
 408 from all the other treatments. The intercropping treatment was significantly
 409 different from the organic and synthetic treatments, but there was no significant
 410 difference between the synthetic pesticide and organic piper emulsion pesticide.

411 Overall, the cabbage yield decreased with increasing pest infestation but no
 412 significant correlation occurred between them ($r = -0.37$, $P = .05$). However, a
 413 negative correlation occurred between cabbage yield and DBM ($r = -0.62$, $P =$
 414 .05) and looper ($r = -0.63$, $P = .05$). Meanwhile, a negative correlation occurred
 415 between cabbage yield and the number of sprouted cabbage plants ($r = -0.62$, P
 416 = .05).

417



418

419 Fig. 4. Impact of treatments (i.e. control, intercropping, organic or synthetic
 420 pesticides) on cabbage yield ($t \text{ ha}^{-1} \pm \text{SD}$); Values with different letters are
 421 significantly different according to Tukey's HSD, $P = .05$

422

423 4. DISCUSSION

424 4.1 Effect of Treatments on Cabbage Pests

425 The significantly higher pest population recorded for the untreated cabbage plants
 426 compared to the treated plants indicates effectiveness of the various pest
 427 management practices that were used to protect the cabbage plants, which is
 428 consistent with other findings [3]. The significantly lower pest infestation in the
 429 cabbage-tomato intercropping is likely due to the confusing olfactory and visual
 430 cues received from tomato, which resulted in the reduction of larvae numbers for
 431 the different pests [3,36]. Hence, the repellent and attractant ability of tomato was
 432 as effective as the insecticidal properties of both the synthetic pesticide and
 433 organic piper emulsion pesticide [3]. However, other studies on cabbage
 434 intercropping demonstrated idiosyncratic responses to pest infestations without
 435 reliably controlling DBM [3]. Nonetheless, this may be due to varying factors

436 (including the type of associated crop, plant spacing, planting time, etc.).
437 Incidentally other studies used higher plant density and row spacing, which likely
438 had less effect on the pest dynamics as compared to the present study where
439 tomato as a companion crop exhibited deleterious effect on DBM [3].

440 The lower snail infestation recorded in organic pesticide plots compared to
441 other treatments is likely due to the presence of isobutyl amides (natural lipophilic
442 amides piperine and piperiline) plant secondary metabolite, which is an active
443 ingredient in piper that acts as neurotoxins in insects [37,38]. Piper-derived
444 extracts demonstrated strong potential for mitigating insect pests [39].
445 Correspondingly, the efficacy of mixed powders of *Piper guineense* and *Zingiber*
446 *officinale* was reported against *Callosobruchus maculatus* [40,41]. Meanwhile, the
447 comparable pest mitigation performance observed for the intercropping, synthetic
448 pesticide and organic piper emulsion pesticide are consistent with the first and
449 second hypotheses of this study. Therefore, smallholder cabbage farmers in Sub-
450 Saharan Africa can conveniently use intercropping systems or the organic piper
451 emulsion pesticide as alternative management strategy for commercial synthetic
452 pesticides, without jeopardizing crop performance or environmental sustainability.

453

454 **4.2 Impact of Treatment on Cabbage Performance**

455 Cabbage performance was generally consistent with the observed rate of pest
456 infestations, as cabbage performance increased with decreasing pest population
457 and vice versa. Correspondingly, cabbage performance is consistent with the third
458 hypothesis of this study that advocates greater cabbage yield in the cabbage-
459 tomato intercropping treatment. The highest number of sprouted cabbage plants
460 recorded in the control that differed with all the other treatments is consistent with

461 the level of pest infestations recorded in the respective treatments. This could be
462 attributed to the rate of pest damage to cabbage plants in relation to the level of
463 protection by the respective treatments [3]. Likely, the observed pests were able
464 to feed on the growing point of cabbage plants, causing growth disturbances that
465 resulted in multiple shoot formation from the buds (sprouted plants). Hence, by
466 mitigating pest infestations, the different treatments were able to reduce the
467 potential effects of pests on cabbage sprouting (i.e. multiple heads). Although
468 both DBM and **looper** are known to cause sprouting of cabbage plants, **looper** was
469 reportedly more damaging [42]. However, the stronger correlation of DBM with
470 sprouted cabbage compared to **looper** in this study is likely due to the higher pest
471 population of DBM, which increased cabbage sprouting as compared to **looper**
472 **[43]**.

473 The low cabbage yield recorded in the control treatments is consistent with
474 the level of pest infestation, with the corresponding higher leaf and head damage
475 that likely reduced photosynthetic carbon fixation and consequently plant growth
476 **[44]**. This is consistent with report of DBM as the most serious pest of cabbage
477 that is responsible for low yield [3]. In addition, **looper** and **webworm**
478 demonstrated significant cabbage damage that is comparable to DBM damage,
479 and therefore considered as major yield reducing cabbage pests [8]. The higher
480 cabbage yield recorded in the cabbage-tomato intercropping as compared to the
481 **synthetic pesticide** and organic **piper emulsion pesticide** treatments is not
482 consistent with the observed trend of pest infestation in this study. **Therefore**, this
483 strongly indicates additional factors that contributed in improving cabbage **yield**.
484 **Likely**, the complete pest damage of tomato plants in the sole tomato control and
485 cabbage-tomato intercropping treatments might have contributed in improving soil

fertility and nutrition of the cabbage plants in the intercropped treatment. Moreover, the additional fertilizer input supplied to the cabbage-tomato intercropping treatment together with the decomposing biomass of the dead tomato plants likely enhanced soil nutrients and biological dynamics, which favoured the growth and yield of cabbage plants [45]. Crop residue compost reportedly produced highly mummified organic matter that conditioned the soil and plant responses [46,47]. Meanwhile, improved soil fertility and plant nutrition resulting from changes in soil biological parameters have been reasonably linked to substrate availability for microbial growth [46,48,49]. In addition, improved cabbage performance may have also resulted from the compost humic fraction that enhanced the proliferation of cabbage roots [50,51]. The higher cabbage yield recorded in the cabbage-tomato intercrop as compared to the other treatments highlights the need for integrated farm management practices that integrate the below and aboveground, including soil fertility and pest management strategies.

500

501 5. CONCLUSION

Besides poor soil fertility and plant nutrition, pest damage causes significant yield loss to cabbage farmers, particularly smallholder farmers in Sub-Saharan Africa with inadequate finances to purchase synthetic pesticides. Moreover, pest evolution and resistance to synthetic pesticides coupled with the associated health and environmental risks have necessitated a change of course to more sustainable alternative management strategies. This study demonstrated comparable pest mitigation effect of synthetic pesticides and locally produced organic piper emulsion or cabbage-tomato intercropping. Hence, the locally produced organic piper emulsion pesticide effectively reduced cabbage pest population below the

511 economic injury threshold. Thereby, enabling cabbage yield increase with
512 potentially higher income for farmers considering the relatively low cost of
513 producing the organic piper emulsion pesticide. Hence, the locally produced
514 organic piper emulsion pesticide and cabbage-tomato intercropping treatments
515 are the best-bet options to manage cabbage pests and stimulate cabbage growth
516 and performance without negative consequences. Therefore, these treatments
517 can be used preferably over synthetic pesticides as sustainable alternatives in
518 smallholder cabbage production systems in Sub-Saharan Africa.

519

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524

525 COMPETING INTERESTS

526 Authors have declared that no competing interests exist.

527

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