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Valorization of Agricultural Side-Streams for the Rearing of Larvae of the Lesser Mealworm, *Alphitobius diaperinus* (Panzer)

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Abstract: During the last decade, insects have shown up as a promising answer to the increasing animal protein demand for a continuously growing human population. A wide spectrum of substrates of plant origin can be currently used as insect feed; the sustainability of insect rearing though greatly increases when organic side-streams and wastes are valorized and upcycled through their bioconversion with insects. Additionally, the exploitation of low-cost organic residues as insect feed can also significantly suppress the rearing cost and, consequently, the price of the insect meal. In this context, the aim of our work was to evaluate organic side-streams, generated through several agro-industrial processes, as feeding substrates for the larvae of the lesser mealworm, *Alphitobius diaperinus*. In a laboratory trial, eleven agricultural side-streams were provided to larvae singly to assess their potential to support complete larval development, whereas in the second trial, larvae were fed two groups of isoproteinic diets consisting of the side-streams that performed well in the first trial. Our results showed the suitability of several agricultural side-streams as feed for *A. diaperinus* larvae, e.g., barley by-products (classes I and II), sunflower meal, cotton cake and oat sidestream, which, when fed singly, efficiently supported larval growth, resulting in high survival rates and final larval weights, comparable to the control. Similarly, several of the side-streams-based diets tested were shown to be suitable for *A. diaperinus* rearing. These results aim to contribute to the utilization of agricultural side-streams singly or in composed diets for the rearing of *A. diaperinus* larvae.

Keywords: insects as nutrient source; insect feeds; larval growth; lesser mealworm; agricultural side-streams

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1. Introduction

Insect farming has been proposed as a new means to produce high-quality nutrients since insects are considered a promising alternative nutrient source that can be exploited for animal feed [1–3], human food [2–4], as well as for other technological applications in the field of cosmetics [5,6], bioplastics [7] or medicine [8]. Most of the research on the topic has been focused on a few insect species and particularly on the black soldier fly, *Hermetia illucens* (L.) (Diptera: Stratiomyidae), and the yellow mealworm, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae). One insect species that has been so far overlooked and not extensively studied as a nutrient source is the lesser mealworm, *Alphitobius diaperinus* (Panzer) (Coleoptera: Tenebrionidae) [9]. The inclusion of this species as an ingredient in aqua feeds has been approved in the EU since 2017 [10], whereas recently EU permitted the use of *A. diaperinus* meal also in poultry and pig diets [11]. From a nutritional point of view, its larvae are rich in protein and lipids [12], whereas their amino acid composition is similar to that of soybean protein [13]. Due to their high nutritional value, *A. diaperinus* larvae have been proposed for several food applications [14,15]. Current research on the rearing of *A. diaperinus* has focalized on the optimization of the rearing conditions, e.g., relative humidity and temperature [16,17], as well as its diet [16,18–20].

One of the characteristics of insect rearing that renders insect production so attractive is their ability to be reared on low-cost organic side-streams and wastes [21,22]. The valorization and upcycling of locally produced side-streams and by-products and their bioconversion to high-value animal protein through insect rearing is fully aligned with circular economy practices that are currently strategically favored and promoted at the EU level [23,24]. In the case of *A. diaperinus*, several side-streams stemming from the agri-food sector have been exploited as insect-feeding substrates [25–28]. For instance, when a variety of by-products of the cleaning process of cereal and legume seeds, i.e., lupin, triticale, lentil, lucerne, broad bean and barley, was evaluated for the larval development of *A. diaperinus*, all cereal by-products efficiently supported complete larval development, whereas lupin gave the best results among the legume by-products evaluated [28]. Similarly, rapeseed meal and wheat middlings supported good larval growth, especially when they were combined with brewery grains as wet feed [26]. Apart from larval performance, it has been demonstrated that larval production on side-streams may result in changes in the larval nutrient composition of *A. diaperinus* compared to the standard diet [27]. Therefore, it becomes evident that organic side-streams and wastes could serve as an important pool of nutrients for insects; their potential, though has to be fully unfolded.

In this framework, the aim of the present study was to determine the larval development of *A. diaperinus* on a series of Greek agricultural side-streams tested singly or as ingredients of isoproteinic diets. This paper is a follow-up study to previous work on the suitability of the same side-streams and side-stream-based diets as rearing substrates for *T. molitor* larvae [29].

2. Materials and Methods

2.1. Insects

Rearings of *A. diaperinus* were maintained in the Laboratory of Entomology and Agricultural Zoology of the University of Thessaly (Volos, Magnesia, Greece) since 2018, when larvae were originally bought from a local retailer (FEEDERS, Thessaloniki, Greece). Insect cultures were maintained in walk-in-chambers at dark, 26 ± 1 °C, 55% relative humidity (r.h.), and were fed a substrate composed of wheat bran and baker's yeast (Angel Yeast Co., Ltd., Yichang, China) at 9:1 ratio. Insects were provided with fresh potato slices as a moisture source twice a week. Egg acquisition was performed by letting *A. diaperinus* adults lay their eggs for 7 d in white wheat flour. Thereafter, adults were separated from the oviposition substrate, and eggs were sieved by using a 250 μm opening sieve. Newly-hatched larvae (<2 d old) were collected and used for experimentation.

2.2. Side-Streams

Eleven agricultural side-streams originating from the production and processing of barley, oats, sugar beet, cotton, sunflower, peas and vetch were evaluated. The nutrient composition of the side-streams and their energy content have been previously described [29] and are provided here as Supplementary Materials (Table S1). All side-streams were finely ground (Thermomix TM31-1C, Vorwerk Elektrowerke GmbH & Co. K, Wuppertal, Germany) to improve feed intake from *A. diaperinus* larvae, sieved at 500 μm and kept at ambient conditions until further use.

2.3. Bioassay I: Single Side-Streams

Twenty newly-hatched larvae were weighed and introduced in plastic vials (7.5 cm Ø, 8.8 cm in height) together with 1 g of the tested side-streams. A mixture of wheat bran (90%) and baker's yeast (10%) was used as control, whereas three times a week, larvae were given one carrot slice (0.6 ± 0.1 g) as a moisture source. Larvae were allowed to grow uninterrupted for an interval of 4 weeks. After the termination of this interval, for each vial larvae were separated from the diet, and larval survival and total weight were recorded. Briefly, the number of live larvae was divided by the number of larvae initially introduced into the vials to calculate the percentage of survival. The same procedure was repeated every two weeks until the emergence of the first pupa. During the bioassay, all vials were checked three times per week to prevent larvae from running out of feed. If the feed was almost consumed, new feed was added. There were six replicates for each dietary treatment. Development time, i.e., the time from the initiation of the bioassay until the emergence of the first pupa, was recorded for each vial. The feed conversion ratio (FCR) for each treatment was calculated according to Equation (1):

$$\text{FCR} = (\text{Feed consumed})/(\text{Weight gained}) \tag{1}$$

For FCR calculations, the assumption that all feed offered to the larvae was consumed was made, whereas carrot weight was not taken into account for the calculations. The specific growth rate (SGR) was calculated using Equation (2):

$$\text{SGR} = 100 \times (\text{lnFBW} - \text{lnIBW})/\text{days}, \tag{2}$$

where FBW and IBW stand for the final and initial body weight, respectively. Both SGR and FCR were calculated on a fresh weight basis.

2.4. Bioassay II: Side-Streams-Based Isoproteinic Diets

Based on the results of Bioassay I, two sets of isoproteinic diets at 16.9 and 20% protein were designed as previously described [29]. The percentages in which each side-stream was included in the two sets of isoproteinic diets, as well as their proximate compositions, are provided here as Supplementary Materials (Tables S2 and S3). For the low protein level (Group A), wheat bran was used as a control, whereas for the high protein level (Group B), a diet consisting of wheat bran and baker's yeast (9:1) was the control. The same experimental procedure described for Bioassay I was followed.

2.5. Statistical Analysis

Prior to analysis, FCR and SGR data, as well as final survival rates and final individual larval weights, were tested for homogeneity of variance (Brown Forsythe test) and for normal distribution (Shapiro–Wilk test), and no data transformation was required. All data, separately for each bioassay, were submitted to an one-way analysis of variance (ANOVA), with FCR, SGR, final survival rate and final individual larval weight as response variables and dietary treatment as the main effect. Afterward, means were separated using the Tukey HSD test ($p < 0.05$). A Kaplan–Meier analysis was performed to assess whether development time significantly differed among dietary groups, whereas differences among dietary treatments were determined with a Mantel–Cox test. The Pearson correlation coefficient was used to assess correlations between development time and FCR and SGR. All analyses were performed using SPSS 26.0 (IBM Corporation, Armonk, NY, USA).

3. Results

3.1. Bioassay I: Single Side-Streams

The survival rates of *A. diaperinus* larvae over time on the evaluated side-streams are shown in Figure 1, whereas the final survival rates at the end of the bioassay are presented in Table 1. The highest final survival rates were recorded for barley (class I) (84%) and oat side-streams (77.5%) and were similar to the survival rate recorded for the control (78%). In contrast, survival was low for both the vetch side-stream (class II) and cotton seed meal and did not exceed 10.8% at the end of the bioassay.

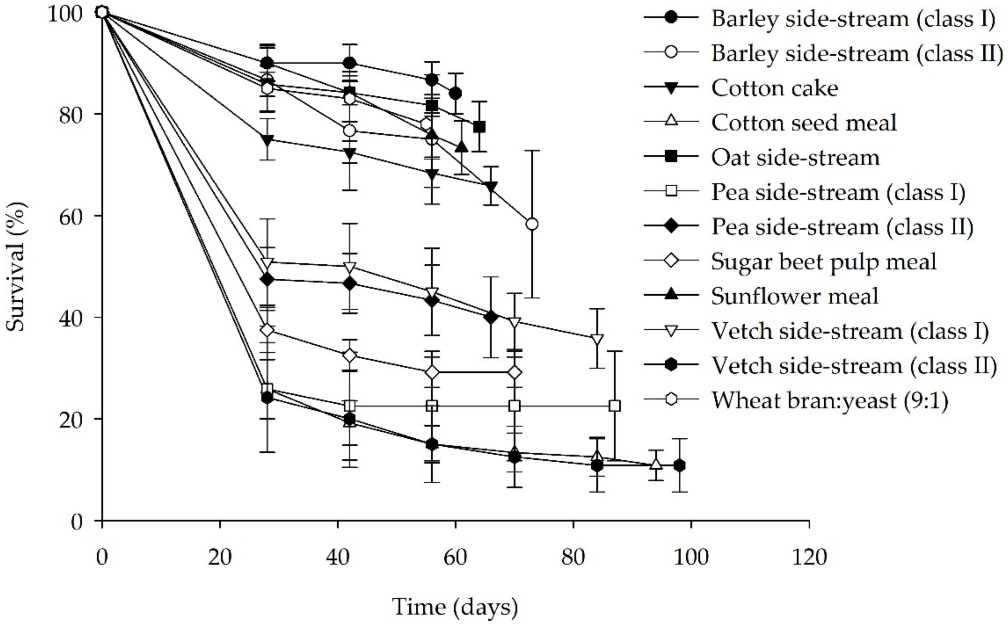

Figure 1. Percentage of survival (%) of *Alphitobius diaperinus* larvae fed eleven (11) agricultural side-streams and a control diet consisted of wheat bran and baker's yeast (9:1). For all treatments, values refer to means (n = 6).

Table 1. Feed conversion ratio (FCR), specific growth rate (SGR; %), final survival rate (%) and final individual larval weight (mg) of *Alphitobius diaperinus* larvae fed eleven (11) agricultural side-streams and a control diet consisting of wheat bran and baker's yeast (9:1).

Substrate	FCR	SGR (%)	Final Survival Rate (%)	Final Individual Larval Weight (mg)
Barley side-stream (class I)	5.2 ± 0.6 d	7.4 ± 0.7 a	84.0 ± 4.0 a	13.6 ± 1.6
Barley side-stream (class II)	5.5 ± 18 d	5.6 ± 0.7 abcd	58.3 ± 14.5 ab	16.9 ± 1.2
Cotton cake	5.5 ± 0.7 d	6.3 ± 0.2 abcd	65.8 ± 3.7 ab	17.4 ± 1.8
Cotton seed meal	22.9 ± 2.1 a	2.5 ± 0.4 e	10.8 ± 3.0 c	16.3 ± 3.2
Oat side-stream	4.1 ± 0.3 d	7.0 ± 0.4 abc	77.5 ± 5.0 a	18.2 ± 0.5
Pea side-stream (class I)	15.7 ± 4.6 b	4.0 ± 0.4 de	22.5 ± 10.8 c	11.3 ± 2.5
Pea side-stream (class II)	12.3 ± 2.4 bc	4.8 ± 0.6 bcde	40.0 ± 8.0 bc	12.3 ± 1.7
Sugar beet pulp meal	14.3 ± 1.3 b	4.6 ± 0.3 cde	29.2 ± 3.0 c	16.6 ± 2.0
Sunflower meal	5.7 ± 1.2 d	7.2 ± 0.4 ab	73.3 ± 5.3 a	16.0 ± 2.4
Vetch side-stream (class I)	12.7 ± 2.3 bc	4.3 ± 0.4 de	35.8 ± 6.0 bc	15.2 ± 1.7
Vetch side-stream (class II)	8.0 ± 2.9 bc	3.8 ± 0.7 de	10.8 ± 5.2 c	12.7 ± 3.2
Wheat bran/yeast (9:1) (control)	3.9 ± 0.1 d	7.8 ± 0.6 a	78.0 ± 4.1 a	16.1 ± 2.5

Values represent means ± SEM (n = 6). Within each column, means followed by the same lowercase letter do not significantly differ according to Tukey HSD test ($p < 0.05$). Where no letters exist, no significant differences were noted.

Apart from the survival, variation was also recorded for larval growth, expressed as individual larval weight (Figure 2), which at the end of the bioassay fluctuated between 11.3 [pea side-stream (class I)] and 18.2 mg (oat side-stream) (Table 1); however, in all cases, differences among dietary treatments were not significant. High larval weights at the end of the bioassay were also recorded for cotton cake (17.4 mg) and barley side-stream (class II) (16.9 mg), as well as for the control (16.1 mg).

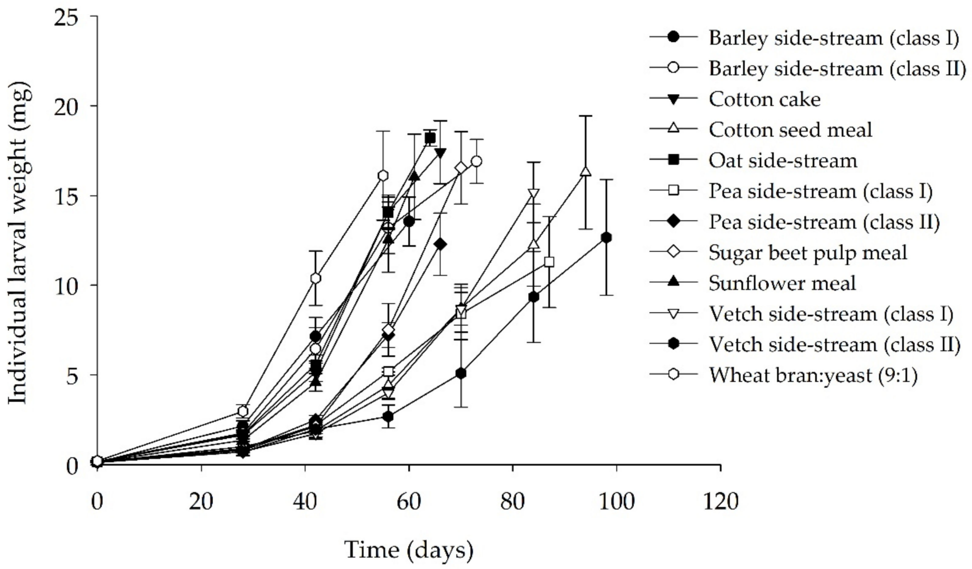

Figure 2. Individual larval weight (mg) of *Alphitobius diaperinus* larvae fed eleven (11) agricultural side-streams and a control diet consisted of wheat bran and baker's yeast (9:1). For all treatments, values refer to means (n = 6).

The development time for *A. diaperinus* larvae was significantly affected by the dietary treatment (Mantel–Cox $\chi^2 = 64.4$, df = 11, $p < 0.001$) and ranged between 55 (control) and 98 d [vetch side-stream (class II)] (Figure 3). FCR took its lowest values, when larvae were fed wheat bran (control) (3.9), oat side-stream (4.1) and barley side-stream (class I) (5.2) (Table 1). The highest FCR values were recorded for cotton seed meal (22.9) and pea side-stream (class I) (15.7). SGR values varied between 2.5 (cotton seed meal) and 7.8 (control). In general, there was a correlation between shorter development times and lower FCR values ($r = 0.463$, $p < 0.001$), as well as higher SGR values ($r = -0.737$, $p < 0.001$).

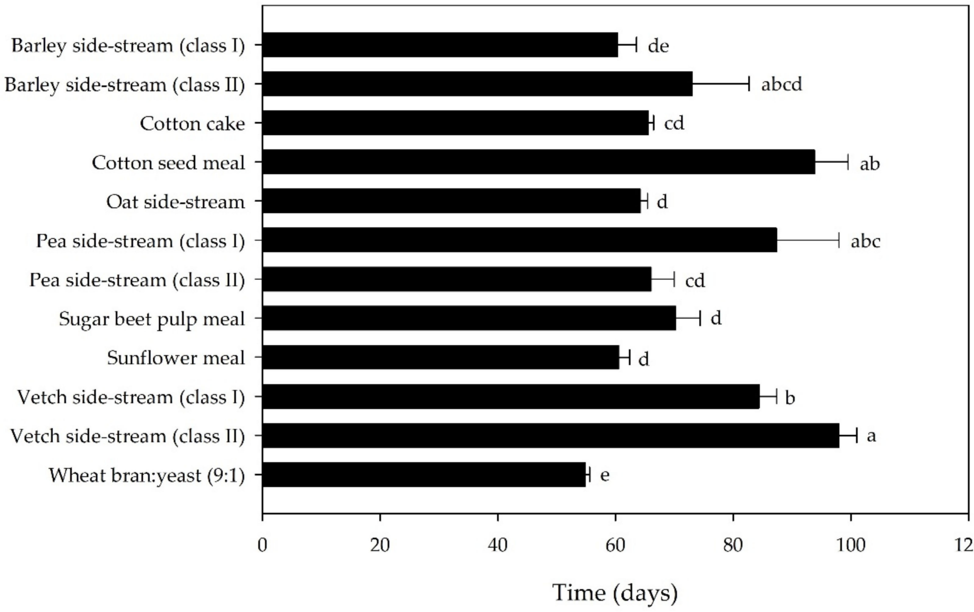

Figure 3. Development time (days) of *Alphitobius diaperinus* larvae fed eleven (11) agricultural side-streams, and a diet control consisted of wheat bran and baker's yeast (9:1). Means followed by the same lowercase letter are not significantly different. For all treatments, values refer to means ± SEM (n = 6; df = 11; p = 0.05).

3.2. Bioassay II: Side-Streams-Based Isoproteinic Diets

In general, similar survival patterns were recorded for both diet groups (Figure 4), with the final survival rate ranging between 30.8 and 43.3% for Group A and between 39.2 and 45.0% for Group B at the end of the bioassay (Table 2).

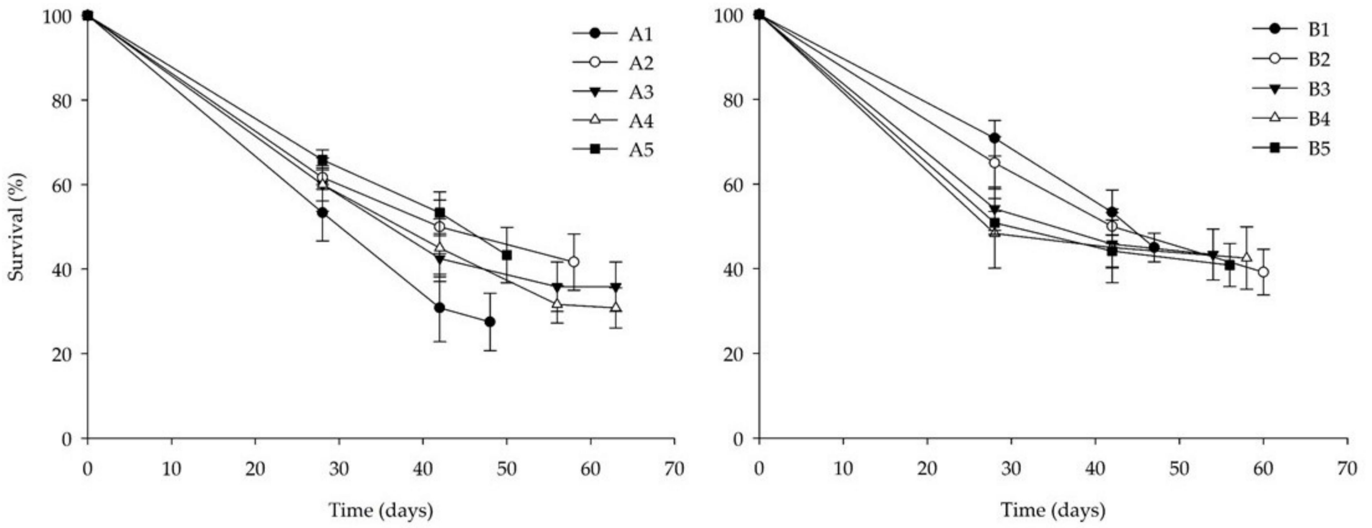

Figure 4. Survival rate (%) of *Alphitobius diaperinus* larvae fed two groups of isoproteinic diets (Group A = 16.9% protein; Group B = 20.0% protein). For all treatments, values refer to means ($n = 6$).

Table 2. Feed conversion ratio (FCR), specific growth rate (SGR; %), final survival rate (%) and final individual larval weight (mg) of *Alphitobius diaperinus* larvae fed two groups of isoproteinic diets (Group A = 16.9% protein; Group B = 20.0% protein).

Diet	FCR	SGR (%)	Final Survival Rate (%)	Final Individual Larval Weight (mg)
A1	12.0 ± 1.8	8.0 ± 0.6 ab	33.0 ± 7.5	14.8 ± 5.1
A2	8.6 ± 2.8	6.6 ± 0.5 ab	41.7 ± 6.8	20.9 ± 1.4
A3	9.4 ± 1.2	6.4 ± 0.6 ab	35.8 ± 5.8	19.1 ± 1.5
A4	12.9 ± 2.7	5.7 ± 0.5 b	30.8 ± 4.7	19.1 ± 7.7
A5	12.8 ± 3.9	6.5 ± 0.9 ab	43.3 ± 6.5	16.7 ± 2.0
B1	7.0 ± 0.5	8.9 ± 0.4 a	45.0 ± 3.4	19.4 ± 1.3
B2	10.4 ± 0.9	6.3 ± 0.6 b	39.2 ± 5.4	17.1 ± 1.5
B3	10.4 ± 1.8	7.0 ± 0.3 ab	43.3 ± 6.0	16.3 ± 1.8
B4	11.4 ± 2.6	6.9 ± 0.4 ab	42.5 ± 7.4	16.2 ± 2.3
B5	8.1 ± 0.7	7.4 ± 0.3 ab	40.8 ± 5.1	21.5 ± 1.7

Values refer to means ± SEM ($n = 6$). Within each column, means followed by the same lowercase letter are not significantly different according to Tukey HSD test ($p < 0.05$). Where no letters exist, no significant differences were noted.

Individual larval weight at the end of Bioassay II for Group A varied between 14.8 (A1) and 20.9 mg (A2), whereas for Group B, final larval weight fluctuated between 16.2 (B4) and 21.5 mg (B5) (Figure 5, Table 2).

The development time varied between 46.8 and 62.7 d for all diets tested (Figure 6), the shortest being recorded for both control diets (46.8 d for A1; 47.8 d for B1) and the longest for A3 (62.7 d), A4 (62.5 d) and B2 (60.2 d) (Figure 6). The lowest value of FCR was recorded for the wheat bran/yeast (9:1) mixture (7.0), used as a control diet for Group B. In contrast, high FCR values were calculated for A1 (12.0), A4 (12.9) and A5 (12.8). FCR was correlated with the development time ($r = 0.314$, $p < 0.001$), whereas SGR varied between 5.7 (A4) and 8.9 (B1) and was negatively correlated with the development time ($r = -0.702$, $p < 0.001$).

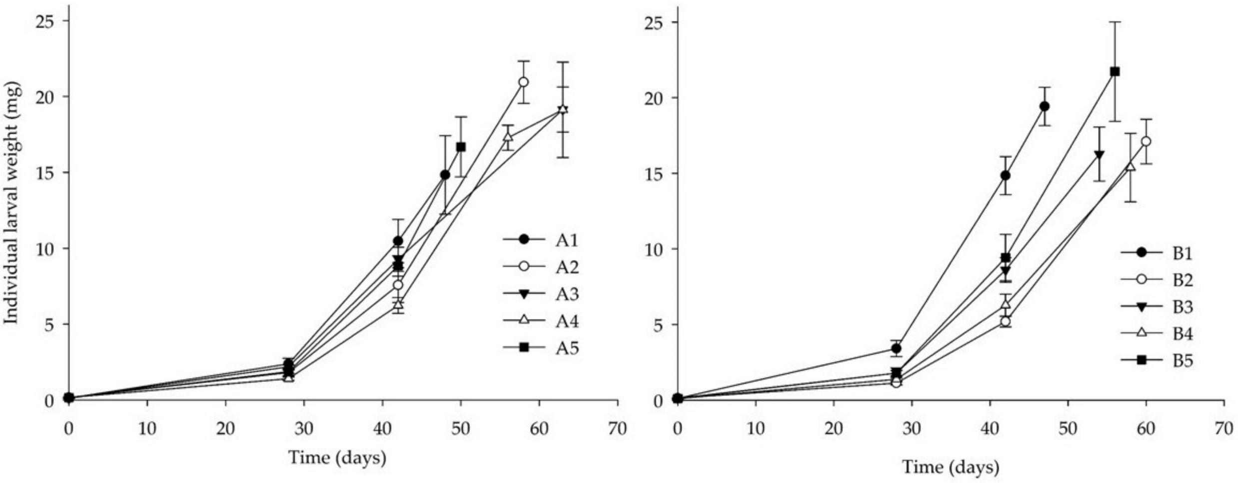

Figure 5. Individual larval weight (mg) of *Alphitobius diaperinus* larvae fed two groups of isoproteinic diets (Group A = 16.9% protein; Group B = 20.0% protein). For all treatments, values refer to means (n = 6).

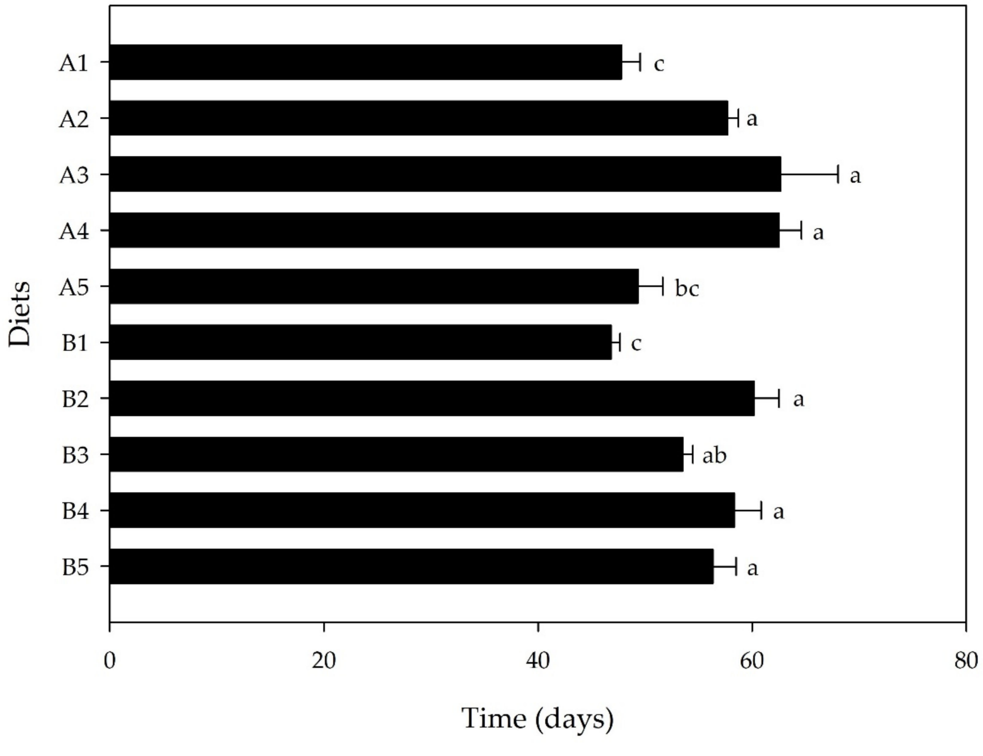

Figure 6. Development time (days) of *Alphitobius diaperinus* larvae fed two groups of isoproteinic diets (Group A = 16.9% protein; Group B = 20.0% protein). Means followed by the same lowercase letter are not significantly different. For all treatments, values refer to means ± SEM (n = 6; df = 11; p = 0.05).

4. Discussion

The results of this study showed the suitability of several agricultural side-streams as feeding substrates for the larvae of *A. diaperinus*. When fed singly, barley side-streams (classes I and II), sunflower meal, cotton cake and oat side-stream efficiently supported larval growth, as indicated by the high final survival rates (>65%) and final larval weights (>13.6 mg) recorded for these side-streams that clustered together with the control. The good larval performance of *A. diaperinus* larvae on cereal side-streams was not a surprise, as this species can be found in nature infesting stored grain commodities, such as wheat, barley, maize, rice and related amylaceous substrates, as a secondary storage insect pest [30,31]. Several previous studies have shown the preference of *A. diaperinus* for amylaceous commodities [28,32]. For instance, among more than 30 different commodities, the population growth of *A. diaperinus* was highest in the amylaceous substrates tested, i.e., the cereal grains, as well as the non-grain cereal commodities, such as brans, flours or flakes [32]. In a similar study, increased growth was reported when larvae were fed a by-product of the seed cleaning process of triticale [28]. However, apart from the cereals tested, the results of our work showed the potential of two non-amylaceous commodities, i.e., sunflower meal and cotton cake, as feedstock for *A. diaperinus* larvae, which, to our knowledge, were evaluated for the first time for *A. diaperinus* rearing. Both substrates, though, have previously given promising results when fed to *T. molitor* larvae [29]. The suitability of various side-streams and by-products for the rearing of *A. diaperinus* larvae has also been demonstrated previously [26,28]. In a recent study, *A. diaperinus* larvae fed a by-product of the lupin seed cleaning process gained the highest individual larval weight (17 mg) among the substrates tested at the end of the bioassay, even higher than the control [28]. In the same work, by-products of the cereal seeds cleaning process, i.e., triticale, barley or durum wheat by-product, were also shown to support good larval performance. In a similar study, good results were also obtained when two other side-streams, i.e., wheat middlings and rapeseed meal, were fed singly to *A. diaperinus* larvae [26]. These results indicate the potential of a broad range of organic remains of several industrial processes of the agri-food sector as feeding substrates for the larvae of *A. diaperinus*. However, not all side-streams tested in this study were able to support the efficient growth of *A. diaperinus* larvae when fed singly. Larval development on vetch and pea side-streams, as well as cotton seed meal, was slow and restricted, resulting in low final survival rates. Limited growth has also been reported for *T. molitor* larvae fed the same pea side-stream (class II), and this result was attributed to the presence of anti-feedant components in this substrate [29]. This may be the case also for *A. diaperinus*.

Feeding insects with single-ingredient diets is subject to several limitations, as one single substrate may not fulfill the nutritional requirements of the insects. Therefore, following the rule of compound diets which is common practice for all traditional livestock animals, nutritionally balanced compound diets have to be designed and evaluated for successful insect rearing [33]. Several studies have investigated the effect of side-stream-based diets on the development of *A. diaperinus* larvae [25–27]. For instance, when diets based on six side-streams originating from the agri-food sector, i.e., rapeseed meal, wheat middlings, corn gluten feed, rice bran, distillers dried grains and solubles (DDGS) and brewery grains, were evaluated, *A. diaperinus* larvae grew on all diets; however, larval growth performance varied among the diets tested. Using similar side-streams, i.e., maize DDGS, spent grains, bread and cookie remains, beer yeast and potato steam peelings, an earlier study designed and evaluated several experimental diets and reported, for some of the diets tested, larval survival and growth rates similar to the control diet [25]. However, all previous aforementioned studies reported on not nutritionally balanced diets, e.g., diets with diverse protein content. However, this renders comparison of the generated results rather difficult. Therefore, in the present study, we designed and evaluated isoproteinic diets based on the side-streams that performed better when singly evaluated. To our knowledge, this is the first time that diets with the same protein level were comparatively evaluated for the growth of *A. diaperinus* larvae. Our results show some variation among the dietary treatments tested regarding larval growth and survival, as well as development time, FCR and SGR, even among diets with the same protein level. However, in most cases, differences among diets for the growth parameters evaluated were not significant. For instance, the development time for larvae fed the A5 diet was similar to the wheat bran control and significantly shorter than the rest of the diets tested within the same protein level (20.0%). This finding suggests that apart from the protein content of the diet, other factors related to the diet nutrient profile, e.g., amino acid and fatty acid profile or mineral content, should be taken into account when designing insect diets for mass rearing [33]. Similar results, i.e., variable larval performance, were also reported for *T. molitor* larvae fed two groups of isonitrogenous diets [29], and the authors attributed this variation to the diverse nutrient profile, as well as the nutrient availability and the digestibility of the diets. The nitrogen and subsequently the protein content of the diet, though, remains a crucial parameter when formulating optimal diets, which significantly affects larval performance. When *A. diaperinus* larvae were reared on wheat bran–based feeding substrates with increasing percentages of yeast (0–40%) and subsequently increasing nitrogen (2.7–4.8) and protein (16.7–30%) content, it was shown that the higher the diet protein content, the higher the survival and growth rate, and the shorter the development time [16]. In the present study, this was not always the case; namely, in several cases, *A. diaperinus* larvae performed similarly when fed the low protein diets than when reared on the high protein diets. A similar conclusion was also drawn when the same isoproteinic diets were fed to *T. molitor* larvae [29].

In the present study, FCR values for both bioassays ranged between 3.9 and 22.9, similar to the ones calculated for *A. diaperinus* in previous studies [25,28]. For instance, when *A. diaperinus* larvae were fed three experimental diets based on agri-food side-streams and a commercial control diet, FCR took values between 3 and 24.6, the highest being recorded for the low in protein and high in starch diet [25]. Interestingly, when larvae were fed the control diet consisting of wheat bran and yeast used in both Bioassays I and II, different FCR values were calculated for the two bioassays, i.e., 3.9 for Bioassay I and 7.0 for Bioassay II (Diet B1). Differences were also recorded in the survival rate between the two bioassays when larvae were fed the control diet (final survival rate of 78% and 45% for Bioassays I and II, respectively). As both studies were conducted under the same conditions and following a similar protocol, differences may be due to the different batches of insects used for each bioassay. Specifically, the larvae used in each bioassay originated from adults of different ages; namely, the larvae used in Bioassay II were produced from older females compared to Bioassay I. It is well known that adult age may affect various factors relevant to reproduction, as well as offspring fitness. For the relative species *T. molitor*, it has been shown that the female reproductive output was reduced with the increase in the adult age [34], whereas larvae originating from old females grew faster than the respective ones from young females [35]. For the same species, a reduction of the hatching rate has been reported with the increase in the parents' age [36], whereas as far as it concerns the longevity of adult offspring, it has been shown that it is reduced with the increase in the age of the parents [36,37]. No information is available on the effect of adult age on the performance of *A. diaperinus* offspring. Therefore, further experimentation is needed in this direction that could provide an explanation for the variation observed in our study.

5. Conclusions

The results of our work demonstrate the ability of *A. diaperinus* larvae to be reared on a wide variety of agricultural side-streams, as well as a range of compound diets based on these side-streams. Moreover, it has been shown that larvae may perform differently even when fed diets with the same protein content, indicating that apart from the protein content, other parameters should also be taken into consideration when designing optimal insect diets. As the insect market is continuously growing [38], it is becoming more and more critical to identify promising, preferably underexploited substrates for insect rearing. The findings of this study aspire to contribute to this direction.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14137680/s1, Table S1: Proximate composition (%DM) and energy content (Kj/g DM) of a control diet and eleven agricultural side-streams based on duplicate analysis; Table S2: Inclusion percentages of side-streams in two sets of isoproteinic diets (A = 16.9% protein; B = 20.0% protein); Table S3: Proximate composition as a % of dry weight basis and energy content (Kj/g DM) of two sets of isoproteinic diets (A = 16.9% protein; B = 20.0% protein).

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