RESEARCH ARTICLE

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Comparative life history and demographic parameters of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) on maize and oat flours

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Abstract
Ephestia kuehniella Zeller (Lepidoptera: Pyralidae), Mediterranean flour moth, is a major pest of stored food products, causing significant economic losses. Understanding the life history and population dynamics of *E. kuehniella* is crucial for developing effective pest management strategies and improving the sustainability of the food industry. In this study, we conducted an age-stage, two-sex life table analysis of *E. kuehniella* reared on maize and oat flours. The aim of the study was to compare the demographic parameters of the *E. kuehniella* populations reared on the two different types of flour including maize and oat in laboratory conditions at 26 ± 1 °C, 60 ± 5% R.H., and a 16:8 (light: dark) photoperiod. Our findings suggest that while the flour type had a minor effect, there was no significant impact on the developmental time, survival rate, fecundity, and population growth rate of *E. kuehniella*. However, adult female longevity was significantly longer in the maize flour group compared to the oat flour group. The pre-adult survival rate was higher in the maize flour group (83%) than the oat flour group (72%). Additionally, our results indicate that fecundity of the *E. kuehniella* was slightly higher on oat flour than on maize flour, while the population growth rate was similar on both flours. Our results demonstrated that the larvae fed with maize flour consumed a significantly higher amount of flour (394 mg) than those fed with oat flour (278 mg). Furthermore, after 120 days of simulation the population growth projection of *E. kuehniella* was twice as high in oat flour compared to maize flour. These findings suggest that both maize and oat flours are susceptible to *E. kuehniella* infestation, which has important implications for the development of effective pest management strategies and the sustainability of the food industry.
Keywords: Mediterranean flour moth, Maize flour, Oat flour, Stored product pest, Life table

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INTRODUCTION

Ephestia kuehniella Zeller (Lepidoptera: Pyralidae), commonly known as Mediterranean flour moth, is an economically important insect pest of a wide range of stored food products such as grains, seeds, nuts and dried fruits (Hagstrum et al., 2013). In addition, *E. kuehniella* is one of the major pests of flourmills (Jacob and Cox, 1977) and flour is one of the most commonly infested food products with *E. kuehniella*. Larvae affect food quality and safety by contaminating stored products with feces, webbing, and cast skins, making the product unmarketable (Hill, 2003). The presence of the moth in stored food products can also result in health risks, the contamination of the product with *E. kuehniella* may be allergenic to consumers (Mäkinen-Kiljunen et al. 2001).

Ephestia kuehniella has been widely studied species due to its worldwide distribution and economic significance (Rees, 2004). In particular, the study of the life history and population dynamics of *E. kuehniella* is important for developing effective pest management strategies and minimizing economic losses in the food industry. Life tables are essential tools for understanding the ecology of pests and the demographic parameters of pests can shed light on the factors that influence its survival and reproduction, and how it adapts to different types of food sources at population level (Harcourt, 1969). Compared with traditional life table analysis, the age-stage two-sex life table can include stage differentiation and both sexes in data analysis (Chi et al. 2020). To date, some previous studies investigated the demographics of *E. kuehniella* on a variety of flours including rice, barley, maize, wheat, millet, buckwheat, sorghum, teff, and quinoa flours (Faal-Mohammad-Ali and Shishehbor, 2013; Tarlack et al. 2015; Seyedi et al., 2017; Mohammadi et al. 2020; Parra et al., 2022; Altunç et al., 2023a; Karayar, 2023).

Maize and oat flour are commonly used as ingredients in many food products, including cereal products and animal feed (Serna-Saldivar, 2012). Maize flour is particularly susceptible to infestation by *E. kuehniella*, and the pest has been found to cause significant damage to maize flour products (Hagstrum et al., 2013). However, there is limited information available on the demographic parameters and population dynamics of *E. kuehniella* in oat flour, which is also commonly used as a food ingredient. The comparison of *E. kuehniella* population dynamics in maize and oat flour can provide valuable insights into the factors that influence the population growth rate and pest management strategies.

Therefore, the aim of this study was to conduct an age-stage, two-sex life table analysis of *E. kuehniella* reared on maize and oat flours, and to compare the demographic parameters of the populations on these two different types of flour. The results of this study can provide valuable insights into the impact of these flour types on the life history and population dynamics of *E. kuehniella*, and inform the development of effective pest management strategies of *E. kuehniella* populations and for improving the sustainability of the food industry.

MATERIALS AND METHODS

Ephestia kuehniella rearing and flours

The *E. kuehniella* used in this study was obtained from a main colony that has been continuously reared for over ten years in the Laboratory of Entomology, Plant Protection Department, Ordu University. The colony was maintained using a stock colony rearing medium comprising ten parts of wheat bran, half a part of wheat flour, and a quarter of corn flour. Rearing cages, consisting of 1.2-liter plastic containers with muslin attached to the lid for aeration, were used to rear the moths. The cages were kept in a growth chamber under controlled conditions of 26 ± 1 °C, 60 ± 5% R.H., and a 16:8 (light: dark) photoperiod. Maize and oat flours procured from local markets (İngro, Konya/Türkiye) were stored in a refrigerator prior to experiments to prevent any insect infestation. The *E. kuehniella* was reared for one generation prior to experimentation to obtain the F_0 generation.

Life table experiments

After obtaining 0-24 h old adults from the F_0 generation, the moths were transferred to copulation cages and allowed for mate and oviposition during a day. The copulation cages consist of two intertwined 1.2-liter containers, with the bottom of the top container replaced with mesh to allow eggs to pass through to the bottom container. One hundred 0-24 h old eggs were obtained and individually placed in experiment cages, which were 30 cc plastic containers with 3 cm diameter holes in the lid for aeration. One gram of either maize or oat flour was added to each cage, which were then kept in the chambers under the same conditions described above for development.

After emergence, new adults (0-24 h old) were paired separately and transferred to 30 cc copulation cages. Eggs laid by each female were counted and were transferred to another 30 cc plastic cup in order to observe hatching. As new adults (0-24 h old) emerged, they were paired separately and transferred to 30 cc copulation cages. The eggs laid were counted and removed every day. In cases where both sexes did not emerge on the same day or if one of the sexes in the mating cages died, the remaining individual was mated with a one-day-old individual from the stock colony of the same flour. However, data from these individuals were not used for life table analysis. Fecundity of females were calculated form both total and hatched eggs. Observations were made at 24-hour intervals for egg hatching, longevity, and fecundity in both maize and oat flours until all individuals died. The total amount of consumed flour and pupal weights of both sexes were also measured and recorded.

Data analysis

The age-stage, two-sex life table theory (Chi et al., 2020) was utilized to evaluate the obtained data, with life table analysis performed by using the TWOSEX-MSChart computer program (Chi, 2023a). The formulae for life table parameter analysis are shown in Table 1. Means and standard errors all life table data together with the consumption and pupal weights were estimated using the 100,000 bootstrap sampling technique (Efron and Tibshirani, 1993; Huang and Chi, 2012). Comparison of data was performed using paired bootstrap tests at %5 significance level (Wei et al., 2020).

Population growth of *E. kuehniella* was projected for both maize and oat flours based on the net reproductive rate (R_0) parameter using the TIMING-MSChart computer program (Chi and Liu, 1985; Chi, 1990; Chi, 2023b). The

Table 1. Description and formulas of the life table parameters used in the study

Parameter	Description	Formula	Remarks	Reference
l_x	Age-specific survival rate	$l_x = \sum_{j=1}^{k} s_{xj}$	s_{xj} characterizes the probability that a newborn nymph will survive to age *x* while in stage *j*, and *k* is the number of stages	Chi and Liu (1985); Chi (1988)
m_x	Age-specific fecundity	$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$	f_{xj} is the age–stage specific fecundity of the individual at age *x* and stage *j*	Chi and Liu (1985); Chi (1988)
R_0	Net reproductive rate	$R_0 = \sum_{x=0}^{\infty} l_x m_x$	The total number of offspring produced by an average individual during its lifetime	Chi and Liu (1985); Chi (1988)
r	Intrinsic rate of increase	$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$	Estimated according to the Euler–Lotka formula, with age indexed from 0 by using the iterative bisection method	Chi and Liu (1985); Chi (1988), Goodman, (1982)
λ	Finite rate of increase	$\lambda = e^r$	The increase rate per day as the stable age–stage distribution is reached	Chi and Liu (1985); Chi (1988)
T	Mean generation time	$T = \frac{\ln R_0}{r}$	*T* is the time required for a population to increase to R_0-times its size as the stable age distribution is reached	Chi and Liu (1985); Chi (1988)
e_{xj}	Age–stage-specific life expectancy	$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s'_{iy}$	s'_{iy} is the probability that an individual of age *x* and stage *j* will survive to age *i* and stage *y*	Chi (1988); Chi and Su (2006)
v_{xj}	Age–stage reproductive value	$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{k} s'_{iy} f_{iy}$	Contribution of an individual of age *x* and stage *j* to the future population	Fisher (1958); Huang and Chi (2011); Tuan et al., (2014)

population projections were started with an initial population of 10 eggs of *E. kuehniella* and continued for a scenario of four months (120 d) storage of the flours to obtain the total population size without suppression by biotic and abiotic factors. The population growth and its variability based on the 0.025th and 0.975th percentiles of the bootstrap results of the net reproductive rate (R_0) were projected 120 days (Huang et al., 2018).

RESULTS

Developmental periods

The developmental duration of *E. kuehniella* on maize and oat flours is presented in Table 2. The average duration of the egg stage on maize flour was 4.33 ± 0.08 days, while it was 4.16 ± 0.04 days on oat flour. Similarly, the larval and pupal stages did not differ significantly between the two flour types, with mean durations of 33.85 ± 0.60 days and 15.56 ± 0.69 days, respectively, on maize flour, and 33.87 ± 0.42 days and 14.75 ± 0.56 days, respectively, on oat flour.

There were no significant differences in pre-adult (i.e. egg, larva and pupa) development durations and total longevity between the two flour types. The adult male longevity was slightly shorter on oat flour, exhibiting a mean ± SE of 14.43 ± 0.41 days, in comparison to 15.39 ± 0.94 days on maize flour; however, the difference was not statistically significant. The adult female longevity was significantly shorter on oat flour, with a mean ± SE of 8.30 ± 0.42 days, compared to 10.13 ± 0.81 days on maize flour. Male individuals were significantly live longer than female ones in maize ($P = 0.00007$) and oat flour ($P < 0.00001$) (Table 2).

The age-stage specific survival rates (s_{xj}) indicate that developmental stages of *E. kuehniella* exhibited overlapping patterns on both maize and oat flours (Figure 1). The maximum age reached by male individuals was approximately 88 and 85 days in maize and oat flours, respectively. Similarly, the maximum larvae ages were the same in both flours.

Life table parameters

The key life parameters measured for *E. kuehniella* fed on maize flour and oat flour were not significantly different, except for the oviposition day (OvD) (Table 3).

Table 2. Development duration (d) (mean ± SE) of the stages of *Ephestia kuehniella* reared on maize and oat flours

Developmental durations	*n*	Maize flour	*n*	Oat flour	*P*-value
Egg	54	4.33 ± 0.08	81	4.16 ± 0.04	0.05055
Larva	39	33.85 ± 0.60	67	33.87 ± 0.42	0.98393
Pupa	39	15.56 ± 0.69	67	14.75 ± 0.56	0.35638
Female*	16	10.13 ± 0.81	27	8.30 ± 0.42	0.04670
Male	23	15.39 ± 0.94	40	14.43 ± 0.41	0.34865
Preadult	39	53.72 ± 1.19	67	52.72 ± 0.94	0.50931
Total longevity	54	60.78 ± 1.37	81	60.28 ± 1.94	0.83551

*indicates difference is significant based on the paired bootstrap test at the 5% significance level
Standard errors (SE) were estimated with 100,000 bootstrap resamplings

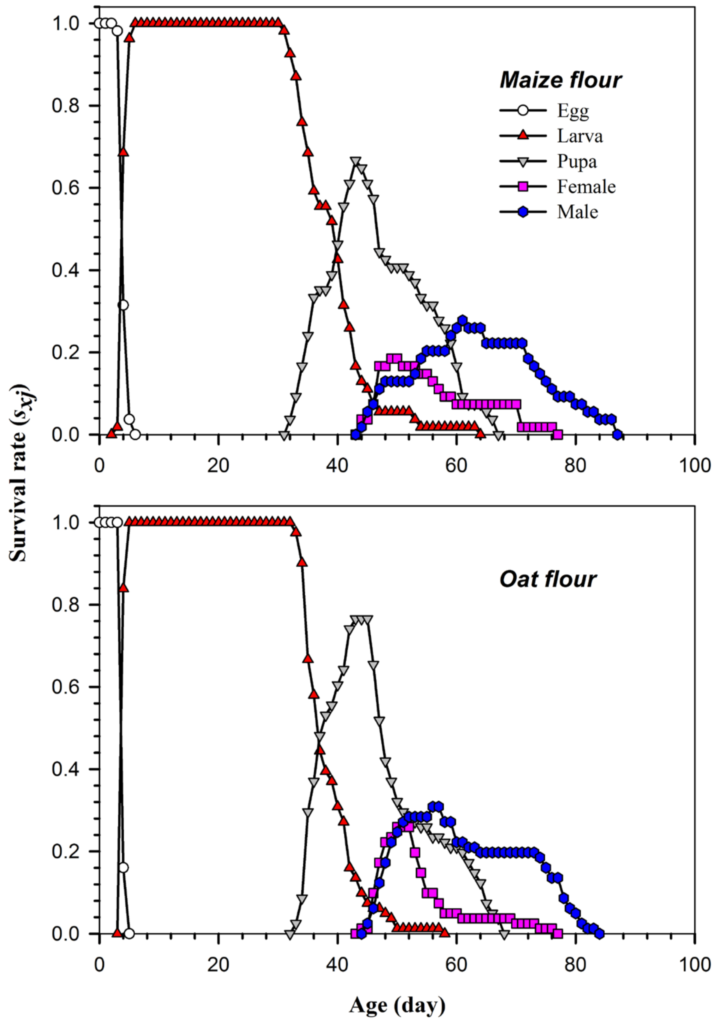

Figure 1. Age-stage survival rate (s_{xj}) of *Ephestia kuehniella* on maize and oat flours

No significant differences were observed between the two types of flour in terms of the intrinsic rate of increase (r) or finite rate of increase (λ). The mean intrinsic rate of increase was 0.0842 ± 0.0053 on maize flour and 0.0936 ± 0.0038 on oat flour. Similarly, the finite rate of increase was 1.0878 ± 0.0057 on maize flour and 1.0981 ± 0.0041 on oat flour. There were also no significant differences in the net reproductive rate (R_0), mean generation time (T), fecundity (calculated from both total eggs, F_T and hatched eggs F_H), oviposition period (OP), adult pre-oviposition period (APOP), and total pre-oviposition period (TPOP) between *E. kuehniella* reared on maize and oat flours, as shown in Table 3. However, *E. kuehniella* exhibited a significantly longer oviposition day (OvD) when fed on maize flour compared to oat flour, with a value of 7.50 ± 0.69 (Mean ± SE) on maize flour and 6.04 ± 0.28 on oat flour.

Table 3. Life table and reproduction parameters (mean ± SE) of *Ephestia kuehniella* reared on maize and oat flours

Parameters**	Maize flour	Oat flour	*P*-value
r	0.0842 ± 0.0053	0.0936 ± 0.0038	0.12865
λ	1.0878 ± 0.0057	1.0981 ± 0.0041	0.12811
R_0	99.1 ± 23.4	129.5 ± 21.1	0.33793
T	54.61 ± 1.60	51.96 ± 0.74	0.11578
F_T	334.4 ± 37.2	388.4 ± 17.5	0.18721
F_H	318.9 ± 38.3	367.8 ± 25.6	0.28567
OP	8.00 ± 4.91	6.00 ± 3.39	0.87681
OvD*	7.50 ± 0.69	6.04 ± 0.28	0.04790
APOP	1.81 ± 0.23	1.78 ± 0.35	0.93311
TPOP	53.25 ± 1.80	51.70 ± 1.19	0.47129
Pre-adult survival rate	0.83 ± 0.04	0.72 ± 0.06	0.15649

* indicates difference is significant based on the paired bootstrap test at the 5% significance level,
** r, intrinsic rate of increase (d^{-1}); λ, finite rate of increase (d^{-1}); R_0, net reproductive rate (offspring/individual); T, mean generation time (d); F_T, fecundity calculated over total eggs (eggs/female); F_H, fecundity calculated over hatched eggs; OP, oviposition period (d); OvD, oviposition days (d); APOP, adult preoviposition period (d); TPOP, total preoviposition period (d); pre-adult survival rate
Standard errors (SE) were estimated with 100,000 bootstrap resamplings.

Table 4 Weight of consumed flour (mg) and of pupae (mg) of *Ephestia kuehniella* reared on maize and oat flours

Parameter	*n*	Maize flour	*n*	Oat flour	*P*-value
Consume*	39	394.2 ± 16.5	67	278.1 ± 11.7	< 0.00001
Pupa weight	39	31.62 ± 0.46	67	30.38 ± 0.44	0.05111
Female pupa weight	17	32.74 ± 0.58	27	32.13 ± 0.69	0.50247
Male pupa weight*	22	30.75 ± 0.62	40	29.19 ± 0.48	0.01998

* indicates difference is significant based on the paired bootstrap test at the 5% significance level,
Standard errors were estimated with 100,000 bootstrap resamplings

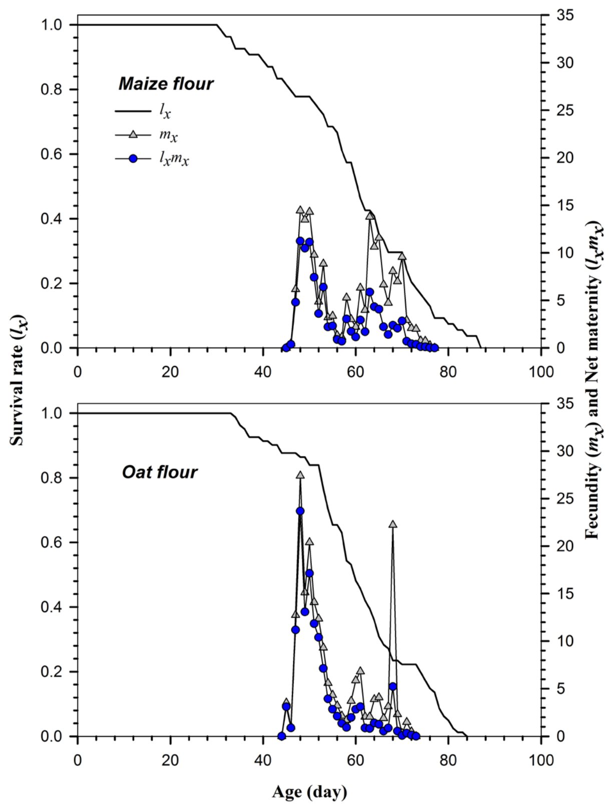

Figure 2. Age-specific survival rates (l_x), age-specific fecundity (m_x), and net maternity (l_xm_x) of *Ephestia kuehniella* on maize and oat flours

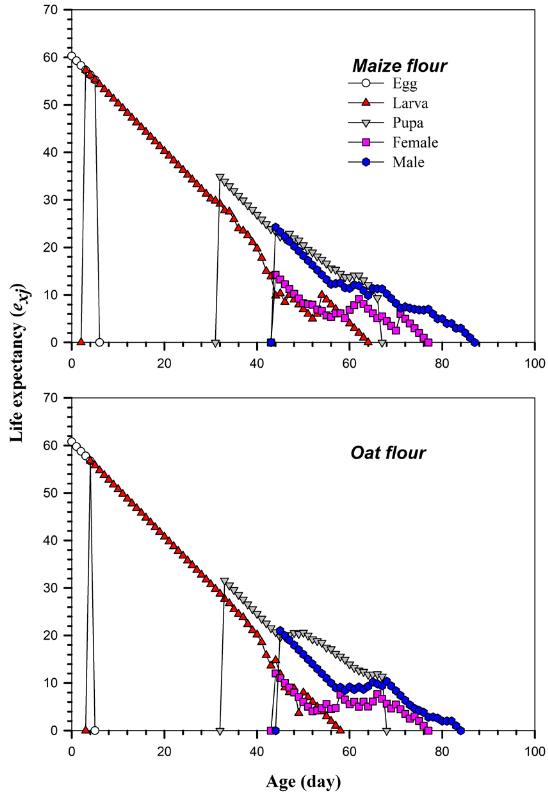

Figure 3. Age-stage-specific life expectancy (e_{xj}) of *Ephestia kuehniella* on maize and oat flours

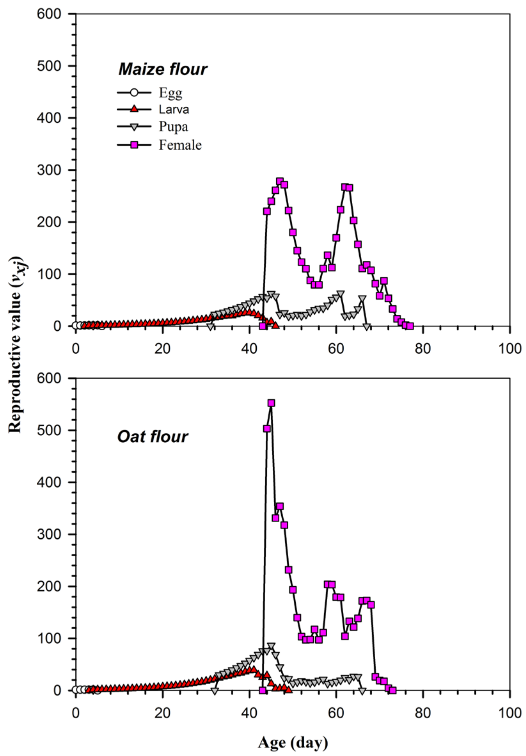

Figure 4. The age-stage specific reproductive value (v_{xj}) of *Ephestia kuehniella* on maize and oat flours

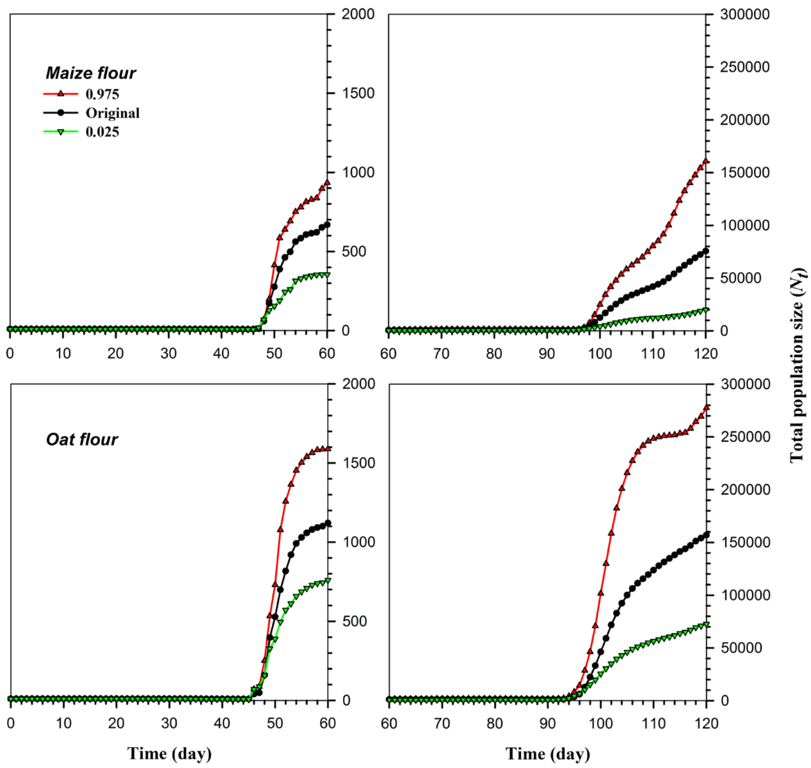

Figure 5. Total population size (N_t) after population projection of *Ephestia kuehniella* on maize and oat flours for 120 days

The age-specific survival rates (l_x) of *E. kuehniella* on both maize and oat flours showed a similar pattern of decline, beginning at 31-34 days (Figure 2). However, the maximum age-specific fecundity value (m_x) was significantly higher on oat flour (27.4 d) compared to maize flour (14.5 d). The fecundity (m_x) values exhibited fluctuations in both flours.

Ephestia kuehniella on maize and oat flours

The life expectancies (e_{xj}) for each age stage of *E. kuehniella* were also similar between maize and oat flours, with a life expectancy at birth of 60.28 and 60.78 days, respectively (Figure 3). These values represent the expected lifespan of individuals of age x and stage j after reaching age x.

The age-stage reproductive value (v_{xj}) of *E. kuehniella* on maize flour showed a peak at the later ages of adult females, while on oat flour, it gradually decreased with female age. The maximum v_{xj} value on oat flour was 552, compared to approximately half that value at 278 on maize flour (Figure 4).

Larval consumption and pupa weight

The weight of consumed flour was significantly different between the two flour types, with larvae consuming 394.2 ± 16.5 mg of maize flour and 278.1 ± 11.7 mg of oat flour. While, the weight of pupae (mixed sex) was not significantly different between the two flour types with mean weights of 31.62 ± 0.46 mg on maize flour and 30.38 ± 0.44 mg on oat flour we found difference in the male pupae of the *E. kuehniella* depend on the flour. Female and male pupa weights of *E. kuehniella* were different in both maize (*P*= 0.01998) and oat flours (*P* = 0.0005) (Table 4).

Projection of population

The total population of *E. kuehniella* over a four-month storage estimated a total population of approximately 157,000 individuals in oat flour and exceed 75,000 individuals in maize flour (Figure 5).

DISCUSSION

This study found that the life table parameters and development durations of *E. kuehniella* were mostly similar in maize and oat flours. While no previous comparison of age-stage, two-sex life table parameters of this pest reared on oat and maize flours was found in the literature. However, several studies have investigated the effect of different grain flours on demographic parameters of *E. kuehniella* (Seyedi et al. 2017; Kurtuluş et al., 2020; Mohammedi and Mehrkhou, 2020; Türkoğlu and Özpınar, 2021; Karayar, 2023). These previous studies reported variable values for life table parameters of *E. kuehniella* were diverse among the flour types. For instance, Mohammedi and Mehrkhou (2020) reported lower values for R_0 (76 offspring/female) and mean generation time *T* (42 d), and faster pre-adult development (47 d) than our findings on maize flour. Pashaei et al. (2023) also reported a shorter oviposition period of 6 days, which is lower than our result. However, the age-specific fecundity (m_x) value was higher in our study (around 15 offsprings) than in other studies (around 10 offsprings). The pre-adult survival rate in this study was the same as our findings, with 83% in maize flour. Ayvaz and Karabörklü (2008) reported the longevity of female and male adults of *E. kuehniella* reared on oat and maize flours as 7.2-7.4 days and 8.3-8.4 days, respectively, which is shorter than our findings. They also reported significantly lower fecundity of 248 egg/female in oat flour and 184 egg/female in maize flour compared to our results. However, the pre-adult development duration was the same at 52 days in oat flour, while we found a longer development duration in maize flour.

In addition to the changes of the population parameters and damage caused by stored product pests depending on the commodity (Athanasiou et al. 2016; 2017), it may also be correlated with the variety of the grains (Altunç et al. 2023b).

For instance, Razmjou et al. (2022) reported significant variations in the age-stage two-sex life table parameters of *E. kuehniella* based on different maize hybrids. Similarly, Tarlack et al. (2015) found differences in the demographic parameters of *E. kuehniella* depending on the wheat flour varieties. Furthermore, Naseri and Bidar (2015) reported varying intrinsic rates of increase for *E. kuehniella* depending on barley and wheat cultivars. Although the specific varieties of the maize and oat flours used in our study are unknown, our use of standardized flours from the same brand ensured consistency in the composition of the diet. However, future studies should investigate the varietal differences in oat flour and their impact on the demographic parameters of *E. kuehniella* to better understand the effects of grain variety on the life history of this pest.

Diet may affect the qualitative and quantitative characteristics of *E. kuehniella* as well as the pupal weights (Solis et al. 2006; Moghaddassi et al. 2019; Sönmez et al. 2019; Kurtuluş et al. 2020; Türkoğlu and Özpınar, 2021). Karayar (2023), also found that pupa weight differs in *E. kuehniella* when reared on gluten free grains such as millet, buckwheat, sorghum, and tef with varying values between 25.4-30.5 mg. In barley pupal weights were found at rage of 17.1-18.6 mg and in wheat it was between 18.6-21.1 mg depending to variety of grains (Naseri and Bidar, 2015). In another study, mean pupae weight of *E. kuehniella* was 23.3 mg on maize, 17.4 mg on wheat, and 16.5 mg on barley flours (Seyedi et al. 2017). Mohammadzadeh et al. (2020) also found that the pupal weight of *E. kuehniella* is higher when reared on barley and maize compared to wheat and oat diets. We found no impact of flour type in the pupal weight of *E. keuhniella* regardless of sex. Also, our findings were higher from all those literature data with 30.4 mg in oat flour and 31.6 mg in maize flour, but this may be cause of varietal difference of the grains used in our study.

On the other hand, *E. kuehniella* is served as a host to some parasitoids and predators for mass rearing (Nielsen, 2003; Özder, 2006; Çobanoğlu et al., 2007; Yanik and Unlu, 2011), some of which are crucial for the control of stored product pests. Consequently, this pest is the subject of many biological control studies that involve rearing natural enemies, and extensive mass production of *E. kuehniella* is carried out in laboratories. Several studies have focused on optimizing the diet for time and cost-effective mass production of *Ephestia* species for finding the faster development of stages, higher fecundity, and higher pre-adult survival rates (Ayvaz and Karabörklü, 2008; Faal-Mohammad-Ali and Shishehbor, 2013; Moghaddassi et al., 2019; Nezhad et al., 2016; Pehlivan, 2021; Wang et al., 2021).

Examining our study data from a different perspective reveals that utilizing either maize or oat flour as a diet for mass rearing *E. kuehnilella* produces noteworthy outcomes. Moghadamfar et al. (2020) found that under conditions similar to ours (25°C, 50 ± 5% RH), the pre-adult development duration of *E. kuehniella* on laboratory diet consisting of wheat flour and yeast powder was around 65 days, while we observed a quicker development duration of 54 days on maize flour and 53 days on oat flour. Additionally, we observed a fecundity value of 334 and 388 eggs/female and an R_0 value of 84 and 139 offspring/female on maize and oat flours, respectively, while Moghadamfar et al. (2020) reported a fecundity value of 351 eggs/female and an R_0 value of 99 offspring/female under similar conditions. In a similar study, Seyedi et al. (2017) compared maize, wheat, and barley flours to determine the best diet for *E. kuehniella*'s biological and physiological characteristics. They found that the highest survival rate (88%) and growth index (9.8) of larvae occurred on maize flours. The authors also noted the maximum protein content and proteolytic activity in individuals fed on maize flours, two critical parameters for natural enemies' optimal development on *E. kuehniella*.

CONCLUSION

This study found that most of the life table parameters and development durations of *E. kuehniella* were similar when reared on either maize or oat flour. However, the oviposition day was significantly longer in insects fed with maize flour, and the weight of consumed flour was significantly higher in larvae fed with maize flour compared to those fed with oat flour. Furthermore, the computer simulation demonstrated that *E. kuehniella* can reach high population levels on oat flour than maize flour, highlighting the importance of effective control measures to prevent infestations and minimize crop losses. This study provides important information on the biology and population growth of *E. kuehniella* in different types of flour, which can be useful in developing effective management strategies for this pest. In addition, the results of our study can be used as practical implications for the development of more efficient and cost-effective rearing methods for *E. kuehniella,* which is widely used effectively in the production of natural enemies, but further research is needed to determine the optimal conditions for mass rearing of *E. kuehniella* on maize and oat flours and to explore the potential for scaling up these methods to industrial-scale production.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution

AG: conceptualization, data curation, formal analysis, resources, writing - review & editing, ŞK: conceptualization, investigation, data curation, YEA: conceptualization, data curation, formal analysis, writing draft - review & editing

Ethical approval

Ethics committee approval is not required.

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Data availability

Not applicable.

Consent for publication

Not applicable.

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