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The right banker plant for the right application: Comparison of three candidates for aphid biocontrol, barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and finger millet (*Eleusine coracana* (L.) Gaertn)

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Abstract

BACKGROUND: In temperate regions, aphid biological control in greenhouses is mostly achieved by the regular release of biocontrol agents. Due to the rapid growth rate of the aphid population, biocontrol agents must be released frequently in order to be present before pest outbreaks and to act rapidly to prevent exceeding the economic threshold. Banker plants reduce these numerous releases by providing natural enemies with a high-quality environment to develop and reproduce. Optimally, banker plants should be easy to produce, resistant to environmental conditions, provide a large amount of suitable banker prey in order to produce a high number of biocontrol agents, and resist the herbivory pressure of the banker prey. The present study aimed to compare the value of three banker plant candidates of the Poaceae family under laboratory and greenhouse conditions: barley (*Hordeum vulgare* L.), finger millet (*Eleusine coracana* (L.) Gaertn), and corn (*Zea mays* L.).

RESULTS: Our results show that the three plants were suitable for different contexts. Finger millet yielded the biggest fresh plant biomass, supported the highest load of banker prey, and resisted aphid feeding longer than the other plant species. Corn was the cheapest to produce, and barley was the fastest to grow.

CONCLUSIONS: Overall, finger millet could be more fitted for long crop cycles, pests with rapid population growth rates, and voracious or fast-reproducing biocontrol agents. Meanwhile, barley and corn may be better suited for rapid crop cycles, pests with slow population growth rates, and biocontrol agents that are not too voracious or have low reproductive rates.

Keywords: maximal charge of aphids; senescence; growth characteristics; greenhouses; bird cherry-oat aphid

1 INTRODUCTION

In temperate regions, aphid biological control in greenhouses is often achieved through the repeated release of a high number of mass-reared natural enemies, under an augmentative approach.[1,2] Due to the rapid rate of increase of aphid populations,[3,4] these approaches are sometimes inefficient or too costly for growers to ensure the constant presence of beneficial insects inside the greenhouses. The delay between the pest's arrival and the introduction and subsequent action of biocontrol agents is a major problem in biological control. It often provides time for aphids to reach high densities and damage the crops.[5,6] The use of banker plants in greenhouses is an ideal tool to overcome this problem because they ensure the presence of biocontrol agents before pests arrive.[1,6,7] The system relies on the addition of banker plants into the protected crop, providing an alternative food source (banker prey for predators) and a breeding medium (alternative host for parasitoids) for the natural enemies of the target pest. For aphid control by predators and parasitoids, the banker plant is usually not the same species as the protected crop and is often inoculated with an aphid prey or host, different from the targeted pest.[1,5,6,8,9] Banker plants present numerous advantages over augmentative biocontrol. They

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ensure high-quality biocontrol agents by avoiding transport and reducing release manipulations, they are cheaper than conventional releases of beneficials, and they can promote the recruitment of other natural enemies.[1,6,8,10,11] Nonetheless, they require an investment of time and space from the growers and can sometimes act as sinks of natural enemies if they are preferred over the focal crop/pest.[1,12,13]

The selection of a banker plant relies on different aspects related to the system/pest, such as the individual characteristics of the banker plant itself, as well as the relation between the banker plant and its banker prey, the biocontrol agent, and the crop with its target pest.[1,9,14] A suitable banker plant should be fast-growing, cheap to produce, sustain a high population of banker prey, resist the feeding of the latter, and be compatible with the growth parameters of the targeted crop.[1,5,14] The plant species can have an impact on several of those characteristics.[5] For instance, some plants can be better hosts for the banker prey by engendering better development and higher population growth rates.[15–17] Some plants also have better resistance to the feeding of banker prey and greenhouse conditions.[16] For example, Jacobson and Croft[16] found that control of the melon aphid (*Aphis gossypii* Glover 1877) by the parasitoid wasp *Aphidius colemani* Viereck, 1912 could be achieved with three different banker plants: ryegrass (*Lolium perenne* L. 1753), corn (*Zea mays* L. 1753), and wheat (*Triticum aestivum* L. 1753). Corn was considered the most suitable because it required less maintenance. Wheat often succumbed to mildew or other diseases, and the banker prey (the bird cherry-oat aphid, *Rhopalosiphum padi* (L.) 1758) did not thrive on ryegrass and needed to be reinoculated often. The banker plant system must also be appropriate for the crop and the selected biocontrol agent. The latter must be able to develop and reproduce on the banker plant system, but choose to lay eggs preferentially on the focal crop/pest system.[1,5,13] For example, a study in an experimental greenhouse found that the use of barley (*Hordeum vulgare* L., 1753) banker plants with *R. padi* provided better control of *A. gossypii* on daisies than on pansies and, by contrast, provided better control of *Myzus persicae* (Sulzer) 1776 on pansies than on daisies.[18] Therefore, the choice of the right banker plant, including the plant species and the banker prey species, is a key factor for the success of a biocontrol program for a protected crop.[1,19–21]

In general, banker plant systems used against aphids are composed of monocotyledons with *R. padi*, serving as an alternative host for parasitoid wasps such as *A. colemani* and *Aphidius matricariae* Haliday, 1834 or as banker prey for predatory midges such as *Aphidoletes aphidimyza* (Rondani) 1847.[1,5,6,12] The most used banker plant system against aphids is barley (*H. vulgare*) or wheat (*T. aestivum*), infested with *R. padi* for the parasitoid wasp *A. colemani*.[9] Nonetheless, even if those plants have been efficient at controlling pests in numerous situations,[22–24] their superiority over other monocotyledons has not received much attention[1,5] except for a few comparative studies.[14,16,25] Among other species, corn and finger millet (*Eleusine coracana* (L.) Gaertn 1788) have proven to be effective banker plants for controlling different pests, including aphids, mostly with parasitoid wasps, but also predatory midges as biocontrol agents.[11,16,26,27] Several characteristics of corn, finger millet, and the commonly used barley banker plant, have been investigated in greenhouse, field, and laboratory experiments. According to Boll *et al.*[26] finger millet was described as needing little maintenance, lasting 'several months' under greenhouse conditions and feeding by banker prey. Fischer and Leger[11] suggested that due to its dense architecture, the plant could sustain a high population of banker prey. It grows slowly however, reaching maturity after 3–6 months.[28,29] Corn was also stated as resistant, lasting 3 months under greenhouse conditions and feeding of banker prey,[16] while reaching maturity in approximately 3 months.[30] Barley is fast-growing, reaching the two-leaf stage (aimed for banker plant use) in only 3 weeks.[31] However, it was described as poorly resistant to high temperatures, needing to be replaced every 7 to 14 days under greenhouse conditions.[18,32] All that information considered, except for anecdotal data scattered in multiple experiments, the individual characteristics predisposing finger millet, corn, and barley as adequate banker plants have never been properly compared.

The present study aimed to evaluate the suitability of barley, finger millet, and corn as banker plants for aphid biocontrol programs in greenhouses. We hypothesized that the plants would generate different benefits depending on their respective characteristics. According to the information cited previously, we predicted that: (a) barley would be shorter and easier to produce while being less resistant to aphid feeding and sustain a smaller banker prey population than the other plants, (b) finger millet and corn would take longer to grow but would be more resistant to aphid feeding and greenhouse conditions, and (c) finger millet would sustain a higher population of banker prey.

2 MATERIAL AND METHODS

2.1 Biological material

Plants were grown in the greenhouses complex of the University of Quebec in Montreal (UQAM), under the following conditions: 23 °C average temperature, 16 L: 8 D photoperiod supplied with artificial light (high-pressure sodium lamp), and 50% relative humidity (R.H.). Barley, *H. vulgare* for cattle feeding, and finger millet, *E. coracana* for human consumption, were sown directly in pots of 13 × 13 × 15 cm with approximately (or precisely for the growth characteristics experiment) 300 and 800 seeds per pot, respectively, to ensure maximum density. Corn, *Z. mays* variety P9188 for cattle feeding, was sown in seed trays and after 2 weeks individually transplanted in pots of 13 × 13 × 15 cm. All seeds used were free of pesticide treatment. Plants were watered two to three times a week and fertilized (N-P-K, 20-20-20 at 6 g/L) once a week.

Insect rearing was done at the Biological Control Laboratory (UQAM). *Rhopalosiphum padi* were purchased from Anatis Bioprotection Inc. (https://anatisbioprotection.com/en/) and reared in a growth chamber (Conviron E15) on barley plants (18 °C, 16 L:8D photoperiod, and 60% R.H.), in cages of 36 × 36 × 38 cm covered with muslin.

2.2 Maximal aphid charge and resistance to aphid feeding

The experiment took place under controlled conditions (25 °C, 16 L:8D photoperiod, 50% R.H.). Barley, finger millet, and corn were inoculated with 1000 *R. padi* of all stages and placed in cages (25 × 25 × 60 cm for barley and finger millet, and 25 × 25 × 95 cm for corn) covered with muslin. At the time of inoculation, barley measured between 22 cm and 25 cm (23.8 ± 1.6 cm on average), finger millet between 21 cm and 45 cm (28.3 ± 6.5 cm on average), and corn between 60 cm and 110 cm (82.7 ± 14.1 cm on average). The optimal height of the plant was determined as the optimal compromise between developmental time, space required in a greenhouse, and production of fresh biomass. The plant condition (based on pre-established degradation characteristics projected on a scale from 100 to 0%, Table 1) and the number of aphids were estimated at the beginning of the experiment and once a week afterward. The number of aphids on each plant was estimated by counting precisely on a portion of the plant and multiplying that count by 1/proportion. In the case of spontaneous parasitism, mummies were counted and removed. Spontaneous parasitism never reached more than 10% of the aphid population. The maximal charge of aphids was defined as the maximum number of aphids reached on each plant. Watering was done two to three times a week and fertilization (N-P-K, 20-20-20 at 6 g/L) was done once a week. Seventeen repetitions were performed with barley, 15 with finger millet, and 15 with corn.

2.3 Plant condition in greenhouses

The experiment took place in two 30 × 7 m greenhouses, situated in two different regions (Montérégie, Québec and Lanaudière, Québec) and lasted from June until September 2020. Most of the crop was cucumber. Each of the first 2 weeks, two barley banker plants and two finger millet banker plants, inoculated with *R. padi*, were introduced for a total of four plants per greenhouse per week. In the following weeks, plants were replaced either when they died or when they were free of aphids. The plant condition was evaluated every week (Table 1). Corn was not tested in that experiment because it would have produced too few repetitions/plant species for statistical analysis (see Section 3).

2.4 Growth characteristics of plants

The experiment took place in the greenhouse complex of UQAM [23 °C, 16 L: 8D photoperiod supplied with artificial light (high-pressure sodium lamp) and 50% R.H.]. Respectively, 300 and 800 seeds per pot (13 × 13 × 15 cm) of barley and finger millet were planted in direct seeding to maximize density. Before sowing, the seeds (300 or 800 by pot) were weighed. The corn kernels were planted in a multicell tray and transplanted into larger pots (13 × 13 × 15 cm) 1–2 weeks later, depending on when the seeds germinated. Plant size was measured once a week and the plants were watered twice a week and fertilized (N-P-K, 20-20-20 at 6 g/L) once a week. When the plants reached the expected size (average size of the banker plants used in the maximal aphid charge and resistance to aphid feeding experiment), the number of strands (representing the number of germinated seeds) was counted, and the fresh biomass was weighed. In this experiment, no aphids were introduced. A total of 18 barley plants, 18 finger millet plants, and 25 corn kernels were planted.

2.5 Statistical analysis

All statistical analyses were performed using R statistical software version 4.0.3. (R Core Team, 2020). The packages lme4[33] (for the quadratic mixed model), mgcv[34] (for the general additive models), and emmeans[35] (for post hoc analysis of mixed models and estimation of the marginal means presented in the figures) were used. For all models, the choice of inclusion of the fixed effects and interaction terms was based on the biological pertinence of the terms as well as on the comparison of the AIC of the different models. The validation of the models was done with Shapiro tests and Q-Q plots for the normality of residuals. Plots of Pearson residuals against explanatory variables were performed to verify the homoscedasticity of variance.

2.5.1 *Maximal aphid charge and resistance to aphid feeding*

Maximal charge of aphids, after square root transformation, was evaluated by an ANOVA followed by a Tukey multiple comparisons of means test. The difference in the evolution of aphid charge through time between the three plant species was modeled by a generalized additive model with time, plant species, and interaction between time and plant species as fixed effects and replicate identity (ID) as a random effect. The response variable, number of aphids by plant, was transferred on the square root scale for better normality of the residuals. Mean number of weeks before senescence was compared between the three plants by a non-parametric Kruskal–Wallis rank sum test followed by a Dunn's test due to the absence of normality of raw data or transformations. The difference between the three plant species in terms of decline of the plant condition through time was evaluated by a quadratic model with time, square time, plant, and interaction between time and plant as fixed effects and replicate ID as random effect. The response variable, plant condition, was transferred on the square root scale for better normality of the residuals. The time to reach a 50% diminution of the number of aphids or of the condition of the plant was calculated with emmeans by predictions of marginal means.

2.5.2 *Plant condition in greenhouses*

The analyses were only carried out over the first 4 weeks after introduction. Beyond that period, the size of aphid colonies on banker plants was too variable between plants due to natural enemies and became a non-intrinsic variable influencing the rate of decline in plant condition. With the two greenhouses combined, 16 barley plants and 11 finger millet plants were included in the analyses. The difference between the two plants in terms of decline in plant condition over time was evaluated with a generalized additive model with time, plant species, and interaction between plant species and time as fixed effects, and ID as well as greenhouse as random effects.

2.5.3 *Growth characteristics of plants*

The average price per weight of barley and corn seeds was calculated as the mean of the annual price of seeds from 2010–2011 to 2015–2016 provided by the annual report of the *Financière Agricole du Québec*, available on the website of *Producteurs de grains du Québec* (2022). The average price per weight of the finger millet was calculated as the mean of the price of four suppliers

Table 1. Plant condition scale

100–76%	75–51%	50–26%	25–0%
Good health, straight and strong leaves, absence or little honeydew.	Sagging of the leaves, presence of honeydew.	Yellowing of the leaves, possible presence of mold.	All or almost all the leaves completely yellow, low abundance of aphids.

Criteria used to determine the condition of the plant, projected on a scale from 100 to 0%.

chosen randomly. As this plant is not produced locally, the price may be more variable. Also, the shipping was not included in the calculation so the price might be underestimated. The price of barley and finger millet plants was estimated by multiplying the weight of the seeds used for each plant by the average retail price per weight of the seeds (e.g., for replicate #1, 12.7 g of weight for the 400 barley seeds planted × 0.00058$/g for barley seeds). As corn was sown individually, (1 seed/pot), the weight was calculated the same way but was divided by the germination rate to account for the fact that more seeds need to be planted to have the desired number of plants (e.g., for replicate #1, 0.30 g of weight for the corn seed planted × 0.0013$/g of retail price for corn seeds / 0.84 of germination rate). For the fresh weight of corn, only leaf biomass was included in the analysis considering that most of the stalk biomass is not accessible to aphids. Differences between the three plants in terms of time before senescence, fresh weight, and price for 100 banker plants (without aphids) at optimal height were analyzed by non-parametric Kruskal–Wallis tests followed by Dunn's multiple comparison tests, adjusted with the Bonferroni method.

3 RESULTS

3.1 Maximal aphid charge and resistance to aphid feeding

The average maximal charge of aphids (maximal number of aphids at the highest week of production, mean ± SE) was significantly higher on finger millet, 25 806 ± 5228 aphids, than on barley, 13 077 ± 2981 aphids ($n = 32$, P-value = 0.027) (Fig. 1(a)). The average maximal charge of aphids on corn, 16 526 ± 1758, was not significantly different from the two other plants ($n = 30$, and P-value = 0.24 for finger millet and $n = 32$, P-value = 0.591 for barley) (Fig. 1(a)). Nevertheless, the temporal dynamics of aphid colonies (number of aphids ±95% CI) through time on the banker plants were different between the three species (Fig. 1(b)). The maximal charge of aphids occured on average at 2.0 weeks after inoculation for barley ($n = 17$), 3.0 weeks after inoculation for finger millet ($n = 15$), and 2.9 weeks after inoculation for corn ($n = 15$). A 50% diminution of the average abundance of aphids was reached after 2.7 weeks for barley, 3.7 weeks for corn, and 5.5 weeks for finger millet. The abundance of aphids was similar for the three plants 1 week after inoculation but significantly lower in barley than in corn and finger millet from 2 weeks ($n = 32$, t-ratio (corn) = 6.29, t-ratio (finger millet) = 9.33, and both $P < 0.001$) until 3 weeks after inoculation ($n = 32$, t-ratio (corn) = 3.91, t-ratio (finger millet) = 10.24, and both $P < 0.001$). All barley plants reached senescence before the fourth week after inoculation. Aphid colonies on finger millet were significantly larger than on corn from the second week after inoculation until corn senescence (6 weeks after inoculation) ($n = 30$, t-ratio (week two) = 3.01, t-ratio (week 3) = 6.63, t-ratio (week 4) = 8.75, t-ratio (week 5) = 7.06, and t-ratio (week 6) = 4.27, and all $P < 0.001$).

Finger millet resisted significantly longer to aphid feeding pressure than corn and barley ($n = 15$, Z-value = 3.60, and P <0.001 for corn, and $n = 17$, Z-value = 5.75, P <0.001), with a mean time before senescence (mean ± SE) of 7.0 ± 0.3 weeks compared with 4.3 ± 0.3 weeks for corn and 3.2 ± 0.1 weeks for barley (Fig. 2(a)). As presented in Fig. 2(b), contrary to corn, the condition of finger millet and barley decreased following a linear trend with no statistically significant quadratic effect of time ($n = 15$, t-value = −0.12, and $P = 0.90$ for finger millet, and $n = 17$, t-value = 0.91, and $P = 0.36$ for barley). The rate of degradation of barley was greater than the one of finger millet ($n = 32$, t-value = −2.57, and $P = 0.011$). For corn, the quadratic effect of time was statistically significant ($n = 15$, t-value = 6.81, and P <0.001) with a faster decrease at the start, and the inclination of the slope was significantly more pronounced than the finger millet, but not more than barley ($n = 30$, t-value = 6.26, and P <0.001 for finger millet, and $n = 32$, t-value = 1.23, and $P = 0.22$ for barley). According to the statistical model, the

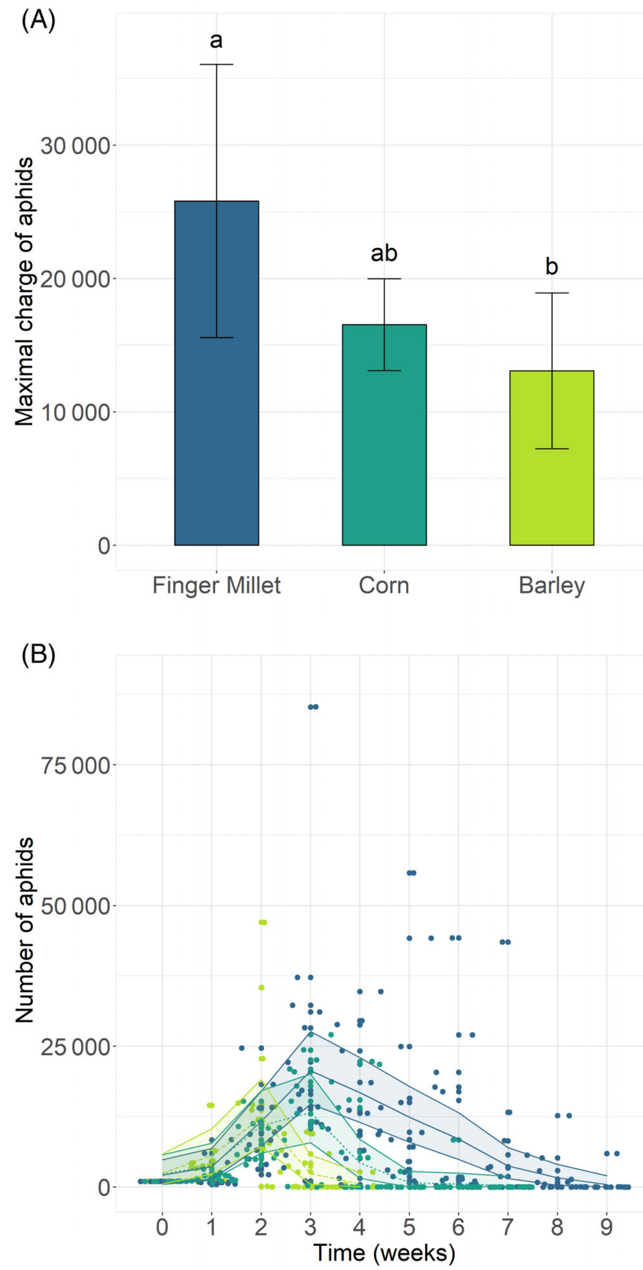

Figure 1. Aphid charge of the finger millet, barley, and corn infested by 1000 *R. padi*; (A) Maximum (mean ± 95% CI) (ANOVA followed by a Tukey multiple comparisons of means test, letters indicate a significant difference with alpha = 0.05); (B) Temporal pattern of aphid charge (mean ± 95% CI) (Generalized additive model with time, plant species, and interaction between the two factors as fixed effects, and ID as a random effect). Means and CI displayed are estimated marginal means and CI derived from the model.

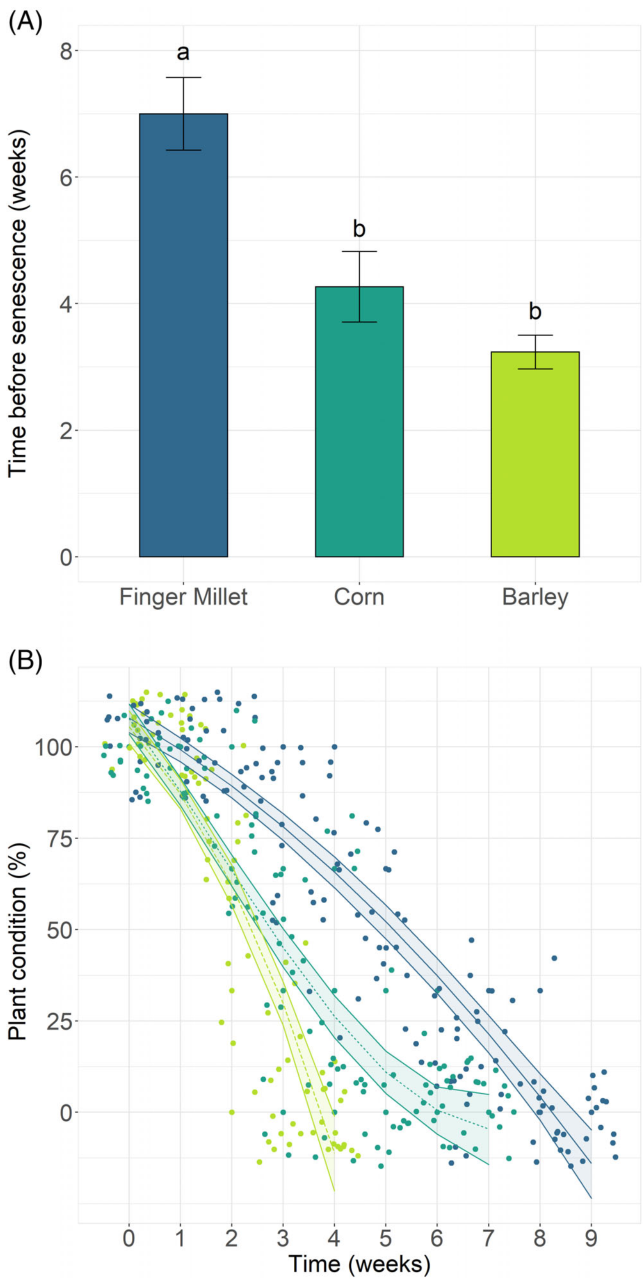

Figure 2. Resistance to aphid feeding of finger miller, barley, and corn infested with 1000 *R. padi*; (A) Time before senescence (mean ± 95% CI) (Kruskal–Wallis rank sum test followed by a Dunn's test, letters indicate a significant difference with alpha = 0.05; (B) temporal evolution of the plant condition (mean plant condition ± 95% CI) (Quadratic model with time, square time, plant, and interaction between time and plant as fixed effects, and replicate ID as random effect). Means and CI displayed are estimated marginal means and CI derived from the model.

average plant condition had decreased by 50% 2.4 weeks after inoculation for barley, 2.8 weeks for corn, and 5.2 weeks for finger millet.

3.2 Plant condition in greenhouses

In the greenhouses, the rate of degradation of barley compared to finger millet followed a similar trend to that of the laboratory experiments, the latter maintaining a better condition than barley through time (Fig. 3). The random effect of which greenhouse the plants were located in (In Montérégie or Lanaudière, Québec) was not significant (F-value = 0.00, $P = 0.89$). The global effect of the plant species on the decline of their condition through time was statistically significant ($n = 26$, F-value = 37.64, and $P < 0.001$). There was a significant difference in mean plant condition between the two species from one to four (limit of the data analyzed) weeks after introduction in the greenhouse ($n = 26$, t-value (week 1) = −4.40, t-value (week 2) = −6.04, t-value (week 3) = −6.35, t-value (week 4) = −5.26 and all $P < 0.001$).

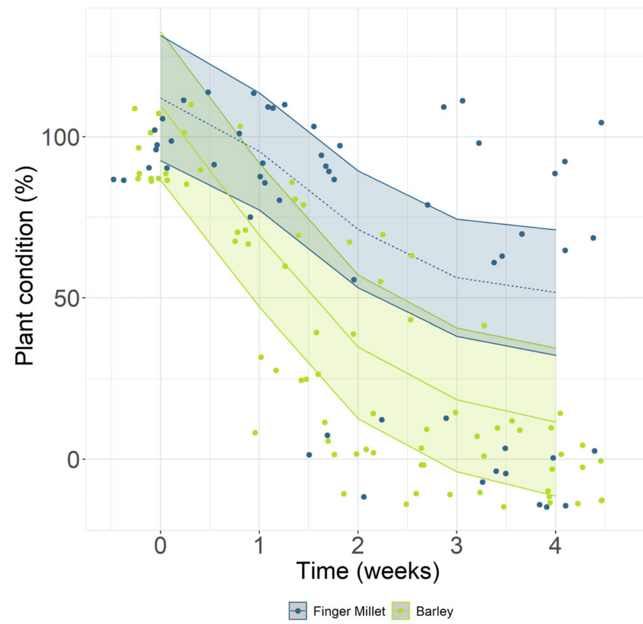

Figure 3. Decline (mean plant condition ± 95% CI) of barley and finger millet condition through time under greenhouse conditions. The difference between the two plants in terms of decline of condition through time was evaluated with a generalized additive model with time, plant species, and interaction between plant species and time as fixed effects, and ID and greenhouse as random effects. Means and CI displayed are estimated marginal means and CI derived from the model.

3.3 Growth characteristics of plants

Barley grew (mean ± SE) 2.0 times faster (2.2 ± 0.1 weeks) than finger millet (4.3 ± 0.1 weeks) ($n = 36$, Z-value = 4.58, $P < 0.001$) and 2.2 times faster than corn (4.8 ± 0.1 weeks) ($n = 39$, Z-value = 6.405, $P < 0.001$) (Fig. 4(a)). The growth time of corn and finger millet was not significantly different ($n = 39$, Z-value = −1.654, $P = 0.294$). At its optimal size (see Section 2 for determination of optimal size), the fresh weight of finger millet was significantly higher (96.9 ± 3.5 g, mean ± SE) than the one of barley (59.0 ± 1.3 g) and corn (53.0 ± 3.6 g) ($n = 36$, Z-value = 4.458, $P < 0.001$ for barley, and $n = 39$, Z-value = 5.62, $P < 0.001$ for corn). Its fresh matter was, respectively, 1.6 and 1.8 times heavier than the one of barley and corn (Fig. 4(b)). No significant difference was found between the fresh weight of barley and corn ($n = 39$, Z-value = −1.0, $P = 0.96$). Finger millet was significantly costlier (mean ± SE) to produce (4.87 ± 0.12$CAD for 100 plants) than corn (0.01 ± 0.00$CAD for 100 plants) and barley (0.25 ± 0.00 $CAD for 100 plants) ($n = 39$, $Z = 7.03$, $P < 0.001$ for barley and $n = 36$, $Z = 3.25$, $P = 0.003$ for corn), being 829.1 times more expensive than corn and 19.2 times more expensive than barley (Fig. 4 (c)). Barley was 43.3 times costlier to produce than corn ($n = 36$, $Z = -3.66$, $P < 0.001$).

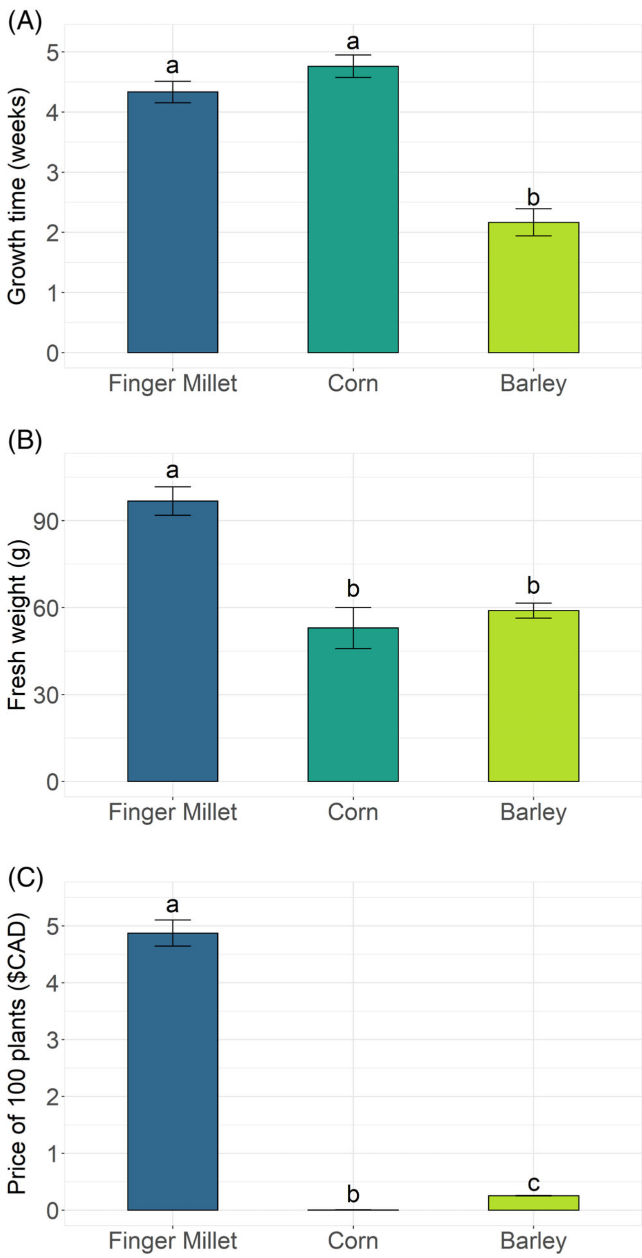

Figure 4. Growing parameters of barley, corn, and finger millet. (A) Growth time (mean ± 95% CI) to reach optimal size; (B) Fresh weight (mean ± 95% CI) at optimal height; (C) Price to produce 100 plants of the three plant species (Kruskal–Wallis tests followed by Dunn's multiple comparison tests for non-parametric data, adjusted with the Bonferroni method for A, B, and C). Letters indicate a significant difference with alpha = 0.05.

4 DISCUSSION

Overall, the results show that the three plant candidates are suitable banker plants. However, they have specific characteristics that predispose them to be used in different contexts. Barley had the advantage of growing rapidly, in 2 weeks, and at a low cost. Nonetheless, as predicted, it produced less fresh biomass and sustained a lower maximal charge of aphids for a shorter period (both under controlled conditions and in the greenhouse). Indeed, the results of the experiment under controlled conditions showed that, for barley, the colony of banker prey and the plant condition decreased very rapidly. Both parameters were reduced by 50%, respectively, only 2.6 weeks and 2.4 weeks after inoculation. This means that even before reaching senescence (at an average of 3.2 weeks) barley's capacity to sustain a high population of biocontrol agents was already significantly lessened, because of its poor condition and of the low population of banker prey it sustained. This implies that this plant needs to be replaced often, most likely, 1 or 2 weeks after inoculation, as stated by Van Driesche *et al.*[18] Those characteristics make that plant species more appropriate for rapid crop cycles, like lettuce which only takes 4 weeks to grow before being harvested.[36] The fact that this plant is cheap and fast to grow and that it reaches its maximal aphid charge faster than corn and finger millet (after 2 weeks) may compensate for its need to be replaced often. Nonetheless, the fact that it does not sustain a high banker prey population means it would most likely support a smaller population of biocontrol agents than the other plants unless a very high quantity of banker plants is introduced in the greenhouse, which is unlikely due to space constraints.[5,37] As described by Yano,[8] the success of biocontrol using banker plants in a closed system is possible if the initial number and growth rate of the pest population can be compensated by the predator/parasitoid population and its predation/parasitism rate. Therefore, because barley would probably provide a lower population of natural enemies, it might not be efficient for aphid pests having a particularly high population growth rate, such as the melon aphid on cucurbits,[38] or for slow-growing crops that allow the population of pests to increase for too long.

The finger millet had opposite benefits to barley. It had the advantage of sustaining an abundant population of banker prey, partly because the plant has a very dense architecture,[11] providing important fresh biomass at maturity. Moreover, population decline on finger millet was slower than on the two other plants (reaching a 50% diminution only 5.5 weeks after inoculation, i.e., 2.1 and 1.5 times slower than on barley and corn, respectively). This implies that finger millet could probably sustain a larger population of biocontrol agents. It might also be appropriate for a larger range of biocontrol agents including voracious predators, like syrphids[39] or ladybeetles that need a high population of banker prey.[40] Again, since bigger and more efficient (voracious or with a high parasitism rate) natural enemies can control faster-reproducing pests,[8] finger millet could be appropriate for pests with high population increase rates. Nevertheless, the consumption of the banker prey by natural enemies also depends largely on the architecture of the plant.[41,42] Indeed, as Prado and Frank[43] showed in a greenhouse experiment, *A. colemani* reduced *M. persicae* densities to a lesser extent (52% vs. 93%) on compact black pearl pepper (*Capsicum annuum* L. 1753) plants compared with regular ones. The dense architecture of finger millet might therefore complicate access to banker prey and reduce the potential production of natural enemies of this plant. However, predators and parasitoids can also have specific searching patterns and the availability of aphids might depend on the natural enemy concerned.[15] Furthermore, finger millet needed more time both to grow and to reach its maximal charge of aphids and was more costly to produce than barley. This means, coherently with the literature,[11] that this plant needs less maintenance, but more investment for its production.

Corn shares some benefits with the other two plants. Like barley, it was cheap to grow but did not produce important fresh biomass at its optimal height. Like finger millet, it grew slowly. Even though it did not produce an important fresh plant biomass, its mean maximal charge of aphids tended to be higher than the one of barley and lower than the one of finger millet but was not significantly different from both plants. It did not, however, tolerate aphid feeding as aphids and plant condition decreased rapidly, reaching a 50% diminution at 3.7 weeks and 2.8 weeks, respectively, after inoculation. Those results are different from the findings of previous studies. Jacobson and Croft[16] stipulated that corn could last around 3 months under the feeding pressure of aphids under greenhouse conditions (21–24 °C). This could be because aphid populations remained low due to pressure imposed by *A. colemani*. Plants indeed had to be reinoculated once during their experiment. The difference could also come from the fact that plants were potentially not the same height (not mentioned) as in the present experiment. If the corn was allowed to grow more, it might have reached a more resilient state and thus have resisted aphid feeding better. Nonetheless, in the present case, the poor resistance of corn was similar to the one of barley, meaning it would need to be replaced every 1 or 2 weeks after inoculation, making it more appropriate for short crop cycles. As it is cheaper to produce, on a scale of 19.2 and 829.1 times compared with barley and finger millet, even if it involves more maintenance than finger millet, and is longer to produce than barley, it is still an interesting banker plant species from an economic point of view. It might also be able to support a slightly bigger population of biocontrol agents[5,37] than barley, or species that are a little more voracious or have a slightly higher parasitism rate. Its use should, however, be confined to short crop cycles and non-inundative use as the natural enemies developing on corn might not be able to control a very high population of pests.

Although the results highlight the great importance of considering plant characteristics when choosing a banker plant system, other critical aspects must also be considered. Among other things, the biocontrol agents targeted need to oviposit and develop well on the banker plant system.[1,5] They must have an oviposition preference for the focal crop infested with the pest over the banker plant system, and the plant species of the latter can influence this balance.[1,6,13] Furthermore, as most of the results are from laboratory experiments, future studies should examine the utilization of the banker plants by natural enemies under greenhouse conditions. Investigation of the potential to combine banker plant species to optimize their use by different beneficials could also be interesting. Chen *et al.*[44] recently showed that the combination of two banker plant systems, *Ricinus communis* L. 1753 with *Trialeurodes ricini* (Misra, 1924) and *Glycine max* L. Merr. 1917 with the aphid *Megoura crassicauda* Mordvilko, 1919 had a positive impact on the control of two major pests in tomato, *M. persicae* and *Bemisia tabaci* (Gennadius, 1889). The combination allowed the population of two important natural enemies, *Encarsia formosa* Gahan 1924 and *Propylea japonica* (Thunberg, 1781) to increase enough for efficient control of both pests. This aspect is of crucial importance as several pests are often present at the same time in crops, so multiple biocontrol agents are needed. Finally, in the present experiment, the height of the plants was determined as the optimal compromise between length of development, space utilization in a greenhouse, and production of fresh biomass. Other experiments using the same banker plant species with different heights would be interesting since, as suggested with corn, it might have an impact on plant resistance to aphid feeding and greenhouse conditions. All of those aspects remain to be studied, and the choice of banker plant system should be based not only on the overall aspects of the plant species, but also on its interaction with the crop and natural enemies, and its compatibility with the growth parameters of the targeted crop.[1,5]

5 CONCLUSION

Overall, each of the three banker plants seem suitable in different specific contexts. Corn, and even more so barley, could be more suitable for short crop cycles and targeted pests with a slower population growth rate than finger millet. Even if they are adequate for similar types of systems, they do not present the same benefits since barley grows faster than corn but is costlier. Finger millet could be more appropriate for long crop cycles with fast reproducing natural enemies, voracious predators, or highly efficient parasitoids and, like corn, would need more planning and investment at the beginning of the growing season. Finally, it appears that the phyto diversity has been very poorly investigated to find suitable banker plants. For example, the work by Khan and collaborators[45] in Africa demonstrated that large studies on numerous plant candidates may allow to find better banker/trapping/attractive or repulsive plants suitable for non-chemical control.[46]

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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