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Advantages of introducing maggot-fed ducks into a rice plantation with and without *Azolla*

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Abstract: This paper discusses the advantages of introducing *Hermetia illucens* (maggot) larvae to the ducks' diet in integrated rice-duck farming, with and without *Azolla*. This study was carried out in South Sulawesi, Indonesia, using a factorial experiment based on a completely randomised design with three replications. The first factor was the *Azolla* and maggot combination package with four levels: D1 (−*Azolla*, −maggot), D2 (+*Azolla*, −maggot), D3 (−*Azolla*, +maggot), D4 (+*Azolla*, +maggot). The second factor was duck stocking density at two levels, K1 (3 ducks per 10 m^2), K2 (5 ducks per 10 m^2). Ducks were introduced between 28 and 56 days after rice planting. The parameters observed were rice production (number of panicles, grain number per panicle, and rice yield) and duck performance (body weights, weight gain, feed intake and feed conversion). The use of ducks in rice plantations at density of five ducks per 10 m^2 increased rice production, improved rice yield by 4.89 $kg \cdot (10\ m^2)^{-1}$ and number of panicles compared to the density of three ducks per the same area. The D2 combination resulted in a lower feed conversion ratio, indicating the increased duck body weight by an average of 1,029.13 g per duck and weight gain compared to other treatments. The rice-duck production economic outcomes showed that maintaining five ducks per 10 m^2 under the D4 treatment best optimised income per unit area and operational cost efficiency, reflected in the most favourable revenue-cost ratio among all treatments. This study presents a potential alternative to enhance land productivity and profitability in integrated rice and duck farming.

Keywords: agriculture, crop yield, duck, economic analysis, duck feed, integrated farming system, livestock density, performance, rice duck farming

INTRODUCTION

An integrated agricultural system is the combination of two or more components aimed at increasing income (Singh and Ravisankar, 2015). This system can be implemented on the same land, where the integration of crops and livestock produce more food without the need for additional land (Hilimire, 2011). One of the fundamental principles is the ability to consider economic, environmental, and social factors in adapting to future challenges (Hendrickson *et al.*, 2008). Accordingly, integrated farming practices focus not only on economic aspects but also production sustainability through efficient management of inputs, particularly in the context of human population growth and climate change (Herrero *et al.*, 2010). Rising human population have reduced agricultural land available per capita for crops and livestock, which declined by 22% between 2000 and 2019 (FAO, 2021). Expanding agricultural land alone cannot address the growing food demand and may, in fact, exacerbate existing climate change challenges (Kumar *et al.*, 2022). In the case of rice cultivation *Oryza sativa*), irregular rainfall and drought periods can be a challenge, as water shortage and excess are critical factors that necessitate irrigation to ensure enough water supply. This is evident from the 4% increase in agricultural land from 2000 to 2019, with irrigated land experiencing the highest growth.

However, since irrigated land uses more water than household and industrial sectors, its proportion of the total production value is projected to increase from 42% in 2012 to 46% by 2050 (FAO, 2021). This requires adopting more productive land management and integration between livestock and crop production, while playing an important role in achieving food security and providing rural households with an affordable source of highly nutritious animal protein (Sekaran *et al.*, 2021). Among integrated farming approaches, the introduction of ducks (*Anas platyrhynchos*), a poultry species known for its relatively high ecological adaptability, has been applied under various climate conditions in several regions with rice production (Yifan *et al.*, 2023).

The rice-duck cultivation includes a mechanism that reduces chemical inputs by utilising ducks' droppings and movement. This mechanism helps control pests and weeds, increases nutrient availability, and ensures increased rice yield by using low amounts of chemical fertilisers (Long *et al.*, 2013). Currently, farmers in South Sulawesi, Indonesia, have introduced ducks in rice plantations. Most of the animal protein consumption needs are met by poultry, and ducks play an important role in this regard. However, the duck population has fluctuated (BPS, 2023a), resulting in a decline in meat production from 2018 to 2022 (BPS, 2023b). The currently available duck-rearing systems are nomadic and intensive farming. In the nomadic system, ducks are reared on the move to fulfil their main feeding requirements, adapting to variable rice planting and harvesting seasons in some regions (Salman *et al.*, 2021). It has been reported that the high price of feed is one of the causes of the duck population decline and has hindered recovery, particularly during Covid-19 pandemic when farmers faced financial constraints (Longgy, Fadilah and Desy, 2023). Several studies have been conducted in relation to this rearing system, such as the potential and availability of feed in rice fields, mostly from rice left during the harvest season (Kasim *et al.*, 2021), the area of paddy fields for duck performance (Mahfudz, Kismiatidan and Sarengat, 2001), including increased rice production and reduced weeds and pests linked to increased duck populations (Azizi, Syamsuddin and Basyah, 2023). Unfortunately, grass as a source of energy and fibre contributes little in terms of protein (Walker and Gordon, 2003), and snails as a source of protein are not always available at consumable sizes (Djeddour *et al.*, 2021). As a result, competition for land and feed for ducks has intensified, making it increasingly difficult to maintain a balanced system and control feed costs, in particular after the harvest season.

The long-term sustainability of duck introduction in rice plantations arise from the relationship between livestock population and feed costs. This relationship has been identified as a weakness for farmers to provide regular supplementary feed with a single rice cropping cycle is relatively costly due to the lack of free feed resources from rice fields (Suh, 2014). To increase protein supply for ducks within rice fields, the provision of *Azolla* can be an option because it could grow above the water surface, drawing nutrients from paddy field mud, and contains about 19.22–27.59% protein, making it a potential animal feed source (Prihantoro *et al.*, 2015). Previous studies examined the use of *Azolla* for growth performance and duck carcass quality, including the nutritional components of *Azolla*, which consist of 22.5% crude protein and 13.0% crude fibre (Chisembe, Banda and Tanganyika, 2020). However, the advantages of introducing ducks reared in the rice plantation, particularly through the use of a combined *Azolla* and maggot (*Hermetia illucens*), have not been widely explored. In addition, the feed costs, an essential matter in maintaining farm profitability, were not evaluated in the previous studies, despite their relevance in mitigating the financial impacts of the global food crisis (Sverguzova *et al.*, 2021).

Therefore, this study examined the combination of the *Azolla*, maggot, and duck density to elucidate the economic advantages of integrated duck-rice production and to enhance land productivity. Various combinations of *Azolla* and maggots under different duck densities were tested through integrated rice-duck farming, where *Azolla* was cultivated with rice plantations and maggots were included in the formulated feed to determine their effects on duck performances, rice production, and economic outcomes. The findings of this study are expected to contribute to the development of integrated rice-duck farming to optimise yields and achieve the highest advantages.

MATERIALS AND METHODS

The study was conducted in a suburban area of Makassar, South Sulawesi, Indonesia, located at 05°06'39.00" S; 119°32'24.20" E, at elevation of 7 m a.s.l. The research was carried out during the period of paddy plantation season from January to April 2023. Meteorological data, including the average temperature of 26.55°C and average humidity of 84.25%, were obtained from the Meteorological, Climatological, and Geophysical Agency Regional IV Makassar (Ind.: Badan Meteorologi, Klimatologi, dan Geofisika – BMKG). Materials used included Inpari 32 paddy seed, 96 Mojosari ducks (*Anas platyrhynchos javanicus*) at 28 days of age of both sexes, fertilisers: 210 kg·ha^{-1} urea, 270 kg·ha^{-1} NPK Phonska, 2 Mg·ha^{-1} fresh *Azolla pinnata* R. Br, and feed components: corn, rice bran, concentrate, and maggot.

The research was arranged as a 4·2 factorial experiment based on a completely randomised design with three replications, a total of 24 treatment units. The first factor consisted of four levels combining the presence (+) and absence (–) of *Azolla* and dietary maggot supplementation to feed ducks during the growing phase in rice plantations: D1 (–*Azolla*, –maggot), D2 (+*Azolla*, –maggot), D3 (–*Azolla*, +maggot), D4 (+*Azolla*, +maggot). The second factor comprised two levels of duck densities in paddy fields: K1 (3 ducks per 10 m^2), and K2 (5 ducks per 10 m^2). The scheme and timeline of research implementation are presented in Figure 1.

The land preparation involved establishing 24 experimental plots, each measuring 4.0 m × 2.5 m for planting and 1.1 m × 0.9 m for duck cages. Fencing was installed using wood, nylon netting, and plastic sheeting attached by rope, with a total height of 40 cm, of which 5 cm was buried into the soil. The field irrigation was managed to maintain water levels in accordance with rice growth requirements. Seedlings were raised by sowing germinated seeds in a nursery plot. After 15 days, the seedlings were transplanted, marking the first day of planting, with two seeds per hole. The 2:1 Legowo cropping was implemented, with 40 cm for the largest inter-row spacing, 20 cm for the smallest inter-row spacing, and 12.5 cm for the in-row spacing. This layout provides a wider open space between plant rows, facilitating movement of ducks within the rice field (Muslimin *et al.*, 2021). The maintenance activities included replanting,

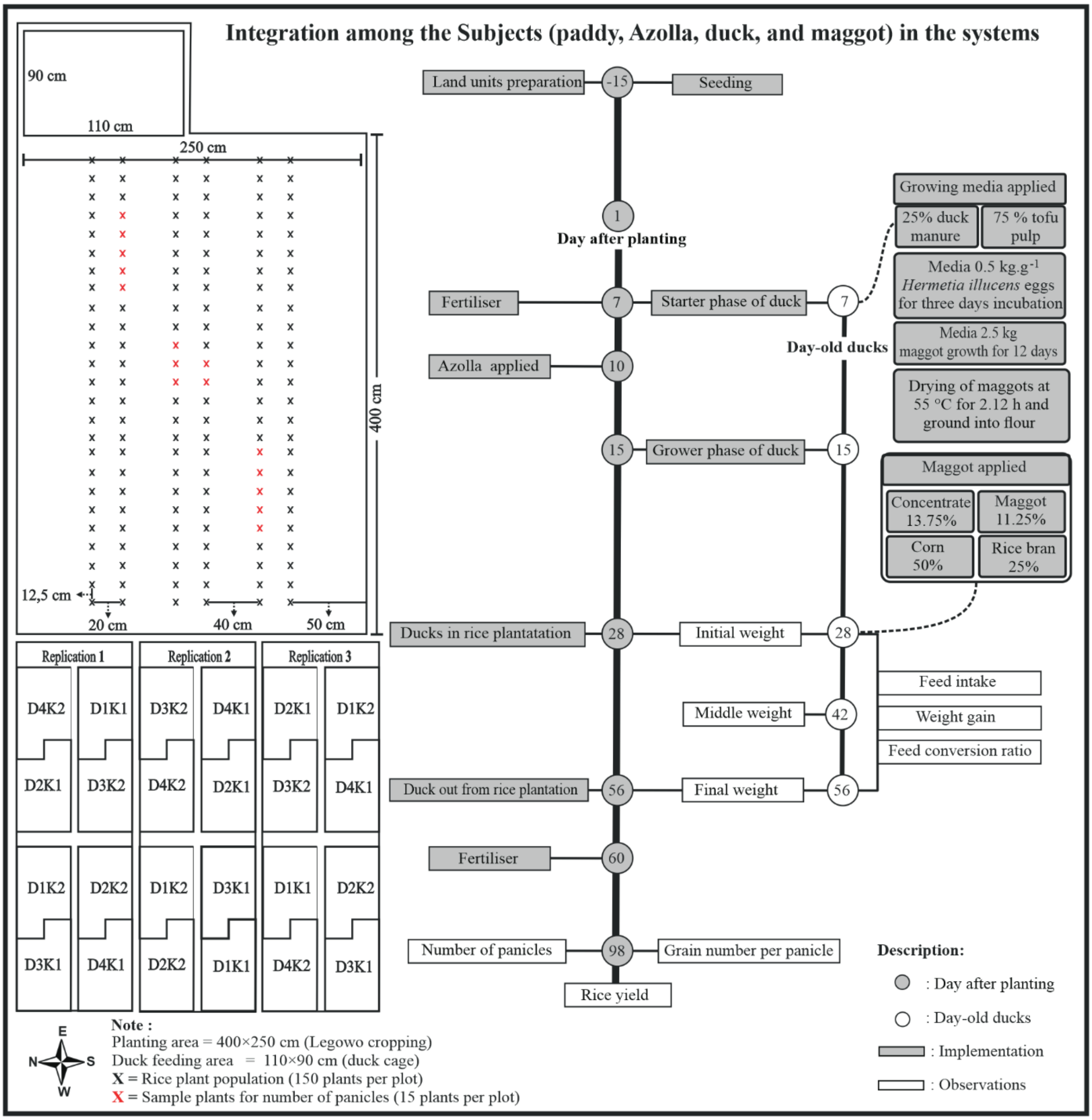

Fig. 1. Time schedule of the research; D1 (−*Azolla*, −maggot), D2 (+*Azolla*, −maggot), D3 (−*Azolla*, +maggot), D4 (+*Azolla*, +maggot); K1 (3 ducks per 10 m^2), K2 (5 ducks per 10 m^2); source: own elaboration

which was completed seven days after planting (DAP). Fertilisation was carried out using the recommended fertiliser doses by soil test kits, applied in two stages at seven and 60 DAP. After that, *Azolla* was applied at 10 DAP according to the treatment plot at the rate of 2 kg of fresh *Azolla*. The dosage was based on the highest biomass yield and satisfactory rice production (Shamima *et al.*, 2002).

Before the ducks were introduced to the rice plantation, seven days-old ducks (DOD) of both sexes were randomly sourced from hatcheries and nurseries by local farmers. The ducklings were placed in a single cage 6.0 m × 2.0 m × 0.90 m (length × width × height) equipped with four 10-Watt heat lamps operating for 14 h per day for seven days. The standard commercial BP11 feed from PT Charoen Pokphand was provided from seven to 13 days of age (22% crude protein, 5% crude fibre, 3,000 ME kcal·kg^{-1}). Subsequently, from 14 to 27 days of age, a mixed feed consisting of corn, rice bran, and concentrate (16.13% crude protein, 6.81% crude fibre, 3,097.26 ME kcal·kg^{-1}) and tap water was provided as drinking water to support optimal duck growth. During this period, duck manure was used to grow maggot in combination with tofu pulp, using a composition of 25% duck manure and 75% tofu pulp (Mahmud *et al.*, 2020). A total of 3 kg of media was obtained based on the quantity of media that produced 1 kg of fresh maggots, following a three days incubation period for *Hermetia illucens* eggs and 12 days of maggot growth (Rachmawati *et al.*, 2015). After 15 days, the maggot was taken from the media and then soaked and rinsed with water for cleaning. The maggots were dried at 55°C for

24 h and ground into flour. Subsequently, the maggot meal was mixed at 11.25% in the feed ration, based on broilers carcass and abdominal lipid percentages (Rumondor *et al.*, 2015). The proportions of each ingredient were determined according to the nutritional requirements of ducks (National Research Council, 1994). The composition of feed components is shown in Table 1, while the feed formulation is shown in Table 2.

Table 1. Nutrient contents of feed components

Feed component	Nutrient content		
	protein (%)	crude fibre (%)	metabolic energy ($kcal \cdot kg^{-1}$)
Corn[1)]	8.36	3.17	3,291
Rice bran[1)]	8.78	14.91	2,730
Concentrate[2)]	39.00	6.00	3,076
Maggot[3)]	40.03	7.62	2,866

Source: [1)] analysis results of Feed Chemistry Laboratory Faculty of Animal Science University of Hasanuddin Makassar (Supriadi *et al.*, 2021), [2)] commercial feed label CP144 by PT Charoen Pokphand, [3)] analysis results of Feed Chemistry Laboratory Faculty of Animal Science University of Hasanuddin Makassar (Auza *et al.*, 2023).

Table 2. Feed ingredients, price, and chemical composition

Feed ingredient, price, and chemical composition	Grower duck feed composition (%)			
	D1	D2	D3	D4
Corn	50.00	50.00	50.00	50.00
Rice bran	25.00	25.00	25.00	25.00
Concentrate	25.00	25.00	13.75	13.75
Maggot	0.00	0.00	11.25	11.25
Total	100	100	100	100
Feed price ($USD \cdot kg^{-1}$)	0.37	0.37	0.31	0.31
Chemical composition[1)]				
– protein (%)	16.13	16.13	16.24	16.24
– crude fibre (%)	6.81	6.81	6.99	6.99
ME ($kcal \cdot kg^{-1}$)	3,097.26	3,097.26	3,073.61	3,073.61

[1)] Calculated according to National Research Council (1994).
Explanation: ME = metabolisable energy.
Source: own elaboration.

The ducks were introduced into the rice plantation at 28 DOD after being weighed to determine their initial weight, and then placed at experimental plots according to predetermined densities. The ducks were kept until 56 DOD. Feed consumption was determined weekly, from four to five, five to seven, and seven to eight weeks each consisting of 108, 115, and 120 g per duck per day (Prasetyo, 2010). The rearing of ducks lasted from 28 to 56 DAP in the rice plantation, coinciding with the flowering and grain-filling stages – critical phases for rice yield (Long *et al.*, 2013).

To observe the performance, the duck's body weight was measured every two weeks, whereas weight gain (*WG*) and the feed conversion ratio (*FCR*) were calculated using Equations (1) and (2) (Anang, 2007; Nugraha *et al.*, 2017):

$$WG = \frac{BW(t_1) - BW(t_0)}{\Delta t} \tag{1}$$

$$FCR = \frac{FI}{WG} \tag{2}$$

where: $BW(t_1)$ = final body weight, $BW(t_0)$ = initial body weight, Δt = rearing duration, and FI = feed intake is the difference between the feed given and the remaining feed.

Furthermore, rice was harvested at 98 DAP to observe rice production. Pre-determined samples were taken to calculate the number of panicles and grains per panicle. After all the grain from each plot was harvested and dried to a moisture content of around 14%. The grain was then weighed to calculate the yield. The advantage analysis was based on observational data for rice yield and final weight of ducks, with costs derived from the operational expenses of rice and ducks production. The rice production costs included seed, *Azolla*, fertiliser, and labour associated with land cultivated, planting, harvesting, and transportation. The duck production costs comprised the purchase of seven days-old ducklings, heating, vitamin, starter feed, grower feed, vitamins, and labour. Land, cages, and equipment are assumed to be self-owned during a single rice-growing season.

These data were analysed using a two-way analysis of variance (ANOVA) within a general linear model (GLM), where both factors were analysed simultaneously in a single model to evaluate both main effects and their interaction. Significant differences between treatments were further analysed using Duncan's multiple range test (DMRT). All statistical analyses were performed using SPSS software version 25.0, with $p < 0.05$ considered statistically significant. Profit was calculated as the difference between total revenue from rice yield and duck production and the associated production costs. The revenue cost ratio (*RC-R*) is using the equations (Tung, 1992; Bangun *et al.*, 2024):

$$RCR = \frac{R}{C} \tag{3}$$

where: R = revenue of rice yield and duck cultivation and C = cost of rice and duck production, with each revenue and cost for rice and duck calculated separately.

RESULTS

RICE PRODUCTION

The number of panicles, grain number per panicle, and rice yield are shown in Table 3. Grain number per panicle was not affected ($P > 0.05$) by the *Azolla* and maggot combination package and duck density or their interaction. The number of panicles and rice yield were not affected ($P > 0.05$) by the *Azolla* and maggot combination package, but they were affected by duck density ($P < 0.05$). The K2 density was able to produce a higher rice yield and number of panicles compared to the K1 density.

Table 3. Effect the combination package of *Azolla* and maggot at different duck densities on rice production

Package	Duck density	Number of panicles	Grain number per panicle	Rice yield (kg·(10 m^2)$^{-1}$
D1	K1	10.98 ±0.32	113.22 ±5.84	4.17 ±0.39
	K2	11.53 ±0.79	120.42 ±11.42	4.75 ± 0.54
	avg.	11.26 ±0.62	116.82 ±9.02	4.46 ±0.53
D2	K1	11.65 ±0.57	120.20 ±10.38	4.64 ±0.23
	K2	11.47 ±1.05	119.40 ±6.00	4.49 ± 0.67
	avg.	11.56 ±0.76	119.80 ±7.60	4.57 ±0.46
D3	K1	10.62 ±0.58	117.13 ±13.08	4.34 ±0.30
	K2	12.20 ±0.96	125.76 ±7.72	5.32 ± 0.31
	avg.	11.41 ±1.12	121.44 ±10.71	4.83 ±0.60
D4	K1	10.89 ±0.77	119.31 ±10.25	4.36 ±0.38
	K2	11.76 ±0.47	124.51 ±11.96	5.00 ± 0.56
	avg.	11.32 ±0.74	121.91 ±10.36	4.68 ±0.55
Avg.	K1	11.03 ±0.63^b	117.47 ±9.16	4.38 ±0.33^b
	K2	11.74 ±0.78^a	122.52 ±8.65	4.89 ± 0.56^a
P value	D	0.90	0.79	0.48
	K	0.03	0.22	0.01
	D×K	0.28	0.84	0.17

Explanations: avg. = average, D1, D2, D3, D4, K1, K2 as in Fig. 1; means with the different letters within the same row and column are significantly different at $P < 0.05$, D×K, interaction between package of *Azolla* and maggot and duck density.
Source: own study.

DUCK PERFORMANCE

Body weight and weight gain are shown in Table 4. Body weight was affected ($P < 0.05$) by the *Azolla* and maggot combination package. The effects of the *Azolla* and maggot combination package of D2 resulted in significantly increased final body weight by an average of 1029.13 g per duck compared to other treatments. The weight gain was affected ($P < 0.05$) by the *Azolla* and maggot combination package only in case of 43 to 56 days and overall phase 28–56 day-old ducks. The effects of the *Azolla* and maggot combination package of D2 resulted in significantly higher weight gain compared to those of D1 and D3, while there was no significant effect of duck density on body weight ($P > 0.05$) and weight gain ($P > 0.05$).

Feed intakes and feed conversion ratio are shown in Table 5. Feed intakes were not affected ($P > 0.05$) by the *Azolla* and maggot combination package and duck density or their interaction regardless of the duck age. Feed conversion ratio was affected ($P < 0.05$) by the *Azolla* and maggot combination package only in the case of 43–56 days and overall phase 28–56 days-old ducks. The *Azolla* and maggot combination package in treatment D2 decreased the feed conversion ratio. Except during the period of 28 to 42 days, the FCR was significantly lower D2 and D4 than those of D3 and D1. No significant effect of duck density on feed conversion ratio was observed ($P > 0.05$).

FINANCIAL ANALYSIS

The results of the financial analysis of the total costs and total revenues from rice and duck production under different combinations of *Azolla* and maggot, and different duck densities are presented in Tables 6 and 7. A density of five ducks per 10 m^2

Table 4. Effect of the combination package of *Azolla* and maggot at different duck densities on body weight

Age (days)	Package	K1	K2	Average	*P* value D	*P* value K	*P* value D×K
Body weight (gram per bird) at duck density							
28	D1	416.11 ±10.71	418.00 ±11.26	417.06 ±9.88	0.93	0.79	0.92
	D2	415.00 ±17.40	417.67 ± 14.36	416.33 ± 14.34			
	D3	416.11 ±8.22	415.33 ± 8.50	415.72 ± 7.49			
	D4	415.56 ± 14.56	414.33 ± 10.50	414.94 ± 11.37			
	avg.	415.69 ±11.26	416.33 ± 9.81	–			
42	D1	653.06 ±38.34	702.33 ± 53.16	677.69 ± 49.47	0.37	0.26	0.59
	D2	704.44 ±37.50	717.00 ± 32.36	710.72 ± 32.07			
	D3	686.67 ±31.80	681.67 ± 26.05	684.17 ± 26.14			
	D4	695.56 ±33.39	705.33 ± 31.50	700.44 ± 29.52			
	avg.	684.93 ± 36.36	701.58 ±34.42	–			
56	D1	911.11 ±56.66	985.67 ± 67.30	948.39 ± 69.02^a	0.04	0.23	0.45
	D2	1,013.33 ±51.75	1044.92 ±49.70	1029.13 ± 48.56^b			
	D3	962.78 ±46.32	941.67 ± 53.75	952.22 ± 46.34^a			
	D4	986.94 ±47.44	1006.17 ±44.60	996.56 ± 42.50^{ab}			
	avg.	968.54 ±58.46	994.60 ± 60.60	–			

cont. Tab. 4

Age (days)	Package	K1	K2	Average	*P* value		
					D	K	D×K
Weight gain (gram per bird) at duck density							
	D1	236.94 ±28.53	284.33 ±42.62	260.64 ±41.54			
	D2	289.44 ±21.10	299.33 ±28.59	294.39 ±23.12			
28–42	D3	270.56 ±24.96	266.33 ±33.67	266.33 ±33.67	0.27	0.23	0.54
	D4	280.00 ±24.89	291.00 ±27.40	285.50 ±24.18			
	avg.	269.24 ±29.71	285.25 ±31.34	–			
	D1	258.06 ±20.49	283.33 ±18.56	270.69 ± 22.30[ab]			
	D2	308.89 ±19.74	327.92 ±21.78	318.40 ±21.32[c]			
43–56	D3	276.11 ±16.69	260.00 ±28.64	268.06 ±22.75[a]	0.01	0.28	0.36
	D4	291.39 ±21.80	300.83 ±16.30	296.11 ± 17.97[bc]			
	avg.	283.61 ±25.85	293.02 ±31.91	–			
	D1	495.00 ±46.11	567.67 ±56.13	531.33 ±60.78[a]			
	D2	598.33 ±38.19	627.25 ±40.42	612.79 ±38.57[b]			
28–56	D3	546.67 ±40.55	526.33 ±61.86	536.50 ±48.09[a]	0.03	0.20	0.42
	D4	571.39 ±34.02	591.83 ±37.61	581.61 ±33.97[ab]			
	avg.	552.85 ±52.37	578.27 ±57.39	–			

Explanations as in Fig. 1.
Source: own study.

Table 5. Effect of the combination package of *Azolla* and maggot at different duck densities on feed intake

Age (days)	Package	K1	K2	Average	*P* value		
					D	K	D×K
Feed intake (gram per bird) at duck density							
	D1	1,405.14 ±65.46	1475.04 ±39.94	1,440.09 ±61.79			
	D2	1,460.84 ±61.57	1470.07 ±46.44	1,465.46 ±49.03			
28–42	D3	1,453.32 ±75.56	1444.05 ±72.74	1,448.68 ±66.53	0.90	0.36	0.69
	D4	1,441.51 ±61.26	1463.17 ±33.18	1,452.34 ±45.63			
	average	1,440.21 ±60.73	1463.08 ±44.67	–			
	D1	1,477.24 ±69.55	1517.70 ±36.25	1,497.47 ±54.33			
	D2	1,513.36 ±46.71	1511.17 ±61.13	1,512.26 ±48.67			
43–56	D3	1,487.46 ± 7.55	1467.58 ±50.80	1,477.52 ±49.75	0.50	0.68	0.82
	D4	1,452.91 ±72.35	1473.28 ±35.09	1,463.10 ±52.07			
	average	1,482.74 ±57.82	1492.43 ±46.37	–			
	D1	2,882.39 ±134.69	2992.74 ±75.73	2,937.56 ±114.91			
	D2	2,974.20 ±107.02	2981.24 ±104.07	2,977.72 ±94.49			
28–56	D3	2,940.78 ±97.27	2911.63 ±122.13	2,926.20 ±100.03	0.77	0.48	0.73
	D4	2,894.42 ±133.33	2936.45 ±49.81	2,915.43 ±92.91			
	avg.	2,922.95 ±108.66	2955.51 ±85.78	–			
Weight gain (gram per bird) at duck density							
	D1	5.97 ±0.45	5.25 ±0.67	5.61 ±0.64b			
28–42	D2	5.06 ±0.17	4.93 ±0.35	4.99 ±0.25a	0.11	0.25	0.47
	D3	5.39 ±0.30	5.46 ±0.41	5.42 ±0.33b			
	D4	5.16 ±0.25	5.06 ±0.51	5.11 ±0.37ab			

cont Tab. 5

Age (days)	Package	K1	K2	Average	*P* value		
					D	K	D×K
	avg.	5.39 ±0.45	5.18 ±0.47	–			
43–56	D1	5.74 ±0.29	5.37 ±0.27	5.55 ±0.32b	0.01	0.38	0.33
	D2	4.91 ±0.24	4.62 ±0.31	4.76 ±0.30a			
	D3	5.39 ±0.16	5.68 ±0.48	5.54 ±0.36b			
	D4	5.00 ±0.43	4.90 ±0.24	4.95 ±0.31a			
	avg.	5.26 ±0.43	5.14 ±0.52	–			
28–56	D1	5.84 ±0.28	5.30 ±0.41	5.57 ±0.43b	0.01	0.17	0.24
	D2	4.98 ±0.15	4.76 ±0.16	4.87 ±0.18a			
	D3	5.39 ±0.22	5.57 ±0.44	5.48 ±0.32b			
	D4	5.07 ±0.18	4.97 ±0.24	5.02 ±0.20a			
	avg.	5.32 ±0.40	5.15 ±0.43	–			

Explanations as in Fig. 1.
Source: own study.

Table 6. Total cost and total revenue of duck production using a combination package of *Azolla* and maggot at different duck densities

Item			D1		D2		D3		D4	
			K1	K2	K1	K2	K1	K2	K1	K2
Operational cost	7-day-old (USD0.46 per duck)		1,378.23	2,297.06	1,378.23	2,297.06	1,378.23	2,297.06	1,378.23	2,297.06
	heating (USD0.09·kWh^{-1})		10.44	17.39	10.44	17.39	10.44	17.39	10.44	17.39
	vitamin (USD2.95 per box)		23.63	35.44	23.63	35.44	23.63	35.44	23.63	35.44
	starter feed (USD0.60·kg^{-1})		508.57	847.61	508.57	847.61	508.57	847.61	508.57	847.61
	grower feed (USD0.37·kg^{-1})		4,460.37	7,640.35	4,563.40	7,618.84	0	0	0	0
	grower feed (USD0.31·kg^{-1})		0	0	0	0	3,780.64	6,255.52	3,737.18	6,294.30
	labour	7–27 days old duck	110.26	110.26	110.26	110.26	110.26	110.26	110.26	110.26
		28–56 days old duck	152.26	152.26	152.26	152.26	152.26	152.26	152.26	152.26
Total cost (USD)			6,643.75	11,100.38	6,746.79	11,078.87	5,964.03	9,715.55	5,920.57	9,754.33
Productivity duck (kg·ha^{-1})			2,460	4,435.52	2,736	4,702.14	2,599.50	4,237.52	2,664.74	4,527.77
Price per kg (USD)			3.08	3.08	3.08	3.08	3.08	3.08	3.08	3.08
Total revenue (USD)			7,588.16	13,681.88	8,439.50	14,504.32	8,018.49	13,017.13	8,219.71	13,966.44

Explanations: D1, D2, D3, D4, K1, K2 as in Fig. 1.
Source: own study.

(K1) increased the total revenue from duck production as shown in Table 6. With the except of treatment D2, this higher density also resulted in greater total revenue from rice production as shown in Table 7. Specifically, the higher revenue from duck production was accompanied by higher total costs compared to the density of three ducks per 10 m^2, primarily due to higher feed costs. For the density of three ducks (K1), the lowest feed cost of USD3,737.18 was recorded in treatment D4K1, while the highest feed cost of USD 4,563.40 was in treatment D2K1. For the density of five ducks (K2), the lowest feed cost of USD6,255.52 was recorded in treatment D3K2, while the highest feed cost of USD7,640.35 in treatment D1K2 as shown in Table 6. Although total duck production costs increased with duck density, the use of the *Azolla* and maggot combination package with D2 was able to generate higher revenue at both duck densities (Tab. 6). However, the higher feed costs in this treatment reduced economic advantages compared to D4 (Tab. 8). The combination package of *Azolla* and maggot showed higher economic

Table 7. Total cost and total revenue of rice production using a combination package of *Azolla* and maggot at different duck densities

Item			D1		D2		D3		D4	
			K1	K2	K1	K2	K1	K2	K1	K2
Operation-al cost	seeds (USD0.65·kg^{-1})		13.13	13.13	13.13	13.13	13.13	13.13	13.13	13.13
	NPK Ponska (USD0.15·kg^{-1})		40.76	40.76	40.76	40.76	40.76	40.76	40.76	40.76
	urea (USD0.15·kg^{-1})		31.01	31.01	31.01	31.01	31.01	31.01	31.01	31.01
	Azolla (USD13.13·Mg^{-1})		0	0	26.25	26.25	0	0	26.25	26.25
	Labour	land processing per ha	85.32	85.32	85.32	85.32	85.32	85.32	85.32	85.32
		planter (USD5.25·WPD^{-1})	84.01	84.01	84.01	84.01	84.01	84.01	84.01	84.01
		fertiliser (USD5.25·WPD^{-1})	10.50	10.50	10.50	10.50	10.50	10.50	10.50	10.50
		harvester (USD0.35·kg^{-1})	148.85	170.11	163.03	159.48	152.39	187.83	155.94	177.20
		transport (USD0.66·(100 kg)$^{-1}$	27.56	31.50	30.19	29.53	28.22	34.78	28.88	32.82
Total cost (USD)			441.13	466.34	484.19	479.99	445.33	487.34	475.79	500.99
Rice productivity (kg·ha^{-1})			4,170.00	4,750.00	4,640.00	4,490.00	4,341.67	5,316.67	4,361.67	5,003.33
Price per kg (USD)			0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Total revenue (USD)			1,477.86	1,683.42	1,644.43	1,591.27	1,538.70	1,884.25	1,545.79	1,773.20

Explanations: D1, D2, D3, D4, K1, K2 as in Fig. 1.
Source: own study.

Table 8. Effect of the combination package of *Azolla* and maggot at different duck densities on duck and rice production profits (USD)

Advantage	Package	Duck density		Average
		K1	K2	
Duck	D1	944.41	2,581.51	1,762.96
	D2	1,692.71	3,425.45	2,559.08
	D3	2,054.46	3,355,58	2,705.02
	D4	2,299.14	4,212.11	3,255.62
	average	1,747.68	3,393.66	–
Rice	D1	1,036.73	1,217.08	1,126.90
	D2	1,160.24	1,111.28	1,135.76
	D3	1,093.37	1,396.91	1,245.14
	D4	1,070.00	1,272.21	1,171.11
	average	1,090.09	1,249.37	–

Explanations: D1, D2, D3, D4, K1, K2 as in Fig. 1.
Source: own study.

advantages in duck production with treatment D4, while treatment D3 gave higher advantages in rice production as shown in Table 8. This was also indicated by the highest *R*:*C* ratio among all treatments in duck and rice production, respectively, presented in Figure 2.

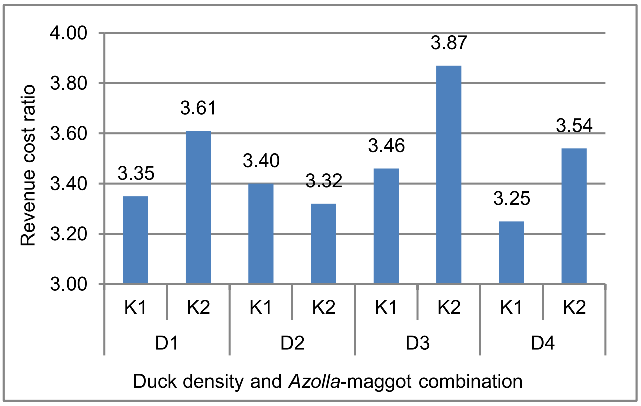

Fig. 2. Revenue cost ratio of rice production using a combination package of *Azolla* and maggot at different duck densities; source: own study

DISCUSSION

RICE PRODUCTION

The experiment aimed to determine the effect of the *Azolla* and maggot combination package and the effect of different duck densities on selected parameters of rice production such as number of panicles, grain number per panicle, and rice yield. The results showed that the number of grains per panicle was not significantly affected by the *Azolla* and maggot combination package and duck density or their interaction. The number of panicles and rice yield were not affected by the *Azolla* and maggot combination package, but the number of panicles in treatment K2 was more, which is related to the increased rice yield compared to the K1. Previous research by Oyange *et al.* (2020) found no effect after giving fresh *Azolla*, because the decomposition of fresh *Azolla* is slower compared to composted *Azolla,* resulting in an increase in P content in rice plants but not in N content (Setiawati *et al*., 2018). This is supported by Ranawake, Amarasingha and Dahanayake (2013), who reported that the beneficial effects of *Azolla* become evident after its decomposition. This is due to portions of *Azolla* plants remaining above the soil surface, thereby limiting microbial decomposition. These results are consistent with Setiawati *et al.* (2018), who observed no difference in rice yield when comparing the application of fresh *Azolla* at up to 20 Mg·ha^{-1} with the control.

Nevertheless, the average rice yield was not large enough to be considered statistically significant. However, an increase in the average value was observed under conditions without *Azolla*, where treatments including maggots provided higher rice yields than those without maggots. One possible explanation is the presence of chitin from maggots, which cannot be fully digested in monogastric digestion. The insoluble fibre from chitin may increase the rate of digestion efficiency (Rahayu *et al*., 2023). By utilising this compound, maggot meal is able to change the caecal microbiota composition in broiler chickens, characterised by a decrease in pathogenic bacteria and an increase in *Lactobacillus* (Saidani *et al*., 2025). This will also result in a higher number of *Lactobacillus* excreted with faeces. Park *et al.* (2017) indicated that faeces of laying hens fed with maggots had higher *Lactobacillus* counts compared to those fed without maggots. This difference possibly affects the balance of nitrogen, phosphorus, and potassium in poultry manure, which can be accurately verified through chemical analysis. Baba *et al.* (2022) found that fermentation using *Lactobacillus* increased nitrogen, phosphorus, and potassium levels in poultry farm waste. In addition, as one of the beneficial microorganisms, *Lactobacillus* contributed to increased crop growth and yield by optimising photosynthesis, producing bioactive substances such as hormones and enzymes, and accelerating the decomposition of lignin in the soil (Javaid, 2010).

Duck density in rice plantations significantly affected the number of panicles and rice yield, with optimal results observed at the higher density (K2) compared to K1. Previous studies have also assessed the effect of duck density on rice cultivation. Baigi and Abbasian (2013) observed that a density of 1,200 ducks per ha resulted in the highest fresh and dry weight of rice shoots. This density also improved air circulation and soil aeration, thereby benefiting the root system compared to lower duck densities. Similarly, Azizi, Syamsuddin, and Basyah (2023) investigated the integrated rice-duck farming with densities ranging from zero to 2,800 ducks per ha and found that the highest rice yield was achieved at a density of 2,800 ducks per hectare. This increase in yield was attributed to duck manure, which provided additional nutrients for the rice plants. This is supported by Isobe *et al.* (2005), who reported that ducks have a beneficial effect on rice growth by enhancing nitrogen supply, with the average weight of duck manure approximately 15–20 g per duck per day. Furthermore, Goh, Song and Manda (2001) found that the foraging and movement of ducks in rice fields was more pronounced at a density of 12 ducks compared to 6 ducks per 10 ares. Based on these findings, increasing the number of ducks from three to five per 10 m^2 in the rice-duck integrated system is required to augment the number of panicles and rice yield.

DUCK PERFORMANCE

The results of this study showed that ducks fed with *Azolla* but without maggot supplementation had higher body weight at 56 days of age. This was associated with improved weight gain during 43–56 days and the overall 28–56 day rearing phase, compared to ducks in the treatments without *Azolla* – either with or without maggot supplementation. Feed intake during 28–42, 43–56 days, and overall 28–56 days of rearing was not significantly affected by the *Azolla* and maggot combination package. The feed conversion ratio of the duck fed *Azolla,* both with and without maggot supplementation, during 43–56 days and overall phase of 28–56 days was lower compared to that of ducks in treatment without *Azolla,* either with or without maggots. The observed difference in feed conversion ratio between *Azolla* and without *Azolla* could be attributed to the increased body weight gain, which was accompanied by feed consumption that did not differ in the case of feeding with or without maggot supplementation. This increase in weight gain was partly due to the additional nutrients, especially the protein from *Azolla*, which contained 25.10% protein and had higher palatability on a fresh-weight basis, providing additional feed for ducks that promoted faster growth compared to a formulated diet alone (Liu *et al*., 1998).

Gariglio *et al.* (2019) and Pertiwi *et al.* (2023) reported no significant differences in body weight or feed conversion ratio between ducks fed with maggot-supplemented diets and those fed without maggots. Additionally, Auza *et al.* (2023) found that feed containing 11.26% maggot meal resulted in a better feed conversion ratio that diets without maggots in native chickens. Studies on ducks reared in rice fields with *Azolla* showed higher final body weights and lower feed conversion ratios compared to those reared in rice fields without *Azolla* (Chisembe, Banda and Tanganyika, 2020). In this study, the body weights of 56-day of age ranged from 948.39 ±69.02 g to 1,029.13 ±48.56 g per duck. These results were lower than those reported by Chisembe, Banda and Tanganyika (2020), which showed that ducks reached a body weight of 1,491 g per duck when a diet containing 17% crude protein was applied. The contribution of *Azolla* to reducing the feed conversion ratio was evident in the study by Acharya *et al.* (2015), who indicated that fresh *Azolla* with higher moisture content better filled the digestive tract. The filling of the digestive tract increases the contact time between nutrients and digestive enzymes, which are almost always accompanied by the degradation of feed nutrients through microbial activity (Svihus and Itani, 2019). In addition to its protein content, oligosaccharides as components of dietary fibre were physiologically similar to soluble fibre (Ochoa, Paniagua Michel and Olmos-Soto, 2014). *Azolla* fibre was beneficial in enhancing the development of probiotic bacteria (Cruz de la *et al*., 2023) and triggered thickening in the digestive tract, which resulted in greater overall body weight (Setyawan *et al*., 2022).

Several previous studies have examined the effect of duck density per unit of land area. Azizi, Syamsuddin and Basyah (2023) reported that increasing the density of ducks within a 25 m^2 plot reduced body weight, likely due to limited space, leading to competition for feed. Conversely, lower stocking densities allow more space for movement. Mahfudz, Kismiatidan and Sarengat (2001) found that feed consumption was not affected by land area, but body weight gain decreased in rice field areas of 20 m^2 plots compared to those on 10 m^2 plots, suggesting that ducks rely on feed energy reserves and that energy deficiency inhibits growth. From a metabolic perspective, energy from consumed feed is partly used on movement, which can affect duck behaviour. Lim *et al.* (2024) found that duck behaviour was affected by the level of metabolic energy in the feed. Lower energy levels reduced walking duration and increased feeding duration, while no difference in performance was observed between ducks fed low and high metabolic energy diets. In the present study, duck density in the paddy fields had no effect on duck performance. A density of three to five ducks per 10 m^2 still allowed equal access to feed without competition, which was supported by the absence of significant differences in feed intake during the period of 28–56 days across different densities. In addition, the paddy field area and the metabolic energy provided per duck were maintained at consistent levels across densities. As a result, the increased with higher density so that the behaviour of ducks to walk and eat did not result in a lack of metabolic energy that could inhibit growth.

FINANCIAL ANALYSIS

Based on the research conducted, rice yields increased with a higher duck density, leading to better profit margins. Furthermore, ducks that were raised in rice fields under treatment *Azolla* without maggot during overall phase 28–56 days of age showed the lower feed conversion ratio, which contributed to increased productivity. However, profits decreased due to variations in feed prices. The treatment *Azolla* with maggot demonstrated higher profits, contributing to a better income to production cost ratio for the ducks. This finding was supported by Utama, Cahya and Sulistiyanto (2024) that the use of maggots successfully reduced feed operational costs, positively impacting income relative to feed expenses. Additionally, Rai *et al*. (2012) showed that *in situ* cultivation of *Azolla* in poultry under semi-range conditions could save feed costs by up to 80%. The use of *Azolla* in rice production resulted in lower profits due to additional costs associated with the initial procurement of *Azolla* as inoculum of 2 Mg·ha^{-1} from local farmers, with an initial cost of around USD10.00 for one ton of fresh *Azolla* (Aziz, 2012). This study indicated the treatment without *Azolla* with maggot at a K2 density provided the highest economic benefits in rice production, as evidenced by the highest *R*:*C* ratio. These results are consistent with Kollah et al. (2016), who reported that although *Azolla* has the potential to improve soil fertility, the costs associated with *Azolla* could reduce net profit margins.

CONCLUSIONS

The integrated rice and duck farming with a combination of (+*Azolla* +maggot) and a density of five ducks per 10 m^2 is the best approach recommended to optimise potential income per land and operational cost efficiency. This density was able to optimise rice production and maintain duck performance. The use of *Azolla* in rice production had lower profits than without *Azolla*; however, maggot in the combination package addressed the disadvantages of *Azolla* and produced higher rice yields compared to without maggot. The use of maggot combined with *Azolla* is more appropriate than without *Azolla* and without maggot in duck production as a potential approach to provide adequate nutrients to optimise duck performance and achieve the highest advantages.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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